From: [redacted]
Sent: Friday, September 18, 2020 12:14 AM
To: FGC <FGC@fgc.ca.gov>
Cc: Ashcraft, Susan@FGC <Susan.Ashcraft@fgc.ca.gov>
Subject: FG 1 petition for regulation change

Dear Commissioners,
I am submitting an FG 1 Petition to the California Fish and Game Commission for Regulation Change. Please find the attached FG 1 petition “FG Comm Petition_Nancy Caruso” and all the referenced supporting documents for the September 22, 2020 Fish and Game Commission Meeting. They were sent before the Supplemental Comment Deadline of September 18 at noon.

Commissioners Please Note: Supporting Reference materials for *MBC 2019* report has not yet been distributed to the public but is available online here https://1drv.ms/u/s!AkLZpj2SiR6xpG_MWqq-Hs8Rqsuo?e=ouAaVG
A Powerpoint overview of that report is attached

Sincerely,

Nancy L. Caruso
Marine Biologist/Founder
Get Inspired
[redacted]
www.GetInspiredinc.org

You can Support our Green Abalone Project here www.gofundme.com/abalone

Tracking Number: (2020-014 AM1)

To request a change to regulations under the authority of the California Fish and Game Commission (Commission), you are required to submit this completed form to: California Fish and Game Commission, (physical address) 1416 Ninth Street, Suite 1320, Sacramento, CA 95814, (mailing address) P.O. Box 944209, Sacramento, CA 94244-2090 or via email to FGC@fgc.ca.gov. Note: This form is not intended for listing petitions for threatened or endangered species (see Section 670.1 of Title 14).

Incomplete forms will not be accepted. A petition is incomplete if it is not submitted on this form or fails to contain necessary information in each of the required categories listed on this form (Section I). A petition will be rejected if it does not pertain to issues under the Commission's authority. A petition may be denied if any petition requesting a functionally equivalent regulation change was considered within the previous 12 months and no information or data is being submitted beyond what was previously submitted. If you need help with this form, please contact Commission staff at (916) 653-4899 or FGC@fgc.ca.gov.

SECTION I: Required Information.

Please be succinct. Responses for Section I should not exceed five pages

1. **Person or organization requesting the change (Required)**
   Name of primary contact person: Nancy Caruso, Marine Biologist, Executive Director of Get Inspired
   Address: [redacted]
   Telephone number: [redacted]
   Email address: [redacted]

2. **Rulemaking Authority (Required) -** Reference to the statutory or constitutional authority of the Commission to take the action requested: *Section 200 and 205, Fish and Game Code §632. Marine Protected Areas (MPAs), Marine Managed Areas (MMAs), and Special Closures. "The commission may authorize research, education, and recreational activities, and certain commercial and recreational harvest of marine resources, provided that these uses do not compromise protection of the species of interest, natural community, habitat, or geological features." "The designating entity or managing agency may permit research, education, and recreational activities, and certain commercial and recreational harvest of marine resources PRC §36710(c)."* Added per Nancy Caruso email - 10/4/20: For Section 30 of T14CCR: Section 6750, Fish and Game Code.Section 632 of T14CCR: Sections 200, 205(c), 265, 399, 1590, 1591, 2860, 2861 and 6750, Fish and Game Code; and Sections 36725(a) and 36725(e), Public Resources Code

3. **Overview (Required) -** Summarize the proposed changes to regulations:

1.Request to modify Section *30.00, Title 14, CCR30.00.*
KELP GENERAL. (a) Except as provided in this section and in Section 30.10 there is no closed season, closed hours or minimum size limit for any species of marine aquatic plant. The daily bag limit on all marine aquatic plants for which the take is authorized, except as provided in Section 28.60, is 10 pounds wet weight in the aggregate. (b) Marine aquatic plants may not be cut or harvested in state marine reserves. Regulations within state marine conservation areas and state marine parks may prohibit cutting or harvesting of marine aquatic plants per sub-section 632(b) [marine protected area regulations].

-Change the recreational take of *Sargassum horneri* from 10 pounds wet weight to "no limit" April through October (during non-reproductive season).

2. Request to modify 14 CCR § 632 Crystal Cove SMCA: Area restrictions defined in subsection 632(a)(1)(C) apply, with the following specified exceptions:
-Allow for unlimited recreational take of *Sargassum horneri* in the Crystal Cove SMCA April through October (during non-reproductive season).

3. *"The commission may authorize research, education , and recreational activities, and certain commercial and recreational harvest of marine resources…"*
-Allow for localized, controlled, year-round removal of Sargassum for 3 years as a research project in Crystal Cove SMCA under direction of Nancy Caruso of Get Inspired to determine if Sargassum is prohibiting kelp recruitment, recovery, and experiment with techniques for eradication.

4.Rationale (Required) - Describe the problem and the reason for the proposed change:
The problem is that *Sargassum horneri* has invaded our coast and is spreading rapidly. It is having a negative impact on our kelp forest ecosystem. DFW has not acted in accordance with the Aquatic Invasive Species Management Plan. Below, we lay out the reasons for the proposed changes to make strides to eradicate it.

1. **DFW failed to respond and stop the spread of the invasive species *Sargassum horneri***

Sargassum horneri is native to Eastern Asia. It has spread aggressively throughout southern California, USA, and Baja California, México since it was discovered in Long Beach in 2003 and poses a major threat to the sustainability of native marine ecosystems in this region (Marks et al. 2015). Now it is ubiquitous in the region and had been found at three of the five Channel Islands (Anacapa, Santa Cruz and Santa Barbara) (Marks et al. 2015). Earlier this year, it was documented by divers in Monterey, CA (pers comm, 2020). Kaplanis et al. 2016 reported that the rapid and uncontrolled spread of Sargassum has serious implications for its expansion along the west coast of North America.
"California does not have an official rapid response plan for AIS, does not have a designated funding source for providing a rapid response, and no agency is designated with overall responsibility for AIS management. For this reason, it is unknown whether the necessary elements to conduct a rapid response operation will come together when the need arises. If the commitment, expertise, and funding fail to coalesce, the state could be faced with substantial environmental and economic consequences caused by AIS infestations." (CA AIS Mgmt plan Appendices 2008).
The invasion of *Caulerpa taxifolia* in Southern California, in 2000, was met with swift action and eradication. This species could have easily spread and caused widespread issues in our bays and wetland areas. The Southern California Caulerpa Action Team (SCCAT) was established to quickly and effectively respond to the discovery of this algae in Southern California. Caulerpa was quickly contained and even treated with chlorine, killing the plant and its roots. There was no such effort for Sargassum. Now let us, the divers who love our reefs, remove this invasive species. Hopefully we can make an impact on eradication of this species which is of no benefit to our California coast. I hope it is not too late to stop this invasion, so I ask that you allow the community to help eradicate it in the areas that are important to them: where they dive, spearfish, or swim. By allowing unlimited take of Sargassum, we can make an impact and help our kelp to thrive.

2. ***Sargassum horneri* is not a marine resource**

"MPAs protect the diversity and abundance of marine life, the habitats they depend on, and the integrity of marine ecosystems.". https://wildlife.ca.gov/conservation/marine/MPAS Sargassum threatens the integrity of our marine ecosystem. Currently, Sargassum is being protected in our MPAs as a "marine resource" and the giant kelp is suffering. In the Crystal Cove SMCA in Orange County, you can take finfish, urchins, and lobsters but you can't take an invasive species. This is illogical and must be changed. The proposed "season" for recreational take from April-October was meant to disentangle from the argument that it can be spread when reproductive. Sargassum is an annual. In general, it recruits in early Summer, becomes reproductive in November, and dies off in April. By creating this "season" of take, that argument cannot be used, as it has for the last 17 years of Sargassum's spread. You have nothing to lose.

In 2015, Cruz-Trejo et. al. studied Sargassum in Baja, Mexico and found the most significant impact to be severe reduction of the canopy forming species on their study sites. In 1982 Ambrose and Nelson found that *Sargassum muticum* appeared to prevent giant kelp recruitment and removal of the invasive species resulted in a significant increase in giant kelp recruitment. They also found higher densities of giant kelp in removal areas. Shading at a critical time in the giant kelp life cycle is suggested as a possible mechanism for the inhibition of giant kelp recruitment (Ambrose and Nelson 1982).

I have been observing and monitoring the reefs of Orange County for 18 years. The warm water events from 2014-2016 gave us our first look at Macrocystis recovery, after a disruption event, WITH *Sargassum horneri* in its ecosystem. Sargassum is an annual and recruits in early summer, BEFORE giant kelp recruits later in winter months. Sargassum has taken advantage of the Macrocystis winter recruitment cycle. When the warm water and high surf decreased kelp and other native algal densities during the warm water "blob" of 2014-2015 followed by an El Nino in 2016, the Sargassum took advantage of the space on the reef prohibiting kelp from recruiting and recovering from these "disruption" events. This is evident in the MBC Aquatic Sciences *Status of the Kelp 2019* report. This report is released annually on the status of the Southern California kelp beds. It contains aerial surveys of our kelp and even tracks local available nitrate (*nutrient quotient*) for kelp growth. Kelp surveys, from this report, confirm that even though the 2018-2019 years had adequate nutrients and temperatures conducive to kelp recovery and growth, Macrocystis densities did not rebound after the 3 years of warm water. Why? There is no room to recruit on the reefs.

Most herbivores do not prefer Sargassum as a food choice and this has helped lead to its success (Marks et. al 2020). *Sargassum horneri* forms monospecific dense forests that fish cannot even swim through, it also limits light penetration to the reef further inhibiting competitors.

Marks et al 2017 findings suggested that controlling *S. horneri* via removal will be most effective if done over large areas during cool-water years that favor native algae. She goes on to suggest that such efforts should be targeted in places such as novel introduction sites or recently invaded areas of special biological or cultural significance. I think the Crystal Cove SMCA fits this description and this year is the year to do it because a *La Nina* is projected. On the Crystal Cove SMCA reefs, in particular, there has been a shift, since our kelp restoration activities in Orange County in 2002-2010, from a Macrocystis forest with healthy understory of other alga and encrusting organisms to a desolate Sargassum covered reef.

3. Reasons we want to do research in the Crystal Cove SMCA

-It is one of the least restrictive MPAs in the system: Take of lobster, finfish, and urchins is already permitted

-We have an 18-year history working in the kelp forests of Crystal Cove, Newport Beach and Laguna Beach

-We have a team of over 300 volunteer divers to help with the effort

-The annual kelp surveys and nutrient data collected by MBC Aquatic Sciences includes this MPA

-Good beach diving access, good boat diving access (Newport Harbor)

-Sargassum densities currently as high as 13.85 plants/m^2

-Kelp has decreased 98% in 2019

-The "nutrient quotient", calculated by MBC Aquatic Sciences, is calculated from data taken at the Newport Pier just 2 miles away. The next closest location is Oceanside (35 miles away). This will give us valuable insight.
-We have the historical knowledge of where giant kelp used to grow in this SMCA
-All the rocky reefs in Orange County with Sargassum growing on them are located in MPAs.
-DFW's recommended test site (Decision Tree) in San Clemente does not contain Sargassum

We have already asked for an SCP for this research project but because of the "Decision Tree", it was denied with the rationale that "It can be done somewhere else" but the next closest rocky reef outside of our Orange County MPA network has no Sargassum (San Clemente, CA). We argue that the requested project location (Crystal Cove SMCA) is unique in several ways and we lay that argument out below. For project details see attached "Timing on *Sargassum horneri* removal as a technique for eradication"

It is clear that Sargassum is a threat to our current native kelp (Cruz-Trejo et al 2015). We have found it at densities as high as 13.8 plants per meter square in Crystal Cove SMCA which is 100% cover in that same meter square at maturity (per observation). It is also clear that despite favorable ocean conditions for the last 2 years kelp densities have decreased (MBC, 2019). Almost all of Orange Counties rocky reefs are in MPAs. In 2019 Crystal Cove SMCA has lost 98% of its kelp, The Laguna Beach SMR lost 89% in North Laguna and 95% in South Laguna, the South Laguna/ Dana Point SMCA kelp beds totally disappeared (MBC, 2019). I believe this is because of Sargassum. In a time when we are relying on these protected areas to preserve our ecosystems, it is vital that we eliminate this threat and study how we can stop its spread. If we do not act, we are countering the very reasoning and rationale for establishing the MPAs. There is no downside to taking this action. We have hundreds of volunteers ready to help. The knowledge gained by this study can be used to eradicate Sargassum in other areas.

The precedence has already been set for this type of action on the North Coast where divers have been given permission to cull purple urchins in the Pacific Grove Gardens SMCA in an effort to restore our precious kelp beds struggling to survive. In an all-out effort, divers are coming together to figure out how they can help preserve the kelp and save our abalone populations as well as the other species that rely on kelp. We only hope that it is not too late. It is clear we cannot afford to wait any longer with regards to Sargassum. It is in the spirit of the MLPA that these areas be protected from invasive threats to allow our native wildlife to thrive, that was the intention. Please use your authority for adaptive management to allow the public to help with this problem. We can help to "save" our reefs from the takeover of Sargassum.

Nancy Caruso, marine biologist, has led a team of more than 300 volunteer divers working on the reefs of Newport Beach and Laguna Beach for 18 years. Restoring giant kelp, monitoring kelp forest recovery, fishes, algae and invertebrates. We have also outplanted abalone (Caruso, 2018) and we are monitoring abalone density, size, recruitment, and mapping abalone populations. We have partnered with DFW as well. This is our community and our reefs that we spoke out for at meetings to implement the MLPA. With the help of 500 students who grew kelp in their classrooms and 250 volunteer divers, we restored our kelp after being gone for 2 decades and want it protected and preserved. We see degradation of our reef communities by *Sargassum horneri* and we want to help fix it. We will conduct a localized removal experiment to test whether Sargassum is hindering kelp recruitment. We will work on the some of the same reefs where we conducted kelp restoration activities, abalone monitoring and restoration since 2002. This SMCA is a familiar large rocky reef system that offers plenty of expanse for a replicated, controlled studies. All of the rocky reefs in Orange County are in MPAs except for the Wheeler Reef system in San Clemente. Steve Schroeter of UCSB (who is managing the monitoring program for the reef) stated that they found only two Sargassum plants in their 92 transects in 2019. The Crystal Cove SMCA used to be a lush garden of algae and a healthy kelp forest where Wheeler North conducted many kelp restoration experiments. We have data going back to the 1980's from Joe Valensic and we collected data on these reefs from 2002-2012. As concerned scientists, we see a problem, we think we may have the answer, and we want to test it. We can add to the available science through a controlled research approach and then share this information with you, for better management practices and to manage our kelp forests like the important resources that they are.

SECTION II: Optional Information

5. **Date of Petition:** **9/18/2020**.

6. **Category of Proposed Change**
   X Sport Fishing
   ☐ Commercial Fishing
   ☐ Hunting
   ☐ Other, please specify: Click here to enter text.

7. **The proposal is to:** (*To determine section number(s), see current year regulation booklet or https://govt.westlaw.com/calregs*)
   X Amend Title 14 Section(s):30.00

(a) Except as provided in this section and in Section 30.10 there is no closed season, closed hours or minimum size limit for any species of marine aquatic plant. The daily bag limit on all marine aquatic plants, ***except as provided in 30.00 (c),*** *for which the take is authorized, except as provided in Section 28.60, is 10 pounds wet weight in the aggregate.*

(b) Marine aquatic plants, ***except as provided in 30.00 (c),*** *may not be cut or harvested in state marine reserves. Regulations within state marine conservation areas and state marine parks may prohibit cutting or harvesting of marine aquatic plants,* ***except as provided in 30.00 (c),*** *per sub-section 632(b)*
(c)Title 14 CCR § 632 Crystal Cove State Marine Conservation Area.

(B) Area restrictions defined in subsection 632(a)(1)(C) apply, with the following specified exceptions:
1. The recreational take of finfish [subsection 632(a)(2)] by hook and line or by spearfishing [Section 1.76], and spiny lobster and sea urchin is allowed.
2. The commercial take of sea urchin; spiny lobster by trap; and costal pelagic species [Section 1.39] by round haul net [Section 8750, Fish and Game Code], brail gear [Section 53.01(a)], and light boat [Section 53.01(k)] is allowed. Not more than five percent by weight of any commercial coastal pelagic species catch landed or possessed shall be other incidentally taken species.
3. Take pursuant to activities authorized under subsection 632(b)(133)(C) is allowed.
(C) Beach nourishment and other sediment management activities, and operation and maintenance of artificial structures inside the conservation area is allowed pursuant to any required federal, state and local permits, or as otherwise authorized by the department.
(D) Take of all living marine resources from inside tidepools is prohibited. For purposes of this section, tidepools are defined as the area encompassing the rocky pools that are filled with seawater due to retracting tides between the mean higher high tide line and the mean lower low tide line.

X Add New Title 14 Section(s):
Subsection 30
(c) Invasive marine aquatic plant *Sargassum horneri* may be removed without a daily bag limit when the plants are not reproductive (April-October).

CCR § 632
(E) Unlimited recreational take of *Sargassum horneri* by hand during the months of April-October.

☐ Repeal Title 14 Section(s): Click here to enter text.

8. **If the proposal is related to a previously submitted petition that was rejected, specify the tracking number of the previously submitted petition** Click here to enter text.
Or X Not applicable.

9. **Effective date**: If applicable, identify the desired effective date of the regulation.
If the proposed change requires immediate implementation, explain the nature of the emergency: We request that this petition be approved immediately. We hope to take advantage of the forecasted La Nina conditions by starting the project now.

10. **Supporting documentation:** Identify and attach to the petition any information supporting the proposal including data, reports and other documents: (Attached)
(Identified)
-ResearchProposal: *Timing of Saragssum horneri as a Removal Technique for Eradication*
-Cruz-Trejo et al 2015 Presence of Sargassum horneri at Todos Santos Bay, Baja California, Mexico: Its Effects on the Local Macroalgae CommunityAmerican Journal of Plant Sciences, 2015, 6, 2693-2707 Published Online October 2015 in SciRes.
-Aquatic Invasive Species Management Plan and Appendices DFW 2008
-Caruso, Nancy L. (2017). Outplanting large adult green abalone (*Haliotis fulgens*) as a strategy for population restoration. California Fish and Game 103(4): 183-194
-Kaplanis NJ, et al (2016) Distribution patterns of the non-native seaweeds Sargassum horneri (Turner) C. Agardh and Undaria pinnatifida (Harvey) Suringar on the San Diego and Pacific coast of North America. Aquatic Invasions 11: 111–124,
-Marks, L.M. et al. 2015. Range expansion of a non-native, invasive macroalga *Sargassum horneri* (Turner) C. Agardh, 1820 in the eastern Pacific. BioInvasions Records 4(4)243-248.
-Marks LM, et al 2017. Assessment of control methods for the invasive seaweed *Sargassum horneri* in California, USA. Manag Biol Invasion.;8(2): 205–213. 10.3391/mbi.2017.8.2.08
-Marks, L.M. 2020. Niche Complementarity and Resistance to Grazing Promote the Invasion Success of *Sargassum horneri* in North America. *Diversity* **2020**, *12*, 54.
-MBC Aquatic Sciences 2020. *2019 Status of the Kelp Beds Orange and San Diego Counties Prepared for the Region Nine Kelp Survey Consortium*. https://1drv.ms/u/s!AkLZpj2SiR6xpG_MWqq-Hs8Rqsuo?e=ouAaVG

11. **Economic or Fiscal Impacts:** Identify any known impacts of the proposed regulation change on revenues to the California Department of Fish and Wildlife, individuals, businesses, jobs, other state agencies, local agencies, schools, or housing: Increase in revenues to the California Department of Fish and Wildlife for fishing licenses that are required for removal activities. There are no additional costs predicted to the state of local agencies.

12. Forms: If applicable, list any forms to be created, amended or repealed:

n/a

SECTION 3: FGC Staff Only

Date received: Click here to enter text.

FGC staff action:

☐ Accept - complete
☐ Reject - incomplete
☐ Reject - outside scope of FGC authority

Tracking Number

Date petitioner was notified of receipt of petition and pending action: ________________

Meeting date for FGC consideration: ______________________________

FGC action:

☐ Denied by FGC
☐ Denied - same as petition ______________________
Tracking Number
☐ Granted for consideration of regulation change

CALIFORNIA
AQUATIC INVASIVE SPECIES
MANAGEMENT PLAN

January 2008

Appendices

APPENDIX A:
DRAFT
AUGUST 2007

RAPID RESPONSE PLAN
FOR AQUATIC INVASIVE SPECIES IN CALIFORNIA

Prepared by:

California Department of Fish & Game
Habitat Conservation Branch
The Invasive Species Program

RAPID RESPONSE PLAN
FOR AQUATIC INVASIVE SPECIES IN CALIFORNIA
TABLE OF CONTENTS

I. INTRODUCTION

Goal: The purpose of this plan is to provide a framework for an effective rapid response to the discovery of any aquatic invasive species (AIS) that is new to California, or of a population of established AIS that is outside of its known distribution in California.

In this document, "rapid response" means that soon after an aquatic species new to the State of California or a specific region of the state is discovered, 1) the state will make a determination of whether it is potentially detrimental and/or invasive and 2) if that is the case, the state will develop and implement a course of action. This also would apply to AIS that are discovered in an adjacent state in a waterway or lake that ultimately enters California.

Possible courses of action for newly discovered AIS may include an effort to eradicate the species, control its spread, prevent future introductions, minimize or mitigate the damage it causes, or study it further before any other action is taken. Rapid response is the second line of defense after prevention to minimize the negative impacts of AIS on the environment and economy of California. Once non-native invasive species become widespread, efforts to control them are typically more expensive and less successful than rapid response measures. The damage caused by an AIS that becomes widespread, and the actions that are taken to control it, may be more harmful to the environment than a successful rapid response.

California does not have an official rapid response plan for AIS, does not have a designated funding source for providing a rapid response, and no agency is designated with overall responsibility for AIS management. For this reason, it is unknown whether the necessary elements to conduct a rapid response operation will come together when the need arises. If the commitment, expertise and funding fail to coalesce, the state could be faced with substantial environmental and economic consequences caused by AIS infestations. Even if an ad hoc rapid response effort is made, the following consequences may result:

1. The effort may be compromised by less than adequate staff levels, authority and funding to carry out necessary actions.

2. Staff assigned on an ad hoc basis are less likely to have received training in advance that would help them function as effectively and efficiently as possible in this situation (e.g. Incident Command System training).

3. The effort may be compromised indirectly by staff in charge of the ad hoc effort spending their time trying to secure staff and funding for the response instead of leading the response itself.

4. The effort may not have the level of organization and accountability to be gained from following an official plan.

5. Some governmental and non-governmental entities may be less cooperative with an ad-hoc response than they would be if the response is a standard procedure that is based on official agency agreements.

6. Any resulting confusion could lead to a perception that public funds are mismanaged, that environmental regulations are not being followed, or that the interests of community leaders have been disregarded.

To address the threat posed to California habitats by new AIS introductions, and the lack of an organized plan and funding to address this threat, Chapter 6 (Task 4A1) of the California Aquatic Invasive Species Management Plan (CAISMP) calls for the development and implementation of a rapid response plan. The CAISMP was completed by the California Department of Fish and Game (DFG) in 2007. The CAISMP acknowledges that rapid response to AIS in California may often require cooperation among a variety of local, state and federal agencies and organizations, and that formal agreement on a plan, in advance of need, increases the likelihood of responding in an effective manner.

This draft Rapid Response Plan will be available for review by agencies and organizations that are likely to have an interest in rapid response. DFG's Invasive Species Program will revise the plan based on the comments received. The goal is to arrive at a plan that can be the basis for agreements to cooperate on rapid response to AIS. In order to finalize, fund and implement the plan, it is hoped that cooperating agencies will assign staff to participate. DFG Invasive Species Program staff will provide coordination for the interagency activities called for in the agreement(s).

Please note that the procedure section of this plan (Section III) is followed by the planning section (Section IV). The order of these sections is deliberate and meant to emphasize that the objective is to have a working product. Both the procedure and planning sections of this document discuss the need to collect data to evaluate the feasibility and success of the plan. This rapid response plan is meant to fit into an adaptive management strategy where evaluation can lead to improved procedures.

It is not possible to plan proactively for every species that might become a nuisance in state waters, hence the need for this generic plan. It stands to reason, however, that a generic plan cannot be implemented as efficiently as a species- or location-specific plan. Therefore, rapid response plans for individual species or related groups of species at high risk of being introduced and becoming destructive should be formulated. This step is called for in Action 4A3 of the CAISMP.

To effectively protect state aquatic habitats from the impacts of AIS, California needs to develop and implement a comprehensive AIS early detection and reporting plan. This document does not attempt to address the issue of early detection, nor provide a detailed discussion of mechanisms for reporting AIS. It focuses on what happens after detection of a suspect AIS. Since some early detection and reporting of AIS already occurs, a rapid response procedure is considered the most immediate need.

II. LEGAL AUTHORITY FOR RAPID RESPONSE

Appendices B and C in the CAISMP provide general information on the federal and state government agencies and regulations involved in the management of AIS. Rapid response activities could potentially require state and/or federal permits, consultations or agreements related to the placement of fill or structures into state and/or federal waters, protection of state or federally listed species, or the protection of other special status plant or animal species. The normal timeline for obtaining permits issued under these laws may critically delay rapid response efforts. A streamlined regulatory permitting process for implementing the Rapid Response Plan will need to be developed and approved by participating agencies. Additionally, permission is necessary to work on private and public properties. Clear protocols need to be developed to avoid misunderstandings or illegal trespassing, while making the process of obtaining access as efficient as possible.

In addition to the laws relevant to AIS discussed in the CAISMP, there are laws that specifically address taking action during an emergency or under special circumstances. These laws can facilitate the implementation of a rapid response procedure. Examples include:

Creation of Emergency Regulations

Under California Government Code Section 11346.1, rulemaking state agencies, departments, commissions, offices and boards can adopt emergency regulations, which can remain in effect for up to 120 days. These are regulations that must take effect immediately for "preservation of the public peace, health and safety or general welfare" and must meet other requirements of that code section. The process for adoption of emergency regulations can be found at the Office of Administrative Law's web site (www.oal.ca.gov/emer_reg.htm).

The California Department of Food and Agriculture (DFA) has specific statutory authority to establish quarantines to protect the state's agricultural industry from pests (Food and Agriculture Code Section 5301). If an AIS is discovered that has the potential to severely damage crops, water delivery, or flood control systems that support agriculture, DFA can invoke their authority to establish a quarantine area.

According to Section 660 of the Harbor and Navigation Code, any entity, local or state, authorized by law to adopt rules or regulations that govern matters relating to boats or vessels may adopt emergency measures within their jurisdiction as long as they are not in conflict with the general laws of the state relating to those matters. The emergency rules or regulations can be effective for up to 60 days and must be submitted to the Department of Boating and Waterways (DBW) on or before their adoption. DBW can authorize these emergency rules or regulations to be in effect for over 60 days if it is deemed necessary.

Use of a Pesticide Outside of its Registered Use

When dealing with species that are new to California, the technical experts participating in a rapid response incident may determine that the best solution is to use a pesticide outside of its registered use or to deploy a new end use product. Section 18 of the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) allows states to apply to use a pesticide for an unregistered use for a limited amount of time if the EPA determines that emergency conditions exist (http://www.epa.gov/opprd001/section18). Under Section 6206 of Title 3 of the California Code of Regulations (CCR), the DFA Director is permitted to apply for a Section 18 exemption when emergency conditions exist. Section 24 of FIFRA authorizes states to register an additional use of a federally registered pesticide or a new end use product to meet a special local need (www.epa.gov/opprd001/24c).

Experimental Unregistered Use of a Pesticide

Section 6260 of Title 3 of the CCR provides the conditions for obtaining a Research Authorization for the experimental use of a pesticide outside of its registered uses. Research Authorizations are administered by the California Department of Pesticide Regulation (DPR).

III. RAPID RESPONSE PROCEDURE

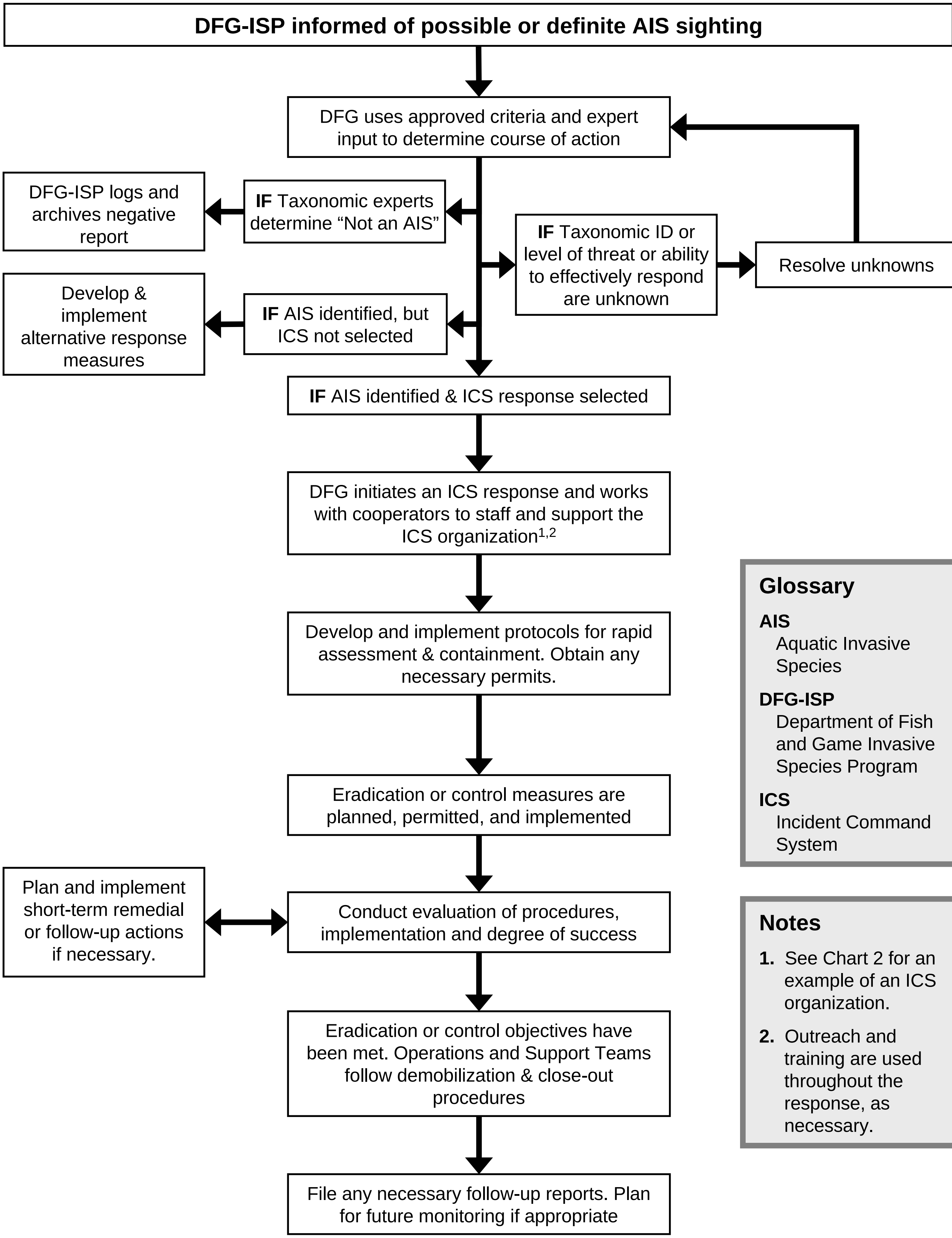
The initial steps in this procedure result in the determination of whether an active response is immediately necessary after a potential invasive species is reported. If immediate action is necessary, and requires more than simple, highly localized measures, resource management staff may decide to implement an incident command system (ICS) response. A set of criteria will be developed to help in this decision making process. Many of the steps listed below are likely to take place simultaneously or overlap to some degree. Examples of these include outreach, rapid assessment, and containment activities. A flow chart showing the general steps of this rapid response procedure is provided as Chart 1.

In an ICS response, participants are assigned specific roles in a well-defined hierarchical system that can be expanded or collapsed based on the size and complexity of the incident. The ICS was developed to allow staff from different government agencies and organizations to work effectively and efficiently together to respond to a natural disaster. Participants essentially check their individual agency identities at the door and participate as members of the ICS organization, dedicated to responding to a particular incident. The system's success relies on participants understanding their role, a clear chain of command and communication, managers having an appropriate span of control, and a standardized process for identifying and communicating objectives, strategies, tasks and deadlines. Because of its proven effectiveness, the ICS has recently been integrated into the National Incident Management System (NIMS). For more information about the principles and features of the ICS go to Lessons 2 and 3 at http://emilms.fema.gov/ICS100G/index.htm. To learn more about the integration of ICS into NIMS, please visit www.fema.gov/emergency/nims. An example of how the ICS staff organization scheme has been applied to an AIS rapid response in California is provided in Chart 2.

Optimal use of this system requires that participants be trained in advance per Section IV (Planning) of this document. The Planning Section also discusses the need to develop the finer details of the procedure, the lists and directories that are referred to in the procedure, and the designation of alternates. This last item ensures that none of the positions described in the procedure are ever vacant.

The procedure that will be followed for a given incident may follow the generic plan provided below or be based on a species-specific rapid response plan approved by the participating agencies. As species-specific plans are developed and approved, staff that have been identified as potential responders will be notified of their approval and location on the Internet. Basic information about each species specific plan will be incorporated into AIS rapid response training.

Chart 1. DRAFT General Procedure for Rapid Response Following Detection of New Aquatic Invasive Species Infestation



Glossary

AIS
Aquatic Invasive Species

DFG-ISP
Department of Fish and Game Invasive Species Program

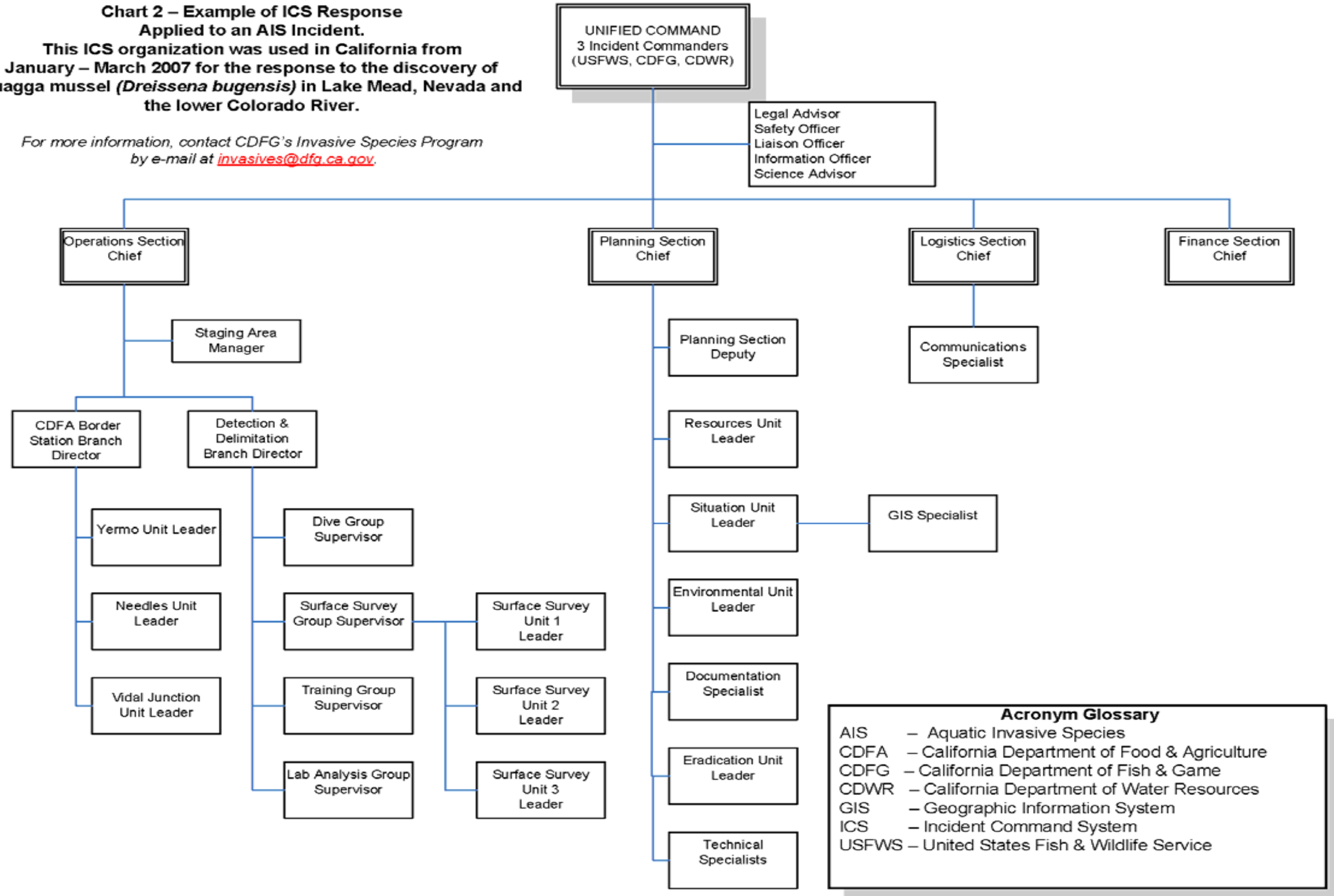
ICS
Incident Command System

Notes

1. See Chart 2 for an example of an ICS organization.
2. Outreach and training are used throughout the response, as necessary.

Chart 2 – Example of ICS Response Applied to an AIS Incident.
This ICS organization was used in California from January – March 2007 for the response to the discovery of quagga mussel *(Dreissena bugensis)* in Lake Mead, Nevada and the lower Colorado River.

For more information, contact CDFG's Invasive Species Program by e-mail at invasives@dfg.ca.gov.



17-STEP RAPID RESPONSE PROCEDURE

Step 1. Identify species and notify authorities

a. Sighting Report: There are three ways in which DFG is likely to receive a report of an AIS sighting.

   1. Either a sighting is reported to DFG via a hotline phone number or e-mail address (Invasives@dfg.ca.gov), and catalogued on *RR Form 1: Suspect AIS Sighting Report* (see Section V).

   2. Staff from another agency or cooperator discovers the AIS and submits the collected information directly to DFG's Invasive Species Program staff.

   3. The initial report is made to one of the federal invasive species reporting systems (e.g. "United States Geological Survey Nonindigenous Aquatic Species Alert System" or the "100th Meridian Initiative") which in turn will alert DFG.

b. Sighting Transmittal: This initial information is transmitted to the DFG Invasive Species Coordinator (ISC). If there is uncertainty about the identification of the species, the Invasive Species Program staff will work with taxonomic experts to resolve the issue.

c. For the purpose of documentation, and to assist making a determination of how to proceed following the initial report, the more detailed *RR Form 2: AIS Alert Report* (see Section V) should be completed.

d. Negative ID: If the identification is negative for AIS no further action is necessary.

e. Indefinite ID and/or level of threat: If uncertainty remains after initial fact-finding, the DFG Invasive Species staff should continue to work with experts from cooperating agencies and research institutions to determine the status of the species reported and the level of threat.

f. Positive ID with a high level of threat: If the discovered organism is invasive and in the presence of vectors that could cause its spread to uninfested areas, DFG Invasive Species Coordinator will consult with DFG executive level staff to determine if an ICS response is appropriate.

   1. If the identification is positive, the DFG Invasive Species staff will ensure that a report is sent to the United States Geological Survey Nonindigenous Aquatic Species Alert System (http://nas.er.usgs.gov/SightingReport.asp). During the response, the alert system should receive updates on any additional locations of the AIS that are found.

   2. Fill out an Incident Brief Form (ICS Form 201).

   3. ICS forms are available at: http://training.fema.gov/EMIWeb/IS/ICSResource/ICSResCntr_Forms.htm

Step 2. Activate command-level participants

a. Incident Command Staff: The executive level DFG staff will work with the Invasive Species Coordinator and executive level staff of cooperating agencies to identify the Incident Command staff. They can utilize the Rapid Response Personnel Directory discussed in the Planning Section of this document.

1. The Incident Commander is the overall supervisor and coordinator for the incident. A detailed description of the responsibilities of an Incident Commander and the other Incident Command officers and General Staff positions, can be found in Lessons 3 and 4 at http://emilms.fema.gov/ICS100G/index.htm.

2. Executive level staff and the ISC will decide to pursue a single command response, with one Incident Commander, or a unified command response, with multiple Incident Commanders working as a team. A Unified Command approach is designed to be used in multi-agency or multi-jurisdiction responses.

b. Initial Unified Command Meeting: If a unified command approach is used the Incident Commanders in the Unified Command should meet to discuss and concur on important issues prior to starting the first operational period planning meetings.

Step 3. Implement the ICS Planning Cycle

a. Begin to utilize the ICS planning cycle to document the current status of the response, identify objectives, strategies, specific task assignments and operational period. See http://www.uscg.mil/hq/g-m/mor/media/Chapter_3.pdf for a description of the ICS Planning Cycle.

1. During every ICS planning cycle, an Incident Action Plan is developed for the following operational period. It contains objectives, safety measures, staff contact information, status of the incident and assignments for each organizational element that will be active during the next operational period. The plan must be approved by the Incident Commander(s).

a) The plan is comprised of standard ICS forms that are available in electronic form. Once the initial set of forms is completed, the Incident Action Plan can rapidly be revised and updated.

Step 4. Develop the Organization

a. Command Post: Establish a command post capable of supporting the space, logistic, communication and other technology needs for managing the operation. It may or may not be a high priority to have the command post located close to the infested site, based on the characteristics of a particular incident. Potential command posts will be listed in the AIS Rapid Response Resource Directory discussed in the Planning Section of this document.

b. Logistics and Finance: The Logistic and Finance Section Chiefs will establish the fundamental tools and means to run the organization, such as setting up the check-in routine, necessary ICS forms, communication services, spending authorizations, and tracking of resources.

c. Assemble Organizational Elements: Using the ICS system, develop an organization that is suitable for the size and complexity of the incident.

1. Directory of Approved Staff: To staff the organizational elements (e.g. sections, branches, units) the Incident Command and upper level General Staff will utilize (but are not limited to) staff directories of people approved to be assigned to rapid response efforts.

2. ICS training materials suggest that “it is better to initially overestimate the need for a larger organization than to underestimate it, as it is always possible to downsize the organization.” (National Wildfire Coordinating Group, 1994, p.3-19).

3. Logistics Section staff will utilize the Resource Directory discussed in the Planning Section of this document in their effort to procure the necessary equipment and supplies among cooperating agencies and organizations during a rapid response procedure.

d. Consider the need to assemble a science advisory panel that may include experts outside of the ICS organization to provide input on such topics as AIS biology, sampling techniques, eradication or control measures.

Step 5. Safety Plan

a. The standard ICS organization includes a Safety Officer who reports to the Incident Commander/Unified Command. One of the duties of the Safety Officer is to develop a Safety and Health Plan that assesses potentially hazardous situations that could exist throughout the operation for responders and the public, and outlines the safety measures that should be taken.

Step 6. Outreach

a. Outreach Plan: The incident's Information Officer develops an Outreach Plan for the incident that addresses short and long-term proactive communication objectives and strategies to be employed with relevant groups such as the media, government agency representatives outside of the ICS response, stakeholders, interest and community groups and the general public.

   1. Develop policy with the Incident Commander(s) and the Liaison Officer regarding protocols for disseminating information.

   2. Besides disseminating information the outreach plan should address obtaining input from stakeholder groups and other interested individuals.

b. The Media: Typically, the Information Officer is assigned to be the contact person for inquiries from the media.

   1. Typical tasks include preparation of press releases, briefings, public meetings, etc.

   2. The Information Officer reports to the Incident Commander.

c. Government Agencies: Typically, a Liaison Officer is assigned to be the point of contact for inquiries from government agencies that have an interest in the response.

   1. The Liaison Officer provides relevant updates on the response to representatives from these agencies.

   2. The Liaison Officer reports to the Incident Commander.

d. Stakeholder and Interest Groups: Outreach to these groups can be crucial, especially if their activities can result in spread of the AIS. Outreach to non-governmental groups needs to be assigned to the Information Officer or the Liaison Officer. A large stakeholder group for a large incident may warrant their own Assistant Liaison Officer or Assistant Information Officer to maximize cooperation from this group and be aware of concerns they may have.

e. General Public: Assign who will be responsible for responding to inquiries from individual members of the public. Determine whether it is advisable to establish and publicize a toll-free call-in number for the incident.

Step 7. Training

a. Develop a Training Plan: There is often a need to establish a training branch within the ICS. As the incident begins to unfold, the Training Director will be responsible for working with managerial level staff to assess and find appropriate means to provide the types of training that are needed, both for staff within the ICS and for cooperating agencies, organizations and volunteers.

   1. A training manual should be developed that contains any specialized protocols and associated training materials (e.g. survey or decontamination protocols).

Step 8. Regulatory Compliance

a. The Planning Section is typically responsible for addressing regulatory compliance with environmental laws, with input from the Legal Specialist assigned to the incident. The issues that are most likely to arise are related to water quality and effects on state or federally listed species during survey or control activities.

Step 9. Containment Actions

a. Take action to prevent the spread of the AIS. Examples of containment actions that might be taken include:

   1. Inspections: Working with public and private managers of infested and potentially infested waterbodies and waterways, locate and inspect potentially contaminated facilities, shorelines, boats, vehicles and equipment to the extent possible. Prioritize a list of potential sites that should be inspected. Some of this work is part of the rapid assessment described below.

      a) Survey boaters about previous and subsequent waterways visited and provide them with information about the AIS problem.

      b) If regulations allow, require, or otherwise, request that aquatic plant and animal material be removed from the watercraft, motor and trailer and for any remaining water to be drained.

      c) Request that boats and equipment be rinsed with high pressure or hot water and dried before launching. The time needed for drying is species specific.

      d) Boats that are found to be contaminated with a legally restricted species per F&G Code Sec. 671 cannot be launched until they are certified by DFG to be decontaminated.

b. Introductions from Out-of-State: Coordinate with California Department of Food and Agriculture's Border Protection Station Program, federal, and other state and national agencies if the introduction is known to have come from out of state or has potential to have come from out of state.

c. Prevent Spread from California: Coordinate with federal and state agencies on preventing spread from California into other states (especially states that border CA), Canada or Mexico.

d. Temporarily quarantine body(ies) of water that contain subject AIS.
   1. Establish a quarantine utilizing one of the methods discussed in legal authority section.
   2. In addition to sites known to contain the subject AIS, consider whether it is appropriate to quarantine areas where the AIS may have been introduced.

Step 10. Rapid Assessment

a. Extent of the Infestation: Get a qualitative "snapshot" of the extent of the infestation and identify potential vectors for spreading the AIS.

   1. Planning and Operations Section staff can work together to identify short vs. longer-term information needs and plan how various types of information should be gathered.

      a) Samples may need to be collected for gathering basic demographic information or more in-depth taxonomic work. Establish protocol for collecting, transporting, and storing samples. Develop appropriate permits for possession and transportation of specimens.

      b) In addition to noting the presence or absence of the AIS, consider whether it's appropriate to systematically get some basic information about the habitat at this point, collect samples of substrate or water, etc.

      c) Determine whether there are known occurrences of, or potential habitat for, state or federally listed species in the area that needs to be surveyed, and whether surveys may require consultation with DFG, the U.S. Fish and Wildlife Service or NOAA Fisheries.

b. Data collection is typically done by the Operations Section of the ICS, with the Logistics and Finance Sections providing assistance with the procurement of equipment, vehicles, travel, etc.

c. Impacted Parties: Obtain contact information for pertinent landowners, land managers, holders of water rights, water users and jurisdiction over the body(ies) of water involved. If it is necessary to enter private property to conduct rapid response work, assign an ICS member to obtain permission to enter.

Step 11. Plan Eradication or Control Measures

a. If appropriate, develop a plan to eradicate the AIS from CA or a control plan to prevent the spread of the AIS. It may not be feasible to finalize the plan during the rapid or ICS phase of the response. Some planning may occur after the ICS is demobilized.

   1. During the assessment phase of the response, the Planning Section can gather and review information on potential eradication or control techniques and confer with experts (Step 4D).

   2. As information is gained from the rapid assessment, and possibly from subsequent detailed sampling, a more refined version of an eradication or control plan can be prepared, discussing the specific measurable objectives, locations and methods for eradication or control, methods for evaluating the effectiveness of the plan, and the potential costs, benefits and impacts.

   3. Conduct any regulatory processes and obtain any regulatory permits that may be necessary prior to implementation of the plan.

Step 12. Implement the Eradication or Control Plan

a. Implementation of the eradication or control plan may place during the “rapid” part of a response; however, if this is not the case, eradication or control measures might be implemented during a later “post –ICS” phase of the response.

b. Document implementation of the eradication or control plan. Note any deviations from the plan and why those occurred.

Step 13. Prevent Reinfestation

a. Develop specific recommendations for actions that can be recommended to prevent reinfestation such as:

    1. Long-term monitoring
    2. Continued outreach and education
    3. Partnerships with business and interest groups
    4. Strengthening relevant regulations
    5. Identify staffing needs
    6. Identify research needs

b. Ensure the potential for introduction from nearby commercial operations (shipping, bait shops, aquaculture, aquarium shops) is removed or minimized to the extent possible.

Step 14. Prepare Demobilization Plan

a. During the response, the Planning Section is responsible for preparation of a Demobilization Plan and having it approved by the Incident Commander(s). The purpose of the Demobilization Plan is to assure that all participants understand their role in an orderly, safe and efficient demobilization of incident resources as rapid response procedures are completed. Equipment and supplies must be returned to appropriate locations, time and cost accounting reports must be completed within required timeframes, and any other required progress and final reports must be prepared and submitted.

Step 15. Monitor the outcome of the Rapid Response

a. Evaluate Eradication or Control Efficacy: If eradication or control actions were taken during the response, monitor and evaluate the efficacy of the treatment(s) used and conduct environmental monitoring that may be necessary to meet regulatory compliance requirements. Prepare a monitoring report and submit a copy to the ISC. If the control or eradication measures require months or years to implement, these evaluation reports may take the form of periodic progress reports.

    1. If the treatments were not successful or an acceptable level of progress is not being achieved, evaluate the potential for remedial measures to improve the results. If there is a strong possibility for improvement, propose possible remedial actions as part of the monitoring report.

b. If eradication or control measures were not taken, there may be a decision to conduct monitoring of the AIS population and provide monitoring reports to the DFG Invasive Species Program.

Step 16. Undertake remedial actions and long-term follow up

a. Remedial Action Approval: If there is efficacy monitoring prior to the demobilization of the incident and remedial actions are recommended, the Incident Commander(s) can approve the implementation of a remedial action plan and utilize the assembled rapid response personnel, assuming any environmental regulatory and/or fiscal issues are addressed.

b. Remedial Action Monitoring: Remedial actions and their results will require subsequent monitoring.

c. Follow-Up Actions: If longer-term actions are necessary, the Planning Section, with input from other rapid response personnel and outside expert input as necessary, will develop a follow-up plan that will be submitted to the DFG Invasive Species Program.

Step 17. Implement the Demobilization Plan

a. Implement the demobilization plan described in Step 14. The work will be carried out by the Incident Teams and Specialists with oversight and coordination from the Incident Command Staff. Reports will be submitted to the ISC for approval and appropriate distribution.

IV. PLANNING FOR RAPID RESPONSE

This section suggests 11 basic task areas necessary to plan for rapid response and completion of this plan.

Task 1. Collaborate to complete plan

Representatives from public agencies and other organizations that are currently involved in rapid response work, or likely to be involved in the foreseeable future, should collaborate to finalize the Rapid Response Plan (see Task 4). The goal is to have a plan that can be the basis for interagency agreements (Task 2). Note that not every item in Task 4 needs to be complete in order to have a plan that supports such agreements. This group could also prioritize and carry out parts of additional planning tasks listed below. The collaboration necessary to carry out the tasks in this section could occur through a technical advisory panel to the CAAIST or AISWG (collaborative groups described in the CAISMP), through the California Biodiversity Council (CBC) Rapid Response Working Group, or through executive or upper management staff of cooperating agencies assigning staff to an interagency Rapid Response Planning Team.

Task 2. Enter into cooperative agreements

DFG Invasive Species Program staff will work with cooperating agencies and organizations to produce a list of entities that should be invited to sign Memoranda of Understanding, Implementation Agreements or similar instruments to cooperate on rapid response to AIS. Existing information in the CAISMP and information collected by CBC Rapid Response Working Group will be used, among other sources, to generate this list. The proposed list and a conceptual outline for these agreements will be presented to CBC and/or directly to relevant agency executives.

Task 3. Secure funding

This Plan cannot be implemented without adequate, stable and dedicated funding. Agencies signatory to the Rapid Response agreement(s) should coordinate efforts to pursue funding options for Rapid Response program development, training and implementation.

Organizations and industries that have a vested interest in successful early detection and rapid response systems could participate in the development of funding sources.

a. Funding Analysis: Consider the following types of funding sources:

   1. A permanent funding source(s) maintained solely for rapid response actions. Without this, rapid response may not occur or may only occur by redirecting funds on short notice from other important programs.

   2. A user-fee system based on vectors for AIS introductions. This would be similar in concept to fees paid by the shipping industry for ballast water inspections or fees paid by the petroleum industry for an oil spill response program. Methods used by states that already have dedicated funding for rapid response can be emulated.

   3. Private/public partnerships for supporting rapid response efforts in the form of equipment, supplies, personnel or funding.

   4. One-time grants for specific planning or research projects related to rapid response.

b. Taxonomy Funds: Develop funding for taxonomic work to identify potential AIS specimens. In some cases, this will include genetic analysis (e.g. to determine presence or absence of microscopic larvae of AIS species, or help determine the origin of an introduction). Expert taxonomic work will bolster confidence that subsequent management decisions are based on solid information. There should also be funding to maintain specimens. The proper maintenance and documentation of specimens is especially important in cases where infestations are the subject of law enforcement actions and may also be beneficial for future AIS identification needs and research.

c. Professional Cost Analysis: Consider whether a detailed, professional analysis of rapid response costs to support funding requests is necessary (Task 10b).

d. Funding Development: Consider using funding for development purposes (i.e. grant writing).

Task 4. Finalize the Rapid Response Plan

Work that needs to be done to finalize the Rapid Response Plan includes:

a. Implementation Criteria: Develop the process and criteria for the State to use in determining the course of action to take for any new AIS introductions. Circulate for peer review.

b. Likely Species & Scenarios: Identify likely species and/or early detection scenarios for AIS. Run these scenarios through the criteria developed for Task 4a to fine-tune the criteria.

c. Agency Preparation: Develop information needed to help cooperating agencies designate and train, in advance, potential responders to AIS introductions.

d. Alternate Staff: Develop a procedure to designate and prepare potential alternate staff. This could avoid gaps in getting work done and minimize managerial time spent searching for substitutes during a response.

e. Personnel Directory: Develop a statewide Rapid Response Personnel Directory. These people could be called upon to participate during rapid response activities, and into an ICS response. Ideally the Directory should include staff that represent the full spectrum of knowledge and skills that might be necessary during rapid response activities (e.g. ICS implementation, logistics, finance, legal and various technical experts). The development of this list and staff participation in Rapid Response planning and training will likely require support of executive level staff from the cooperating agencies.

f. Resource Directory: Develop and maintain a directory among cooperating agencies for equipment, operations centers, supply sources and associated contact people so that resources can be mobilized as quickly as possible during a response.

g. Taxonomic Experts: A list of taxonomic experts and protocols for requesting and using their services needs to be developed and periodically reviewed and updated. This would be a list of experts who have agreed to identify specimens for AIS Rapid Response efforts and appropriately preserve and catalog them.

h. Local Assistance Protocol: Develop a protocol for responding to a private entity or local government agency that wants to conduct a rapid response under its own direction but requests assistance or permits from one or more agencies signatory to the statewide Rapid Response Plan. Include this protocol in the rapid response training program.

i. Notification List: Develop a list of whom, outside of those directly involved, needs to be notified when rapid response procedures are being planned and implemented.

j. Database Compatibility: Consider whether information should be collected in a particular manner in order to be compatible with existing AIS databases. For example, the North American Weed Management Association has a list of required elements for weed mapping projects (www.nawma.org).

Task 5. Streamline permit processes for rapid response

DFG Invasive Species Program staff will coordinate with staff from relevant agencies to investigate and pursue possibilities for streamlining the regulatory permit processes that might be required for rapid response measures. General measures or best management practices necessary to comply with streamlined permitting can be incorporated into the Rapid Response Plan.

Task 6. Revise the Rapid Response Plan

a. Incorporate New Information: Periodically revise the Plan and incorporate anything learned by evaluating the Plan's effectiveness and consulting current scientific research and related technological developments. Revisions may also be necessary due to changes in funding, agency restructuring and environmental regulations. The interagency agreement(s) to cooperate on rapid response should include a procedure for making revisions to the Plan.

b. Notification of Plan Changes: DFG Invasive Species Coordinator should ensure that adopted changes to the Plan are circulated to people listed in the Rapid Response Personnel Directory and other appropriate staff among the cooperating agencies and organizations. Changes should be addressed in training activities.

c. Update Directories: DFG Invasive Species Program staff, with assistance and input from cooperating agencies and organizations, will be responsible for the periodic update and circulation of the Rapid Response Personnel Directory, the Rapid Response Resource Directory and the list of taxonomic experts.

Task 7. Develop species- or location-specific rapid response plans

Identify and prioritize certain species, groups of species or certain locations for the development of specific rapid response plans. Detailed technical information can allow this type of response plan to be implemented more efficiently than a generic response plan. The development of species- or location-specific rapid response plans is called for in Action 4A3 of the CAISMP. The process of prioritizing which species warrant the development of rapid response plans will also help guide the development of outreach materials for early detection efforts.

Task 8. Train employees, participants and team members

a. Training Program: Agencies that agree to cooperate on AIS rapid response need to participate in the development of a training program and train the employees likely to be involved in rapid response activities. Potential rapid response participants need to be familiar with the Rapid Response Plan, Incident Command System (ICS), and may need specialized training related to their likely duties during a rapid response. ICS training is available on-line at: http://training.fema.gov/IS/.

   There may be a need to develop supplemental training materials and presentations for information specific to California, AIS or other topics.

b. Drills: Ensure that training includes AIS rapid response drills using a variety of scenarios and locations around the state. This will also assist in fine-tuning the Rapid Response Plan.

Task 9. Conduct education and outreach

a. Outreach Planning: Outreach specialists from participating agencies and organizations should develop a plan of potential methods and protocols for conducting outreach to local communities, interest groups and the media during rapid response procedures. This could include sharing contact information for key groups such as boaters, anglers and marina owners.

b. Disruption of Regular Work: Within the cooperating agencies, supervisors of employees who are in the Rapid Response Personnel Directory should be made aware that rapid response work can supersede other projects on very short notice. Supervisors and employees who are on rapid response teams could discuss in advance how they plan to handle this potential source of disruption.

Task 10. Conduct research necessary for improved rapid response

a. Response Research: Academic institutions, government agencies and other organizations that agree to cooperate on rapid response should work together through various AIS working groups, professional and environmental organizations and commercial interests to promote research that can specifically improve or promote rapid response efforts.

b. Cost Research: Research the costs of rapid response, possible funding mechanisms (Task 3) and, if feasible, study the environmental and economic benefits and costs of conducting rapid response efforts versus not conducting rapid response. This may help governments decide how much to invest in rapid response measures.

Task 11. Develop interim rapid response protocols

This section addresses the question: What steps can be taken to prepare to implement a rapid response effort while a formal plan is going through the review and approval processes?

a. Memorandum of Understanding (MOU): The Directors of the appropriate agencies could sign an interim MOU directing their staff to participate in rapid response planning and implementation if a new AIS introduction occurs prior to the approval of the final plan.

b. Interim Funding: Management staff could identify and pursue interim funding sources for implementing a rapid response program.

c. Interim Strategy: Management level staff from cooperating agencies could informally agree upon an interim strategy regarding roles and responsibilities should an AIS introduction occur.

d. Permitting: Management level staff from cooperating agencies could discuss how, in the absence of a formal streamlined permitting process, their staff could work within the existing regulatory permit programs to facilitate a rapid response operation and direct staff to follow through on these interim measures.

e. Employee Assignment: Management level staff of cooperating agencies could assign employees to an interim core rapid response team or working group. This team could participate in some advance preparation and planning. In the event of a rapid response, this team would need to be augmented by additional staff based on the location of the response and the necessary areas of expertise.

V: Supporting Materials

Rapid Response Form 1. Suspect AIS Sighting Report

The reporter may not be able to provide all of the information requested below, but please fill in as many of the information fields as possible.

Report Tracking Number: ____________________ Date of Sighting: ____________

Reporter's First and Last Name: ____

Reporter's Phone Numbers: Home: _______________ Work: ____________________

Cell: ____________________

Reporter's E-Mail Address: __________________

Reporter's Mailing Address:

____

____

Type of Organism (as specific a descriptive label as possible (e.g. submerged plant, shellfish, etc.):

Description of size, color, shape and other distinguishing characteristics:

Approximate number of individuals or area they occupy:

Location of sighting:

Directions and description of nearby landmarks:

Were any photographs taken or specimens collected? If so, where can they be obtained?

Landowner or Land Manager:

Possible Source of Introduction:

Name and Contact Information of Person Filling Out This Form:

Rapid Response Form 2. AIS Alert Report [1]

To be filled out by Species Identification Team member following up on a preliminary report of a possible AIS sighting (Form 1). The AIS Report will be expanded to two pages in the final draft to reduce the crowding on this form.

Species Name: Report Tracking #
Name of Person Filling out Form: Phone Number(s):
Agency:
Address: E-mail address:

Reporter's Name:
Reporter's Phone Number(s):
Reporter's e-mail:

Date of Pest Sighting:
If the identification was verified by expert, who provided the verification?
Verifier's phone number(s): E-mail:

Location of voucher specimens:

Sighting Location (if possible attach a map showing the location):
County: Body of water:

Landowner/Manager:
Describe location
(Relationship to nearby road intersection, pier, mile marker, buoy, other landmarks)

If possible, please provide map information (You choose the system):

T____ R____ Sec____, _____1/4 of ____1/4, Meridian: H__ M___ S___
T____ R____ Sec____, _____1/4 of ____1/4, Meridian: H__ M___ S___

Quad Name: Source of Coordinates (GPS, topo map & type):
GPS Make and Model: Horizontal Accuracy______meters/feet

Datum: NAD27____ NAD83____ WGS84____
Coord. System Zone 10 ___ Zone 11___ or Geographic Latitude/Longitude_____

Describe pest species population (approximate number of individuals or stems, area they occupy)

Describe any evidence of reproduction (flowering, juvenile animals, egg masses, etc.)

Describe habitat: (e.g. plant community, associated plant species, host species, water depth, distance from bank, substrate characteristics (e.g. gravel, large rocks, silt, sand), etc.)

Photographs can be accessed at:

1 Based on California Department of Fish & Game, California Natural Diversity Data Base, "Native Species Field Survey Form" and the "Maui County Report A Pest Online Report Form," Maui County, HI.

VI. REFERENCES

Akers, P. California Department of Food and Agriculture (DFA): *Draft Rapid Response Plan*. Prepared for the Western Regional Panel on Aquatic Nuisance Species, 27 pp.

Anderson, LWJ. 2005. "California's reaction to *Caulerpa taxifolia*: a model for invasive species rapid response." *Biological Invasions* 7: 1003-1016.

California Department of Fish and Game, Office of Spill Prevention and Response. 2001 *California Oil Spill Contingency Plan*, Sacramento, CA, 34 pp. (plus appendices).

California Department of Fish and Game (DFG), Biogeographic Information Branch. 2003. "California Native Species Field Survey Form."

California Department of Food and Agriculture, Integrated Pest Control Branch, Plant Health and Pest Prevention Services. *Model Rapid Response Plan for Aquatic Nuisance Species*. Prepared for the Western Regional Panel on Aquatic Nuisance Species, 57 pp.

Federal Interagency Committee for the Management of Noxious and Exotic Weeds. 2001. *National Early Warning and Rapid Response System for Invasive Plants in the United States, Draft Action Plan*. Washington, D.C. August 28, 2001, 22 pp.

Federal Emergency Management Agency. 2006. *National Incident Management System Homepage*. www.fema.gov/emergency/nims.

Fraidenburg, M. 2005. *Rapid Response Plan for Zebra Mussels in the Columbia Basin*. Prepared for the Pacific States Marine Fisheries Commission, Olympia, WA. November 18, 2005, 35 pp.

Gulf of Mexico Regional Panel on Aquatic Invasive Species. 2004. *Rapid Response Plan for the Gulf of Mexico Region*. Prepared for the National Aquatic Nuisance Species Task Force, December 2004.

Great Lakes Commission Staff, Resource Management Program. 2004. *Model Rapid Response Plan for Great Lakes Aquatic Invasions, Iteration II*. Prepared for the U.S, Environmental Protection Agency, Great Lakes National Program Office. April 2004, 56 pp.

Heimowitz, P and S Phillips. 2006. *Rapid Response Plan for Zebra Mussels in the Columbia River Basin: A Comprehensive Multi-Agency Strategy to Expeditiously Guide Rapid Response Activities* (Working Draft). U.S. Fish and Wildlife Service and Pacific States Marine Fisheries Commission. September 2006.

Maui County, HI. 2006 Maui *County Report a Pest Homepage*. http://pbin.nbii.gov/reportapest/maui/. Also contact: reportapest-maui@hawaii.edu.

National Invasive Species Council. 2003. *General Guidelines for the Establishment and Evaluation of Invasive Species Early Detection and Rapid Response Systems*. Version 1. 16 pp.

National Wildfire Coordinating Group. 1994. *Incident Command System National Training Curriculum: Organizational Overview, Module 3*, I-200. National Interagency Fire Center, Publication NFES #2443. October 1994. 36pp.

U.S. Coast Guard. 2001. *Incident Management Handbook, Incident Command System (ICS)*. Commandant Publication P3120.17, Washington, D.C. http://www.lartu.org/ics/USCG%20FOG.pdf

Veldhuizen, T. 2004. *Zebra Mussel Detection and Outreach Program*, California Department of Water Resources.

Veldhuizen, T. 2004. *Zebra Mussel Rapid Response Plan for California*. Prepared for the California Bay-Delta Authority (CBDA Project No. 99-F07) and the U.S. Fish and Wildlife Service. Sacramento, CA. June 30, 2004.

APPENDICES B-D

Introductory Notes

These appendices provide a detailed description of the primary federal and state laws, regulations and public policies that empower and direct different government agencies to manage AIS in California. They also describe the primary activities of government agencies – state, federal and regional – involved in AIS management, as well as most of the major committees and boards set up to coordinate and oversee such activities. These details are provided to support and expand on the information contained in the Management Framework provided in Chapter 4 and the Summary of Laws provided in Chapter 5 of this plan (as such, there is some repetition of information). While these appendices attempt to be comprehensive, there is inadequate space to present every single AIS program, law or activity in the state and nation. Through the web links provided below and further information in the appendices, more details on legal authorities and AIS stakeholders is available to all interested parties. A key to the acronyms used in these appendices can be found in the Acronym Glossary in the introductory pages of this plan. (*Note: Some laws and policies refer to ANS, aquatic nuisance species, rather than AIS, aquatic invasive species.)*

APPENDIX B: FEDERAL AUTHORITIES, LEGISLATION & AGENCIES

FEDERAL AUTHORITIES

No single federal agency has comprehensive authority for all aspects of aquatic invasive species management. Federal agencies with regulatory authority over the introduction and transport of aquatic species that may be invasive or noxious include the U.S. Department of Agriculture Animal Plant Health Inspection Service, the U.S. Department of Agriculture Agricultural Marketing Service, the U.S. Fish and Wildlife Service (USFWS), the U.S. Department of Commerce (DOC), and the U.S. Coast Guard (USCG). Many other agencies have programs and responsibilities that address components of AIS, such as importation, interstate transport, exclusion, control and eradication.

The primary federal authorities for managing and regulating AIS derive from the National Environmental Policy Act, the Nonindigenous Aquatic Nuisance Prevention and Control Act (NANPCA, 1990), the National Invasive Species Act (NISA, 1996), the Lacey Act, the Plant Pest Act, the Federal Noxious Weed Act, and the Endangered Species Act. An Executive Order signed by President William J. Clinton on February 3, 1999 expanded federal efforts to address AIS. The order created a National Invasive Species Council charged with developing a comprehensive plan to minimize the economic, ecological and human health impacts of invasive species.

Brief descriptions of the President's Executive Order, NANPCA and NISA are provided below, followed by an explanation of how federal activities are now coordinated through the national Aquatic Nuisance Species Task Force (ANSTF) and the National Invasive Species Council (NISC), and by descriptions of some of the earlier acts and laws still enforced in AIS management.

Primary Federal AIS Authorities

1990 – Nonindigenous Aquatic Nuisance Prevention and Control Act
(NANPCA; Title I of P. No.101-646, 16 U.S.C. 4701 et seq.)
http://www.anstaskforce.gov/default.php

The Nonindigenous Aquatic Nuisance Prevention and Control Act of 1990 (NANPCA) established a federal program to prevent the introduction and control the spread of introduced aquatic nuisance species. The act provides an institutional framework that promotes and coordinates research, develops and applies prevention and control strategies, establishes national priorities, educates and informs citizens, and coordinates public programs. The act calls upon states to develop and implement comprehensive state management plans to prevent introduction and control the spread of aquatic nuisance species (ANS). Section 1002 of NANPCA outlines five objectives of the law, as follows:

1. Prevent further unintentional introductions of nonindigenous aquatic species;
2. Coordinate federally funded research, control efforts, and information dissemination;
3. Develop and carry out environmentally sound control methods to prevent, monitor and control unintentional introductions;
4. Understand and minimize economic and ecological damage; and
5. Establish a program of research and technology development to assist state governments.

Section 1201 of the act established the national ANSTF, co-chaired by the USFWS and the National Oceanic and Atmospheric Administration. The Task Force is charged with coordinating governmental efforts related to ANS prevention and control. The ANSTF consists of 10 federal agency representatives and 12 ex officio members representing nonfederal governmental agencies (see Other AIS Interests, Appendix D).

1996 – National Invasive Species Act
(NISA; P. No.104-332)

In 1996, the National Invasive Species Act (NISA) amended the NANPCA of 1990 to mandate ballast water exchange for vessels entering the Great Lakes and to implement voluntary ballast water exchange guidelines for all vessels with ballast on board that enter U.S. waters from outside the U.S. Exclusive Economic Zone (U.S. EEZ). Though the act did not make exchange mandatory, it did require all vessels to submit a report form to the USCG documenting specific ballast water management practices. It also authorized the USCG to toughen requirements if compliance proved unsatisfactory, which it did in 2004 (see below). NISA authorized funding for research on aquatic nuisance species prevention and control in Chesapeake Bay, the Gulf of Mexico, the Pacific coast, the Atlantic coast, and the San Francisco Bay-Delta Estuary. In addition, NISA required a ballast water management program to demonstrate technologies and practices to prevent ANS from being introduced into and spread through ballast water in U.S. waters. It modified both the composition and research priorities of the ANSTF and requirements for the zebra mussel demonstration program.

1999 – Executive Order 13112
(64 Fed. Reg. 6183)
http://www.invasivespeciesinfo.gov/council/main.shtml

President William J. Clinton signed Executive Order 13112 on Invasive Species on February 3, 1999. The order seeks to prevent the introduction of invasive species, provide for their control and minimize their impacts through improved coordination of federal agency efforts under a National Invasive Species Management Plan developed by the newly created National Invasive Species Council (NISC). The order directs all federal agencies to address invasive species concerns, as well as to refrain from actions likely to increase invasive species problems.

The NISC has three co-chairs: the secretaries of Agriculture, Commerce, and the Interior. Members also include the secretaries of State, Defense, Homeland Security, Treasury, Transportation and Health and Human Services, as well as the administrators of USEPA, the U.S. Agency for International Development, the U.S Trade Representative and the National Aeronautics and Space Administration. The NISC released the first National Invasive Species Management Plan in 2001. The NISC is currently working to establish federal and non-federal task teams to implement the plan's action items.

The NISC actively works with the Invasive Species Advisory Committee (ISAC), also established under the order. The ISAC is composed of stakeholder representatives from state governments, industry, conservation groups, academia and other interests. Its role is to advise the federal government on the issue of invasive species.

To help coordinate the work of the NISC and the ANSTF, the Department of Commerce (DOC) Policy Liaison to the NISC also serves as the DOC representative to the ANSTF. In addition, NISC and the ANSTF have formed joint working groups on each of the following topics: pathways, risk analysis and screening.

The ANSTF and the NISC are similar in that they perform coordinating functions but differ in their responsibilities: the NISC addresses all invasive species, while the ANSTF focuses on aquatic invasive species. Although many of the same principles apply to managing aquatic and terrestrial invasive species, many management issues are unique to the aquatic environment and need to be addressed separately.

1993-2005 – Coast Guard Regulations under NISA
(33 CFR 151)

The USCG has promulgated a number of ballast water management regulations based on the authority given to it by NANPCA in 1990 and NISA in 1996. As directed by NANPCA, in 1993, the USCG implemented regulations requiring vessels entering the Great Lakes and the Hudson River to conduct ballast water management after operating outside the U.S. EEZ.

To comply with the NISA, the USCG established regulations and guidelines to control the introduction of ANS via ballast water discharges in U.S. waters other than the Great Lakes. Compliance with the resulting voluntary ballast management and mandatory reporting program was only 30%, according to a 2002 Report to Congress. Therefore, under the authority of NISA, the USCG established mandatory ballast water management requirements and penalties for non-compliance. The mandatory program requires ships to use one of three ballast water management methods: 1) retaining ballast water on board, 2) conducting a mid-ocean exchange, and/or 3) using an approved ballast water treatment method. All vessels are required to submit ballast water management reports (failure to submit a report can now result in penalties). These mandatory regulations came into effect on September 27, 2004. Federal regulations also require vessels to maintain a ballast water management plan that is specific for that vessel and assigns responsibility to the master or appropriate official to understand and execute the ballast water management strategy for that vessel.

Under NANPCA/NISA, states are specifically permitted to regulate ballast water on ships. Several states have elected to do so to various degrees. In addition to reporting requirements, California, Oregon and Washington have ballast water exchange requirements and California will soon specify a ballast water discharge standard (see California Authorities section).

Other Federal Authorities

Animal Damage Control Act (1931)
http://www.aphis.usda.gov/

Under the Animal Damage Control Act, the U.S. Department of Agriculture (USDA), Animal and Plant Health Inspection Service has authority to control wildlife damage on federal, state, or private land, including damage from invasive species. The act protects field crops, vegetables, fruits, nuts, horticultural crops and commercial forests; freshwater aquaculture ponds and marine species cultivation areas; livestock on public and private range and in feedlots; public and private buildings and facilities; civilian and military aircraft; and public health.

Animal Health Protection Act (2002)
(7 U.S.C Sec. 8301, et seq.)
http://www.aphis.usda.gov/

The Animal Health Protection Act provides a flexible statutory framework for protecting domestic livestock from foreign pests and diseases. This act authorizes the USDA to promulgate regulations and take measures to prevent the introduction and dissemination of pests and diseases of livestock. The scope of such regulatory authority extends to the movement of all animals, domestic and wild, except humans. The fact that a pest or disease primarily affects animals other than livestock, including humans, does not limit USDA's authority to regulate a species, so long as it carries a pest or disease of livestock. Further, the act defines "livestock" to mean all farm-raised animals, clarifying the USDA's authority to conduct animal health protection activities in connection with farm-raised aquatic animals.

Clean Water Act
http://www.epa.gov/r5water/cwa.htm
http://unds.bah.com/default.htm

Various sections of the Clean Water Act (CWA) regulate discharges of pollutants (such as AIS and ballast water) and fill material to waters of the United States. Section 402 of the act authorizes the National Pollutant Discharge Elimination System (NPDES), a permit program intended to reduce and eliminate the discharge of pollutants from point sources that threaten to impair beneficial uses of water bodies. The act defines point sources to include vessels (Section 502(14)) and prohibits all point source discharges of pollutants into U.S. waters unless a permit has been issued either under Section 402 (NPDES) or Section 404 (dredge and fill activities).

California's Waste Discharge Requirements, issued by the state's Regional Water Quality Control Boards (RWQCBs), incorporate the authority of the federal NPDES permitting program for discharges of wastes to surface waters. In addition, under Section 303(d) of the each of the RWQCBs has the requirement to establish "a total maximum daily load for those pollutants which the (Environmental Protection Agency (USEPA)) Administrator identifies under Section 304(a) (2) as suitable for such calculation." This section of the CWA was developed to support a water quality-based system of effluent limits for chemical pollutants; the interpretation of what an allowable load of invasive species is has not been defined.

Under Section 305(b) of the CWA, California's nine RWQCBs are required to assess water bodies for attainment of beneficial uses every two years and report to the USEPA. In cases where beneficial uses of water bodies are shown to be impaired, Section 303(d) requires the Regional Boards to list the impaired water bodies and "establish a priority ranking for such waters, taking into account the severity of the pollution and the uses to be made of such waters." Section 502(6) defines "pollutant" as dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, *biological materials,* radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal and agricultural waste discharged into water. Ballast water is considered to be a pollutant in discharges based on the above definition and definitions in the State Water Code.

Endangered Species Act of 1973
(ESA; 16 U.S.C.A. §§ 1531 to 1544)
http://www.fws.gov/endangered/

The ESA aims to protect endangered and threatened species. When non-native invasive species threaten endangered species, this act could be used as basis for their eradication or control by the USFWS or by the National Oceanic and Atmospheric Administration – National Marine Fisheries Service (NOAA-Fisheries Service) The potential to harm a federally-listed species and the need to obtain a permit from the USFWS or NOAA-Fisheries Service should be taken into consideration when selecting methods to manage AIS.

Lacey Act (1900; amended 1998)
http://www.fws.gov/laws/lawsdigest/lacey.html

As the first federal act that tried to control migrations and importations of nonindigenous species, the Lacey Act prohibits the importation of a list of designated species and other vertebrates, mollusks and crustaceans that are "injurious to human beings, to the interests of agriculture, horticulture, forestry, or to wildlife or the wildlife resources of the United States." Under this law, it is unlawful to import, export, sell, acquire, or purchase fish, wildlife or plants taken, possessed, transported, or sold: 1) in violation of U.S. or Indian law, or 2) in interstate or foreign commerce involving any fish, wildlife, or plants taken possessed or sold in violation of State or foreign law.

The Lacey Act allows for the import of species for scientific, medical, education, exhibition or propagation purposes. The USFWS is the lead agency for enforcing the Lacey Act's prohibition of fish and wildlife imports.

National Environmental Policy Act of 1970
(NEPA; 42 U.S.C.A. §§ 4321 to 4370e)
http://www.epa.gov/compliance/nepa/index.html

NEPA requires the consideration of environmental impacts for any federal action, including direct federal activities, permitting and federal funding of activities by another entity. NEPA environmental documents may include a "finding of no significant impact (FONSI)," an "environmental assessment (EA)," or a full "environmental impact statement (EIS)." Potential impacts of invasive species, both direct and indirect, may be among the issues that should be considered under NEPA.

Noxious Weed Act
(1974; 7 U.S.C. § 360)

Section 15 of the Federal Noxious Weed Act requires federal land management agencies to develop and establish a management program for control of undesirable plants that are classified under state or federal law as undesirable, noxious, harmful, injurious or poisonous, on federal lands under the agency's jurisdiction (7 U.S.C. 2814(a)). The act also requires the federal land management agencies to enter into cooperative agreements to coordinate the management of undesirable plant species on federal lands where similar programs are being implemented on state and private lands in the same area (7 U.S.C. 2814(c)). The Secretaries of Agriculture and the Interior must coordinate their respective control, research and educational efforts relating to noxious weeds (7 U.S.C. 2814(f)). USDA's Departmental Regulation 9500-10 sets forth departmental policy relating to the management and coordination of noxious weeds activities among the agencies within USDA and other entities.

Plant Protection Act
(2000; 7 U.S.C. 7701)
http://www.aphis.usda.gov/

The Plant Protection Act (PPA) authorizes the USDA to prohibit or restrict the importation or interstate movement of any plant, plant product, biological control organism, noxious weed, article or means of conveyance if the Secretary of Agriculture determines that the prohibition or restriction is necessary to prevent the introduction into the United States, or the dissemination within the United States, of a plant pest or noxious weed.

The PPA specifically authorizes USDA to develop integrated management plans for noxious weeds for the geographic region or ecological range where the noxious weed is found in the United States. In addition, the act authorizes the USDA to cooperate with other federal agencies or entities, states or political subdivisions of states, national governments, local governments of other nations, domestic or international organizations or associations, and other persons to carry out the provisions of the act.

FEDERAL AGENCIES

Numerous federal agencies, presented here in alphabetical order, have authority to implement the laws and policies described above. Other federal agencies have mandates impacted by AIS and thus engage in research, monitoring, prevention or control programs. Still others delegate primary responsibility for implementation to state and regional agencies (see next section). The following descriptions attempt to provide a general introduction to the scope of each agency's work, as well as a brief review of the agency's recent (as of 2006) major AIS-related activities.

Bureau of Reclamation
http://www.usbr.gov/

The Bureau of Reclamation is involved in several important projects related to this issue. The Bureau has partnered with the DFG, USFWS and others to investigate the Chinese mitten crab infestation in the Sacramento-San Joaquin Delta. The agency participates in the Giant *Salvinia* Task Force's efforts to limit the spread of this invader in the Colorado River (see Appendix D), has a detection program for water hyacinth and participates in activities related to the New Zealand mudsnail infestation in Putah Creek. The agency also participated in DFA's *Hydrilla* Eradication Program.

National Oceanic and Atmospheric Administration (NOAA)
http://www.noaa.gov/

NOAA is the primary federal agency charged with management of marine resources. NOAA is the co-chair of the ANSTF and has been designated the Department of Commerce lead as co-chair of the National Invasive Species Council. Within NOAA, a number of national, state and regional agencies and programs are actively involved in AIS issues in California. These include: National Estuarine Research Reserve System (NERRS), a network of protected areas established for long-term research, education and stewardship; National Marine Fisheries Service, which works to protect fisheries habitat, commercial fisheries and endangered fish; National Marine Sanctuaries, the nation's system of marine protected areas, and Sea Grant, a nationwide network of 30 university-based programs that work with coastal communities and conduct scientific research and education projects designed to foster science-based decisions for the use and conservation of U.S. aquatic resources.

National Estuarine Research Reserve System (NOAA – NERRS)
http://nerrs.noaa.gov/
http://sfbaynerr.org
http://www.elkhornslough.org/
http://nerrs.noaa.gov/TijuanaRiver/

There are three reserves in California that provide a platform to increase communication between scientists, decision-makers, land managers, and the public in order to better deal with AIS issues. The San Francisco Bay reserve protects two large, relatively pristine, tidal wetlands: China Camp State Park in Marin County and Rush Ranch Open Space in Solano County. These sites are part of an AIS early detection and assessment study and detailed vegetation maps are being created to serve as a baseline to evaluate future invasions. China Camp serves as an uninvaded reference site for marshes invaded by *Spartina* hybrids in San Francisco Bay. Rush Ranch is a site of active research on invasive fish and invertebrates. The Elkhorn Slough reserve protects approximately 1,400 acres, including Elkhorn Slough, one of the few coastal wetlands remaining in California. Elkhorn estuarine habitats have over 60 species of non-native invertebrates, over 20 species of non-native plants and a few non-native fish and algae. All of these are currently widespread, so eradication seems impossible. Efforts are focused on early detection and eradication of species identified as "least wanted" invaders such as Chinese mitten crabs and *Caulerpa*. The reserve launched an early detection program for aquatic non-native invaders in 2002. The Tijuana River reserve's 2,500 acres encompass beach, dune, mudflat, salt marsh, riparian, coastal sage and upland habitats surrounded by the growing cities of Tijuana, Imperial Beach and San Diego. Critical invasive species issues include: tamarisk, ice plant and other exotic plants displacing native species in the salt marsh and upland habitats; ongoing surveys to understand the dynamics of AIS; and efforts to understand ecosystem recovery following eradication of invasives.

National Marine Fisheries Service (NOAA – Fisheries Service)
http://www.nmfs.noaa.gov/

NOAA-Fisheries Service is in charge sustaining the nation's fisheries, many of which are being directly impacted by AIS, and is involved in many AIS projects in California. It has a key role on the Southern California Caulerpa Action Team. NOAA-Fisheries Service is also involved with a variety of other collaborative research projects including: ballast water exchange, AIS risk evaluation research and hull fouling research funded by the Port of Oakland; analysis of biofouling communities and community effects; and surveys and experimental treatments of several invasive species in San Francisco Bay. NOAA-Fisheries Service also participates on several AIS advisory and coordinating committees including: the Pacific Ballast Water Group, Non-Native Invasive Species Advisory Council and the West Coast Ballast Outreach Project Advisory Team.

National Marine Sanctuaries (NOAA – NMS)
http://sanctuaries.noaa.gov/
http://channelislands.noaa.gov/
http://cordellbank.noaa.gov/
http://farallones.noaa.gov/
http://montereybay.noaa.gov/

California has four sanctuaries – Channel Islands NMS, Cordell Banks NMS, Gulf of Farallones NMS and Monterey Bay NMS. The latter two sanctuaries are in the process of developing aquatic invasive species management plans and have conducted monitoring programs for AIS.

National Sea Grant (NOAA – Sea Grant)
http://www.seagrant.noaa.gov/
http://www-csgc.ucsd.edu
http://ballast-outreach-ucsgep.ucdavis.edu/

The National Sea Grant Program is a partnership between the nation's universities and NOAA (under the Office of Oceanic and Atmospheric Research) that began in 1966. The California Sea Grant program is the largest of these programs. Sea Grant began the West Coast Ballast Outreach Project in 1999 (co-sponsored by the CALFED Bay-Delta Program) to address concerns that ballast water discharges could be introducing foreign marine species into the state's coastal and estuarine ecosystems. The project educates the maritime industry about the ecological seriousness of aquatic exotic species by publishing the newsletter "Ballast Exchange," maintaining an educational Web site and coordinating workshops. In addition, California Sea Grant provides two major services to the state. First, the research arm of California Sea Grant, operating out of the Scripps Institute for Oceanography in La Jolla, funds critical coastal and marine research through an annual request for proposal and a National Strategic Initiative (NSI) program. Through both of these avenues, the college program funded approximately $2.6 million in research on invasive species between 1995 and 2003. Second, Sea Grant and the University of California Cooperative Extension jointly fund a network of eleven advisors and specialists who work on applied research and outreach projects throughout the state, including those related to AIS. Sea Grant funding has supported a wide variety of research projects on key invasive species, such as the Chinese mitten crab, European green crab, an exotic Australian isopod, several invasive seaweeds, and *Spartina* hybrids. Sea Grant sponsored research led to the eradication of the South African *sabellid* worm at the site near Cayucos, California, where it had become established.

National Park Service (NPS)
www.nps.gov

NPS strives to preserve the unimpaired natural and cultural resources of the national park system for the enjoyment, education and inspiration of this and future generations. The Park Service cooperates with partners to extend the benefits of natural and cultural resource conservation and outdoor recreation throughout this country. The NPS has several invasive species monitoring, control, research and eradication programs in California. Eradication and control are supported by two programs. The first is the (California) Exotic Plant Management Team (EPMT), which travels around the state to national parks that have requested assistance in removal and control projects. The EPMT has traditionally focused on terrestrial non-natives but could work on aquatic invaders. Through the second program, individual parks can request funds from Washington or the NPS Western Region for control and eradication projects. Natural resource inventories and monitoring activities occur in all of the National Parks in California, and these programs are well positioned to alert state managers to emerging and growing threats from invasive species. Information from these programs could be shared among the California AIS plan partners and benefit the state's early detection efforts. Finally, the NPS actively supports and hosts research projects on impacts of invasive species on ecological communities. National Parks in California, that participate with the EPMT, conduct invasive species inventories, monitoring and research on lands totaling about 2.4 million acres and include hundreds of miles of coastline. Significant education and outreach occurs at all of these sites.

U.S. Army Corps of Engineers (COE)
http://www.usace.army.mil/

The COE provides engineering, construction and environmental project services for the military and local governments. Congress authorizes the COE to assist local governments with water resource development needs, which include flood control, navigation, ecosystem restoration and watershed planning. For ecosystem restoration, this includes research on invasive species. Specific programs addressing invasive species issues include the Aquatic Nuisance Species Research Program, the Aquatic Plant Control Research Program and the Water Operations Technical Support Program. COE is also responsible for permitting aquaculture projects, including oyster farms, which often involves AIS considerations.

U.S. Coast Guard (USCG)
http://www.uscg.mil/hq/g-m/mso/bwm.htm

The USCG has established a mandatory program aimed at keeping aquatic nuisance species out of U.S. waters using ballast water management methods. USCG activities focus on enforcement and monitoring to ensure compliance with the program, which includes regular on-board inspections. USCG coordinates with California's State Lands Commission, manager of the state's ballast water program. In 2004, USCG issued "Ballast Water Management for the Control of Aquatic Nuisance Species in the Waters of the United States," a guidance document concerning ballast water management.

USCG activities related to AIS are diverse. The agency is working on the development of chemical and engineering methods to verify that a mid-ocean ballast water exchange has occurred. It is also evaluating technologies for the treatment of ballast water. USCG has determined that due to difficulties in establishing the effectiveness of ballast water exchange as it varies across ship types, voyages and from tank to tank, treatment technologies are best evaluated through a ballast water discharge standard (a benchmark for maximum numbers of organisms that may be discharged in ballast water). Such a standard will not only be helpful in evaluating the effectiveness of treatment technologies but also clearly establish when the ballast water no longer contains quantities of organisms that pose a significant risk. A Programmatic Environmental Impact Statement, detailing the evaluation of environmental impacts to the U.S. by several potential ballast water discharge standard alternatives, is currently in development.

USCG has also initiated several projects designed to provide information on the state of development of treatment technologies and the basic characteristics of treatment processes. These efforts have included scientific audits that tested and evaluated three approaches: filtration, ultraviolet light and hydro cyclonic separation. In addition, USCG developed and launched the Shipboard Technology Evaluation Program (STEP) in 2004 to encourage ship owners and operators to participate in evaluating technologies for shipboard application (see also CAISMP Action 7C3). This program allows for the review of experimental plans and treatment technology installations aboard ships. If they perform largely as designed and show promise for reducing the risk of introductions, treatment technology installations will be granted an equivalency with regulations for ballast water management and the Ballast Water Discharge Standard.

U.S. Department of Agriculture (USDA)
http://www.aphis.usda.gov/
http://www.ars.usda.gov/main/main.htm
http://www.invasivespeciesinfo.gov

USDA provides leadership on food, agriculture, natural resources and related issues. USDA conducts a number of programs and activities related to invasive species. USDA's Animal and Plant Health Inspection Service's (APHIS) deals with invaders like the South American wetland rodent, nutria, in the Mississippi Delta region and has also worked on other invasive animal, fish and crab problems around the country. APHIS has done extensive noxious weed work, including exclusion, permitting, eradication of incipient infestations, surveys, data management, public education, and (in cooperation with other agencies) integrated pest management of introduced weeds, including biological control. Aquatic weeds are included in the federal noxious weed list through the APHIS Cooperative Agricultural Pest Survey (CAPS).

The USDA's Agricultural Research Service (ARS) has three Exotic and Invasive Weed Research (EIWR) units in the west: at Davis and Albany, California, and at Reno, Nevada. Scientists at these facilities are responsible for research, the transfer of technology for improvement of management and control, and eradication of invasive aquatic and riparian weeds affecting agriculture and natural resources. These projects address three current ARS program priorities: 1) the reduction of dependence on pesticide use (specifically herbicides); 2) implementation of Executive Order 13112 (see above subsection on this order); and 3) water-quality improvement.

Research is conducted on the biology, reproduction, ecology, management or eradication of several important invasive aquatic weeds. The program provides technology transfer for the eradication and management of several problem species. The EIWR units are also involved in aquatic and riparian weed education for public, state and federal stakeholders.

U.S. Environmental Protection Agency (USEPA)
http://www.epa.gov/owow/invasive_species

USEPA leads the nation's environmental science, research, education and assessment efforts. It develops and enforces regulations, offers financial assistance, performs environmental research, sponsors voluntary partnerships and programs, furthers environmental education and publishes information. USEPA is responsible for enforcing the Clean Water Act (CWA). USEPA released its *EPA Authorities for Natural Resource Managers Developing Aquatic Invasive Species Rapid Response and Management Plans* in December 2005. This document provides an overview of USEPA authorities that apply to state or local AIS rapid response and control actions. The document summarizes relevant sections of the CWA and the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA); summarizes how to apply for CWA Section 404 permits to discharge dredged or fill material; summarizes how to apply for FIFRA Section 18 emergency exemptions and FIFRA Section 24(c) special local need registrations; and describes case studies in which state and local natural resource managers successfully obtained FIFRA emergency exemptions and special local need registrations for AIS eradication or control actions.

Within USEPA, there are three members of the National Estuary Program in California whose activities encompass AIS management.

National Estuary Program (USEPA – NEP)
http://www.epa.gov/nep
San Francisco Estuary Project: http://www.abag.org/bayarea/sfep/sfep.html
Morro Bay National Estuary Program: http://www.mbnep.org/index.php
Santa Monica Bay Restoration Commission: http://www.santamonicabay.org/

Congress established the National Estuary Program in 1987 to protect and improve the water quality and natural resources of estuaries nationwide. There are three programs in California. The San Francisco Estuary Project (SFEP) was formed in 1987 as a cooperative federal/state/local program to promote effective management of the San Francisco Bay-Delta Estuary, and created a consensus-based management plan for the Estuary including concrete actions related to invasive species. More recently, SFEP identified invasive species as the number-one priority issue in estuary restoration. SFEP holds an ex officio seat on the ANSTF and is a member of the Western Regional Panel.

The Morro Bay National Estuary Program was established in July 1995. The estuary contains the most significant wetland system along California's south-central coast. It supports many species of internationally-protected migratory birds, offers rare wetland habitat to a number of threatened native plant and animal species, and provides a protected harbor for marine fisheries. There are plans to suppress or eliminate at least two aquatic invasive species present in the estuary: giant cane and Sacramento pikeminnow. Efforts to eliminate a pioneer population of giant cane growing along Chorro Creek, a major estuary waterway, and its tributaries, are ongoing; eradication is expected by 2008. Efforts to suppress the pikeminnow to the point where native steelhead populations can begin recovery are expected to begin in 2007.

The Santa Monica Bay Restoration Project was established in 1988 to ensure the long-term health of the 266-square-mile Santa Monica Bay and its 400-square-mile watershed. In 2003, this project became an independent state organization, the Santa Monica Bay Restoration Commission. In terms of invasives, the commission has focused most recently on coastal bluff, wetland and riparian vegetation, funding extensive removal and replanting programs as well as outreach on "California friendly" gardens. The newest threat is the arrival of the New Zealand mudsnail in some Santa Monica mountains streams. The commission has convened experts to strategize how to slow the snail's spread.

U.S. Fish and Wildlife Service (USFWS)
http://www.fws.gov/
http://www.100thmeridian.org

USFWS has multiple programs that address AIS management. USFWS serves as co-chair of the Federal ANSTF and is the agency that provides federal funding for the implementation of Task Force approved state AIS management plans. USFWS also provides technical assistance to states regarding AIS management. USFWS administers the Lacey Act, which prohibits importation and interstate delivery of listed species. USFWS prevention programs include the 100th Meridian Initiative (see Appendix D), which focuses on preventing the western spread of zebra mussels. In cooperation with the ANSTF, the USFWS has developed planning documents for Chinese mitten crab, European green crab, New Zealand mudsnail and *Caulerpa.* USFWS refuges support invasive species control programs as part of their overall habitat restoration activities.

U.S. Geological Survey (USGS)
http://www.usgs.gov
http://nas.er.usgs.gov/

USGS acknowledged its role in non-native species management in a White Paper on Invasive Species, which identifies the goal of developing new strategies for the prevention, early detection and prompt eradication of new invaders. The USGS further identifies information management and documentation of invasions as a priority for the agency. In keeping with this objective, the USGS developed and maintains an extensive, spatially referenced database of non-native species, which is accessible online.

APPENDIX C: STATE AUTHORITIES, LEGISLATION & AGENCIES

In California, many state agencies have authority over and regulatory roles for managing natural resources. While diverse agencies have some authority to regulate AIS, there has been no centralized authority or management structure to coordinate AIS activities before this plan. The legal frameworks that apply to control of aquatic invasive species introductions are broad and varied. This section describes the existing authorities that various state agencies and entities have for managing AIS in California, and overlaps somewhat with information presented in Chapters 4 and 5. For help with acronyms, see the Acronym Glossary in the introductory pages of this plan.

CALIFORNIA AUTHORITIES

California Environmental Quality Act (CEQA)
(CA Public Resources Code §§ 21000 et seq.)
http://ceres.ca.gov/ceqa/

The California Environmental Quality Act (CEQA) requires public disclosure of all significant environmental effects of proposed discretionary projects. If a project would cause significant effects, final documents in the CEQA process show: 1) what mitigation measures will be required to reduce particular effects to a less significant level; and 2) provide justifications for the approval of the project with particular significant effects left unmitigated (i.e. a finding of overriding consideration). CEQA also contains lists of project types exempt from this process. A "significant" impact is a "substantial, or potentially substantial, adverse change in any of the physical conditions within the area affected by the project including land, air, water, minerals, flora, [and] fauna . . .". The documented adverse impacts associated with invasive species can fit this broad definition.

California Porter-Cologne Water Quality Control Act
(CA Water Code §§ 1300 et seq.)
http://www.swrcb.ca.gov/water_laws/docs/portercologne.pdf

Under California's Porter-Cologne Water Quality Control Act, "any person discharging waste, or proposing to discharge waste, within any region that could affect the quality of the waters of the state" must file a report of the discharge with the appropriate Regional Water Quality Control Board (RWQCB). Pursuant to the act, the RWQCB then prescribes "waste discharge requirements" related to control of the discharge. The act defines "waste" broadly, and the term has been applied to a diverse array of materials. The San Francisco Bay RWQCB, for example, has determined that "ballast water and hull fouling discharges cause pollution as defined under the Porter-Cologne Water Quality Control Act."

The act, (California Water Code, Division 7), lists a number of types of pollutants that are subject to regulation by the State Water Resources Control Board (SWRCB). Section 13050, for example, specifically includes the regulation of "biological" pollutants by defining them as relevant characteristics of water quality subject to regulation by the Board: AIS are an example of this kind of pollutant if they are discharged to receiving waters. The SWRCB also regards the application of pesticides to control AIS in waters of the state as a discharge of a pollutant requiring an NPDES permit. Several of the Regional Boards have taken legal policy and enforcement actions related to AIS (see also CWA in Appendix B and SWRCB in California Agencies).

Fish and Game Code and Title 14 of the California Code of Regulations
http://www.fgc.ca.gov/html/regs.html
http://www.dfg.ca.gov/ospr/organizational/scientific/exotic/exotic%20report.htm

The Fish and Game Code consists of the laws passed by the state legislature that pertain to fish and wildlife resources. Under statutes in the Fish and Game Code, the California Fish and Game Commission has the responsibility for the adoption of regulations that provide details on how certain Fish and Game laws are to be implemented. These regulations are published in Title 14 of the California Code of Regulations. A summary is provided below of Fish and Game Code Sections that address invasive species issues or may relate to control actions.

F& G Code §§ 2080 – 2089 DFG regulates the take of species listed under the California Endangered Species Act. In addition to the instructions in the Fish and Game Code, guidelines for this process are located in Title 14, Division 1, Subdivision 3, Chapter 6, Article 1 of the California Code of Regulations. These statutes and regulations should be consulted if AIS control measures have the potential to impact State-listed species.

F & G Code §§ 2118, 2270-2300: DFG is responsible for enforcement of importation, transportation and sheltering of restricted live wild animals; places importation restrictions on aquatic plants and animals; and prohibits nine species of *Caulerpa*.

F & G Code §§6400-6403: It is unlawful to place live fish, fresh or saltwater animals or aquatic plants in any waters of this state without a permit from DFG.

F & G Code §§15000 et seq.: DFG is responsible for regulations pertaining to the aquaculture industry, including disease issues.

Harbors & Navigation Code

The Harbors & Navigation Code, Article 2, Section 64, authorizes the Department of Boating and Waterways to manage aquatic weeds affecting the navigation and use of the state's waterways.

Ballast Management for Control of Nonindigenous Species Act (AB 703) of 1999

This act charged the California State Lands Commission (SLC) with oversight of the state's first program to prevent nonindigenous species (NIS) introductions through the discharge of ballast water from commercial vessels of over 300 gross registered tons (GRT). The 1999 act required that vessels originating from outside the United States Economic Exclusive Zone (U.S. EEZ) carry out mid-ocean exchange or use an approved ballast water treatment method, before discharging in California state waters. The SLC was tasked with: receiving and processing ballast management reports from all such vessels, monitoring ballast management and discharge activities of vessels through submitted reports, inspecting vessels for compliance and assessing vessel reporting rates and compliance. The activities and analyses of the first few years of the program are detailed in the 2003 biennial report of the California Ballast Water Management Program. Upon the sunset of the act, the Marine Invasive Species Act (AB 433) was passed in 2003, revising and widening the scope of the program to more effectively address the invasion threat (see below).

Marine Invasive Species Act (AB 433) of 2003
(Public Resources Code, Sections 71200-71271;
Title 2, California Code of Regulations, Section 2271)

The Marine Invasive Species Act, passed in 2003, revises and recasts the state's law pertaining to control of nonindigenous species and ballast water management (AB 703). It imposes additional requirements upon vessel masters, owners, operators and persons in charge of vessels to prevent the introduction of nonindigenous species into waters of the state or waters that may impact the waters of the state. The bill deletes exemptions for specified vessels from compliance with the act and revises the qualifications for the vessels subject to the act.

Ballast water management is required of all vessels greater than 300 gross registered tons (GRT) that intend to discharge ballast water in California waters, though the regulations differ depending on voyage origin. All qualifying vessels coming from ports within the Pacific Coast region must conduct near-coast exchange (in waters at least 50 nautical miles offshore and 200 meters deep) or retain all ballast water and associated sediments. There are exceptions that address safety concerns and for vessels that transit wholly within defined shared waters (San Francisco/-Stockton/Sacramento Delta, and Los Angeles/Long Beach/El Segundo Complex).

All vessels must complete and submit a ballast water report form upon departure from each port of call in California. They must also comply with the good housekeeping practices, ranging from avoiding discharge near marine sanctuaries to rinsing anchors and removing fouling organisms from the hull. They must maintain a ballast water management plan prepared specifically for the vessel; keep a ballast water log outlining ballast water management activities for each ballast water tank on board the vessel, and make the separate ballast water log available for inspection; conduct training of vessel master, person in charge, and crew regarding the application of ballast water and sediment management and treatment procedures; and pay a fee for each qualifying voyage at their first port of call in California.

In addition to requirements imposed upon vessels operating in state waters, the SLC was charged with the development of several legislative reports offering policymaking guidance on commercial vessel AIS issues including: a Report on Commercial Vessel Fouling in California, Analysis, Evaluation and Recommendations to Reduce Nonindigenous Species Release from the Non-Ballast Water Vector; a Report on Performance Standards for Ballast Water Discharges in California Waters; and a Report on the California Marine Invasive Species Program. These efforts have resulted in the development of regulations to stem transport of AIS in the ballast water of vessels operating with the Pacific Coast Region; and legislation directing SLC to adopt regulations on performance standards for ballast water discharges.

Finally, the legislation also requires DFG to conduct a series of biological surveys to monitor new introductions to coastal and estuarine waters of the state and to assess the effectiveness of the management provision of the Act. AB 703, passed in 1999, required a baseline survey of the state's ports, harbors and bays. AB 433 expanded the baseline to include outer coast sites and required continued monitoring of all sites to determine if the ballast control measures have been successful in reducing the number of new introductions.

Coastal Ecosystems Protection Act of 2006
(Public Resources Code, Sections 71204.7 – 72423)
(Revenue and Taxation Code, Section 44008)

The Coastal Ecosystems Protection Act, passed in 2006, adds to the state's law pertaining to the discharge of ballast water (AB 433). It requires the SLC to adopt regulations that require an owner or operators of a vessel carrying, or capable of carrying, ballast water that operates in the waters of the state to implement certain interim and final performance standards for the discharge of ballast water.

California Ocean Protection Council Strategic Plan
http://resources.ca.gov/copc/strategic_plan.html
http://resources.ca.gov/copc

The California Ocean Protection Council, formed to coordinate the activities of ocean-related state agencies and improve state efforts to protect ocean resources, among other mandates (see California State Agencies), adopted a five-year strategic plan in 2006. The strategic plan supports the completion and implementation of both the state rapid response plan and this California Aquatic Invasive Species Management Plan, as well as the California Noxious and Invasive Weed Action Plan.

Delta Protection Act
www.delta.ca.gov

California's 1992 Delta Protection Act recognizes the natural resource significance of the 738,000 acre-Sacramento-San Joaquin Delta. The act seeks to preserve and protect Delta resources for the use and enjoyment of current and future generations and recognizes the threat posed by urban encroachment to the Delta's agriculture, wildlife habitat and recreation uses. Pursuant to the Act, a Land Use and Resource Management Plan for the Primary Zone (Management Plan) was completed and adopted by the Commission in 1995. The Management Plan sets out findings, policies and recommendations resulting from background studies in the areas of environment, utilities and infrastructure, land use, agriculture, water, recreation and access, levees and marine patrol boater education/safety programs. As mandated by the act, the policies of the Management Plan are incorporated in the General Plans of local entities having jurisdiction within the Primary Zone. Some of the plan sections relevant to AIS management include: Environment, Finding 8 and Recommendations 3 & 4; Water, Policy 2; and Marine Patrol, Boater Education & Safety, Policy 6 (see also Delta Protection Commission, Appendix D).

California State Agencies

San Francisco Bay Conservation and Development Commission (BCDC)
http://www.bcdc.ca.gov/

The Bay Conservation and Development Commission is dedicated to the protection and enhancement of San Francisco Bay and to the encouragement of the Bay's responsible use. Any person or government agency wishing to place fill, extract materials or make any substantial change in use of any water, land or structure within the area of the Commission's jurisdiction requires a Commission permit or federal consistency determination. The Commission's jurisdiction includes San Francisco Bay, including tidal flats, subtidal areas and marshlands lying between mean high tide and five feet above mean sea level and a 100 foot shoreline band measured inland from the Bay shoreline, as defined by Section 66610 of the McAteer-Petris Act. The Commission recognizes the threat of non-native invasive species to the Bay's ecosystem and the *San Francisco Bay Plan* contains policies regarding the monitoring, control and eradication of aquatic invasive species in the Bay.

California Department of Boating and Waterways (DBW)
http://www.dbw.ca.gov/

DBW works to help develop convenient public access to California waterways, promote on-the-water safety and keep waterways free of navigational problems. General activities include boating law enforcement, boater education, improvements to boating facilities and vessel sewage management. In addition, DBW manages the state's largest and oldest aquatic weed control program, working with other public agencies to control water hyacinth, and more recently Brazilian elodea, in the Sacramento-San Joaquin Delta, its tributaries and the Suisun Marsh. DBW also leads the California Clean Boating Network, a collaboration of government, business, boating and academic organizations working to increase and improve clean boating education efforts, including invasive species education, across the state.

California Coastal Commission (CCC)
http://www.coastal.ca.gov/

The CCC is mandated to protect and enhance public access, recreation, wetlands, visual resources, agriculture, commercial activity, industrial activity and environmentally sensitive habitats within the coastal zone through coastal development permits, local coastal programs and federal consistency review. The CCC has responsibility to protect both the biology of aquatic ecosystems and the special uses associated with the marine environment, such as commercial fishing and recreation. The CCC regulates development activities in state waters under its coastal development permit authority and is responsible for working with local governments within the coastal zone. The CCC is also the designated coastal management agency administering the federal Coastal Zone Management Act (CZMA) over Pacific waters offshore of California (outside of San Francisco Bay). As such, the Coastal Commission exercises federal consistency review authority over all federal activities and federally licensed, permitted or funded activities affecting the coastal zone, regardless of whether the activity occurs within, landward, or seaward of the coastal zone boundary. Federal agency activities, including permits and plans, are subject to the consistency determination process, and must be "consistent to the maximum extent practicable" with the state's coastal management program, in this case, the Chapter 3 policies of the California Coastal Act (15 CFR § 930.32).

California Department of Fish and Game (DFG)
http://www.dfg.ca.gov/
http://www.dfg.ca.gov/ospr/

DFG has jurisdiction over the conservation, protection and management of fish, wildlife, plants and habitat necessary for biologically sustainable populations of those species. DFG conducts a number of programs related to aquatic invasive species, including serving as the lead agency in developing this statewide AIS management plan, as well as a rapid response plan for invasions (see Appendix A). DFG is responsible for enforcement of regulations concerning the aquaculture industry; the importation and transport of live wild animals, aquatic plants and fish into the state; and the placement of any such animals in state waters. The agency is also responsible for conducting biological surveys to assess the amount and types of AIS present in state waters, and the degree of success of ballast water management activities. Starting in 1999 with ballast management legislation, these surveys have been undertaken by DFG's Office of Spill Prevention and Response (DFG/OSPR). DFG/OSPR also manages the California Aquatic Non-Native Organism Database (CANOD) and is working to establish consistency among the various major databases being used to analyze similar types of AIS-related information. Lastly, DFG has been an active manager or partner in numerous AIS eradication and control programs, especially for those AIS that threaten at-risk species or the conservation and restoration of aquatic or riparian ecosystems.

California Department of Food and Agriculture (DFA)
http://www.cdfa.ca.gov/

DFA is the lead agency for regulatory activities associated with aquatic weeds. This regulatory authority includes quarantine, exterior pest exclusion (border protection stations and inspections), interior pest exclusion (pet/aquaria stores, aquatic plant dealers and nurseries) and detection and control/eradication programs. In addition, the DFA Plant Pest Diagnostic Center identifies plant species and assigns plant pest ratings. DFA maintains a rated list of noxious weed species. "A"-rated pests require eradication, containment, rejection or other holding actions at the state-county level. Quarantine interceptions are to be rejected or treated at any point in the state. For "B"-rated pests, eradication, containment, control or other holding actions are taken at the discretion of the agricultural commissioner. State-endorsed holding actions and eradication of "C"-rated pests occur only when these pests are found in a nursery. Action is taken to retard spread outside of nurseries at the discretion of the commissioner. Rejection occurs only when found in a crop seed for planting or at the discretion of the commissioner. "Q" ratings are temporary "A" ratings pending determination of a permanent rating. DFA is also responsible for the *Hydrilla* eradication program (see Chapter 2).

County Agricultural Commissioners (CACs)
http://www.cdfa.ca.gov/exec/cl/cacasa.htm

CACs have long been at the forefront in the battle against invasive species throughout the state. They work collaboratively with DFA and other agencies to exclude, detect and eradicate or manage a wide range of pest species. CACs perform numerous inspections of incoming plant materials, checking for compliance with quarantine requirements and for noxious weeds and other pests. Nurseries and pet stores are also inspected. The CACs have worked with DFA to obtain additional resources to fund more effective programs. Once plant materials enter the state, it is generally the CACs who perform inspections and carry out most of the weed eradication and management activities. While the CACs are not a "state" agency, they form a statewide system, represented at the state level by California Agricultural Commissioners and Sealers Association (CACASA) and have specific authorities granted by state law to carry out pest prevention programs.

California Department of Parks and Recreation (PARKS)
http://www.parks.ca.gov/

PARKS manages more than 270 park units and approximately 1.4 million acres, of which more than 280 miles is coastline and 625 miles of lake and river frontage. Management objectives of individual properties within the system depend on a unit's classification and range from a preservation mandate to a recreation emphasis. Units of the state park system can be established in either the terrestrial or underwater environment. Management to restore natural processes is basic to many types of state park units. This management includes removal of exotic species and is expected to extend below the waterline in units that are primarily terrestrial.

California Department of Pesticide Regulation (DPR)
http://www.cdpr.ca.gov/

DPR is vested with primary responsibility to enforce federal and state pesticide laws and regulations pertaining to the proper and safe use of pesticides in California. The Department regulates pesticides under a comprehensive program that includes enforcement of pesticide use in agricultural and urban environments, prevention of environmental contamination, environmental monitoring for emergency eradication projects and other related functions. DPR conducts monitoring of emergency eradication projects to ascertain that the public and the environment are being protected and the correct amounts of pesticides are being applied. DPR conducts sampling in consultation with the County Agricultural Commissioners, Department of Fish and Game, the RWQCBs and other stakeholders. DPR works cooperatively with other government agencies sharing information and monitoring results.

California Department of Water Resources (DWR)
http://www.water.ca.gov/

DWR addresses invasive species issues that impact water supply, water delivery and flood control. In general, DWR administers programs involving flood control for the Central Valley, dam safety for more than 1,200 dams statewide, design and construction of water facilities, water quality improvement and water supply data collection and studies. DWR also operates and maintains the State Water Project (SWP).

Recent activities related to invasive species are diverse. DWR conducts monthly monitoring of benthic (bottom-dwelling) invertebrates, zooplankton and phytoplankton throughout the upper San Francisco Estuary and reports trends in invertebrate abundance and community composition, including newly introduced species, to the State Water Resources Control Board. DWR is documenting the distribution of the invasive algal species *Microcystis spp*. in the upper San Francisco Estuary, investigating which strains (toxic versus non-toxic) are present and examining effects on the aquatic food web. DWR is also investigating the impacts of the Chinese mitten crab on the benthic invertebrate community in the Sacramento-San Joaquin Delta and co-authored a white paper on its life history.

On the prevention front, DWR implemented the California Zebra Mussel Watch Program until June 2005 (which included risk assessment, early detection, public outreach, the development of a rapid response plan for the Central Valley watershed and a centralized reporting system for mussel sightings). The future of this program depends on funding. At Lake Davis, DWR has been coordinating with DFG on northern pike control and downstream protection (including the installation of a structure to prevent pike escape over the dam). DWR contributes to programs aimed at controlling invasive weeds along eroding Sacramento River banks, within flood control and water conveyance structures and along urban streams. The agency coordinates its activities with other state and federal agencies as a member of the CALFED Non-native Invasive Species Advisory Council (NISAC).

California Ocean Protection Council (OPC)
http://www.coastalconservancy.ca.gov/

The OPC, created in 2004, is a state cabinet level council consisting of the Secretaries for Resources and the California Environmental Protection Agency, the chair of the State Lands Commission and two members of the Legislature. The OPC is a policy making body and also prioritizes the expenditure of various funds appropriated to other State departments for ocean protection purposes. The OPC has authorized funding for the completion of this AIS plan and is considering inclusion of implementation of this plan in its strategic plan as a major objective over the next five years. OPC's policies are administered by the Coastal Conservancy with direction from an Executive Policy Officer housed at the Resources Agency.

California State Lands Commission (SLC)
http://www.slc.ca.gov

SLC manages the mandatory, statewide, multi-agency Marine Invasive Species Program. This program works to implement regulations governing ballast water management for vessels operating on the West Coast of North America. Commission inspectors board approximately 25% of all vessels that arrive in California to verify compliance with regulations and to disseminate outreach materials to vessels and crews new to California. In addition to its regulatory activities, the Commission facilitates scientific research and technology development to enhance management efforts of the program and to inform policymakers. Limited funding is provided for research that targets priority information gaps and to technologies that show exceptional promise for the treatment of ballast water. In recent years, the SLC has also prepared a number of reports for the state legislature documenting commercial vessel fouling in California, proposing performance standards for ballast water discharges, and summarizing vessel ballast water activities and compliance in California (see also Ballast Water Management, California Authorities, and Chapter 5). In addition to the mandated Marine Invasive Species Program, the SLC has been coordinating interagency efforts to manage invasive aquatic plants such as Eurasian watermilfoil in Lake Tahoe (see Case Study, Chapter 8).

State Coastal Conservancy (SCC)
http://www.coastalconservancy.ca.gov/

SCC has been involved for over twenty years in the control and eradication of aquatic invasives, pursuant to Division 21 of the Public Resources Code. SCC developed, funded and operates the Invasive *Spartina* Project in San Francisco Bay that shows great promise in eradicating nonindigenous species of *Spartina* and their associated hybrids. SCC is also involved in efforts to control *Arundo* in many coastal watersheds. SCC directly develops projects and provides grant funds related to resources enhancement and restoration, including control and elimination of invasives. SCC is also a partner in developing this management plan.

The San Francisco Estuary Invasive *Spartina* Project (ISP)
http://www.spartina.org/

SCC established the ISP in 2000. Its overall goal is to develop and implement a regionally coordinated project to eradicate the four introduced and highly invasive *Spartina* species in the San Francisco Estuary. The ISP is comprised of a number of components, including outreach, research, permitting, mapping, monitoring and allocation of funds for efforts to eliminate populations of nonindigenous *Spartina*. In 2005 the Conservancy and ISP began full-scale implementation of the regionally coordinated *Spartina* Control Program (SCP), employing an aggressive treatment strategy to target nearly all infested sites in the San Francisco Estuary. Initial results show on average about 85% efficacy at treated sites. SCC will continue to coordinate the regional control effort through the ISP, and to allocate funds to land owners and managers around the San Francisco Bay for aggressive treatment activities consistent with the SCP. If funding continues, it's expected that invasive *Spartina* will be effectively eradicated from the San Francisco Estuary between 2009 and 2011 (see also Case Study, Chapter 8).

State Water Resources Control Board (SWRCB)
http://www.swrcb.ca.gov/

The SWRCB's mission is to preserve, enhance and restore the quality of California's water resources, and ensure their proper allocation and efficient use for the benefit of present and future generations. The Board has joint authority over water allocation and water quality protection. Under the State Board are nine Regional Water Quality Control Boards (RWQCBs). The SWRCB and regional boards have been working in support of, and in an advisory capacity to, other state agencies on various AIS activities, such as hull fouling and ballast water management. Invasives come under water board purview as part of the state's efforts to implement and enforce the Clean Water Act (CWA, see also Appendix B). A 2005 federal court ruling defined non-indigenous species as "pollutants" present in discharges from vessels and found that such discharges are not exempt from permitting requirements (NPDES, see also CWA, Appendix B).

In terms of AIS management activities, some of the regional boards have also sought to place specific water bodies within their regions on the CWA's 303(d) list, as impaired by exotics. S.F. Bay was listed in 1998. In 2006, the State Board placed the Delta, the Cosumnes River and a portion of the San Joaquin River on the 303 (d) list. Once on the 303(d) list, the regional boards are required to develop discharger/source based programs for managing pollutants, including the determination of "total maximum daily loads" (TMDLs)), which in the case of exotics have proved somewhat difficult to develop. Trying to allocate loads or goals for zero loads, among dischargers, water users and municipalities is challenging when most of the water bodies in question are already heavily invaded. Despite the implementation challenges, the S.F. Bay Water board's work on the state's first exotics TMDL did, however, widely publicize the problem and led to other successful AIS management and legislative programs.

Other regional boards have become involved in AIS-related water quality issues through watershed management projects, non-point source pollution management programs and wetland mitigation and restoration programs (raising issues about the use of non-native aquatic plant species for these programs, and the control of invasives, for example). The State Board has also participated in AIS management activities concerning the use of aquatic pesticides.

University of California (UC)
www.universityofcalifornia.edu
www.ipm.ucdavis.edu/

UC conducts extensive research on invasive species issues and has a substantial pool of scientists devoted to biological invasions and management. UC faculty serve on NGO, and state and federal government panels and committees charged with invasive species management. They also provide expertise and management for a variety of cooperative government units such as UC's Division of Agricultural and Natural Resources' (ANR) Integrated Pest Management Program and the Center for Invasive Species Research (UC Riverside). This center has managed the Exotic Species Research Program for USDA for almost five years. UC ANR also has Marine Advisors in most coastal counties in the state as part of the Sea Grant extension program. This provides a direct academic presence for extension outreach and applied research collaboration with agencies and campus faculty (see also National Sea Grant, Appendix B). UC also has formal graduate training programs on invasive species, such as the Integrative Graduate Education and Research Traineeship, based at UC Davis, in which the students intern with DFG, USFWS and other government agencies.

APPENDIX D: OTHER AIS INTERESTS

COORDINATING COMMITTEES, EDUCATIONAL INITIATIVES & SPECIAL INTEREST GROUPS

AIS spread across so many jurisdictions and impact so many different types of human activities and environmental priorities that diverse efforts have been made to promote coordination among AIS-involved agencies, organizations and stakeholders. Some of these, such as CALFED or the Western Regional Panel serve important functions in implementing federal and state mandates for coordination. Others provide ongoing forums for information sharing and priority setting among different agencies, organizations and interest groups, or among those attempting to restore or preserve specific waterways.

COORDINATING COMMITTEES & PARTNERSHIPS

Aquatic Nuisance Species Task Force
www.anstaskforce.gov

Federal legislation established the national Aquatic Nuisance Species Task Force (ANSTF), co-chaired by the USFWS and NOAA. ANSTF is charged with coordinating governmental efforts related to ANS prevention and control. ANSTF consists of 10 federal agency representatives and 12 ex officio members representing nonfederal governmental agencies.

Adopt-A-Riverway Program

This program is a government-volunteer partnership established in 2003. Participation in the program includes management of noxious and invasive weeds. Authorized program activities include planting and establishing native seedling trees, shrubs, native grasses, wildflowers, and removing litter and weeds, consistent with an integrated weed management plan. AB 66, a state bill, established an Adopt-A-Riverway Fund for proceeds donated, appropriated, transferred or otherwise received for purposes pertaining to the Adopt-A-Riverway Program.

Association of Fish and Wildlife Agencies (AFWA)
http://www.fishwildlife.org/

AFWA represents the government agencies responsible for North America's fish and wildlife resources. It promotes sound management and conservation and speaks with a unified voice on important fish and wildlife issues. AFWA was awarded a recent grant to create communications strategies on issues related to unwanted invasive aquatic species. This project will help states develop comprehensive programs to address aquatic nuisance species issues within their states and will collectively help the Regional Associations and the AFWA nationally develop a stronger voice and greater capabilities when addressing regional and national aquatic nuisance species efforts.

CALFED Bay-Delta Program (CALFED)
http://calwater.ca.gov/

CALFED is a cooperative effort of more than 20 state and federal agencies working with local communities to improve the water quality and reliability of California's water supplies and restore the San Francisco Bay-Delta ecosystem. One goal of CALFED's Ecosystem Restoration Program (ERP) has been to "prevent establishment of and reduce impacts from non-native species."   The goal includes 10 specific objectives, such as eliminating further introductions of new species in ballast water of ships and preventing the invasion of the zebra mussel into California. CALFED has also developed a strategic plan for managing non-native invasive species in the San Francisco Bay-Delta Estuary and the Sacramento and San Joaquin Rivers and associated watersheds. To date, CALFED has funded 31 projects that address preventing the establishment of, or reducing the impacts from, non-native invasive species in California.

CALFED also created a Non-native Invasive Species Advisory Council (NISAC), a council of agency and technical stakeholders to advise the program on non-native invasive species.

California Horticultural Invasives Prevention (Cal-HIP)
www.suscon.org/invasives

This partnership develops strategies to reduce introductions of invasive plants through horticulture. Partners include environmental NGOs, agency representatives, and nursery and landscaping trade organizations. Sustainable Conservation, a nonprofit organization, facilitates the partnership.

California Interagency Noxious & Invasive Plant Committee (**CINIPC**)
http://www.cdfa.ca.gov/phpps/ipc/CINWCC/cinwcc_hp.htm

This committee, formerly known as California Interagency Noxious Weed Coordinating Committee (CINWCC), was formed in 1995, with a memorandum of understanding among 14 federal and state agencies. The committee changed its name again in 2006. Its mission is to facilitate, promote and coordinate the establishment of an integrated pest management partnership between public and private land managers toward the eradication and control of noxious weeds on federal and state lands and on private lands adjacent to public lands.

California Invasive Plant Council (**Cal-IPC**).
www.cal-ipc.org

This Council is a nonprofit organization that works to protect California wild lands from invasive plants through research, restoration and education. Cal-IPC proposes and facilitates solutions to problems caused by invasive plants. Membership includes public and private land managers, ecological consultants, researchers, planners, volunteer stewards and concerned citizens. Cal-IPC is recognized as an authoritative source of new information on all aspects of wild land weed management.

California Invasive Weed Awareness Coalition (**CALIWAC**)
www.cal-ipc.org/policy/state/caliwac.php

This coalition, made up of primarily industry stakeholders, was formed in 2001 to increase awareness of the invasive weed issue in California. The coalition's goals are to support the development of a statewide management plan for invasive weeds; provide a public forum to increase awareness of the detrimental environmental and economic effects of invasive weeds and contribute to solutions for invasive weed issues; promote increased funding for management of invasive weeds; and influence state and national policy on invasive weeds

California Weed Science Society (**CWSS**)
http://www.cwss.org/

This Society was founded in 1948 to promote environmentally sound proactive research and develop educational programs in weed science; support undergraduate/graduate students seeking a career in weed science; and encourage and support educational activities to promote integrated weed management systems.

County Weed Management Areas (**WMA**)

A Weed Management Area (WMA) is a local organization that brings together landowners and managers (private, city, county, state, and federal) in a county, multi-county or other geographical area for the purpose of coordinating and combining action and expertise in combating common invasive weed species. The WMA Support Program in DFA provides coordination and training opportunities and allocates state funding earmarked for WMAs.

Delta Protection Commission (DPC)
www.delta.ca.gov

California's 1992 Delta Protection Act created a Delta Protection Commission in recognition of the natural resource significance of the 738,000 acre-Sacramento-San Joaquin Delta. The Act seeks to preserve and protect Delta resources for the use and enjoyment of current and future generations and recognizes the threat posed by urban encroachment to the Delta's agriculture, wildlife habitat and recreation uses (see also Appendix C, State Authorities). The 19-member Delta Protection Commission provides for stakeholder representation in the areas of agriculture, habitat, and recreation. A land use and resource management plan for the primary zone of the Delta, completed in 1995 and updated in 2002, acknowledges the impacts of exotic species on Delta resources and makes recommendations for preventing impacts on native fish, and on aquatic, channel island and seasonal wetland habitats (including mosquito abatement projects).

Pacific Ballast Water Group (PBWG)
http://www.psmfc.org/ballast/

This group was formed by representatives from the shipping industry, state and federal agencies, environmental organizations, and others who recognized the need for a cooperative and coordinated regional approach to ballast water management to prevent the introduction of invasive species on the West Coast. The PBWG meets regularly and is currently addressing the development of ballast water discharge standards and inter-jurisdictional issues related to ballast water management on the West Coast.

Pacific States Marine Fisheries Commission (PSMFC)
http://www.psmfc.org/

PSMFC is one of three interstate commissions dedicated to resolving fishery issues. Representation includes the states of California, Oregon, Washington, Idaho and Alaska. The PSMFC does not have regulatory or management authority; rather, it serves as a forum for discussion, works towards coast wide consensus on state and federal authorities and addresses issues that fall outside state or regional management jurisdiction. Over the past four years, the Pacific States Marine Fisheries Commission's AIS program has concentrated on four species of aquatic invaders: Chinese mitten crab, European green crab, zebra/quagga mussel and Atlantic salmon. Program activities include research and monitoring, educational outreach, interjurisdictional planning and coordination, and funding and contracting services for numerous partners.

Western Governors' Association
http://www.westgov.org/

The Western Governors' Association is developing a new program to address undesirable nonindigenous aquatic and terrestrial species in the west. In 1998, the Western Governors passed a resolution on Undesirable Aquatic and Terrestrial Species to develop and coordinate western strategies and to support management actions to control and prevent the spread and introduction of undesirable species; support the use of integrated pest management concepts; encourage broad-based partnerships; and urge adequate support for the U.S. Department of Agriculture's Animal and Plant Health Inspection Service. The Association has formed a working group of state and federal agencies, industry, non-governmental organizations and academia to develop western strategies to limit the spread of these species.

Western Regional Panel (WRP)
http://www.fws.gov/answest/

This panel on Aquatic Nuisance Species was formed as a committee of the ANSTF after the passage of NISA to help limit the introduction, spread and impacts of aquatic nuisance species into western North America. This panel includes representatives from federal, state, and local agencies, Native American tribes, and private environmental and commercial interests, as well as a representative from Canada.

The general goals of the WRP are to prevent nuisance species introductions, coordinate activities of the western states among federal, local and tribal agencies and organizations, and minimize impacts of already established nuisance species. The purposes of the WRP, as described in NISA, are to: identify western region priorities for responding to aquatic nuisance species; make recommendations to the ANSTF regarding an education, monitoring (including inspection), prevention, and control program to prevent the spread of the zebra mussel west of the 100^{th} meridian; coordinate other aquatic nuisance species activities in the west not conducted pursuant to the act; develop an emergency response strategy for federal, state, and local entities for stemming new invasions of aquatic nuisance species in the region; provide technical assistance to public and private stakeholders for preventing and controlling aquatic nuisance species infestations; and submit an annual report to the ANSTF describing activities related to ANS prevention, research and control.

MAJOR NATIONAL EDUCATION CAMPAIGNS

100th Meridian Initiative, USFWS
http://www.100thmeridian.org

The primary goal of the 100th Meridian Initiative is to prevent the further spread of zebra mussels. At the time it was formed, the western limit of the zebra/quagga mussel roughly coincided with the 100th meridian. It is the first large-scale, cross-jurisdictional effort to combat the spread of an aquatic invasive species. Participating entities include federal, state, local and tribal governments, potentially affected industries such as commercial boat haulers and other stakeholders. The initiative has produced an extensive public information and education campaign aimed at marina users, anglers and recreational boaters. It sponsors the production of posters, informational flyers and signs educating boaters about the risks of zebra mussels and other AIS. Its members conduct voluntary boat inspections and boater surveys to identify boats at highest risk for harboring AIS. Collected boater travel patterns are being used to model potential pathways for the mussel's spread. The initiative has supported the establishment of mussel monitoring stations across the west, as well as the development of regional rapid response plans should the mussel establish new populations. Recent programs include the Lewis and Clark Initiative, a program aimed at increasing outreach efforts to recreational boaters retracing the path of the historic expedition during its bicentennial. Among other accomplishments, the effort resulted in the establishment of more AIS monitoring stations and a mussel monitoring database for the Columbia River Basin region.

Habitattitude
www.habitattitude.net

Habitattitude is an ANSTF collaboration of the Pet Industry Joint Advisory Council (PIJAC), the U.S. Fish & Wildlife Service, the NOAA National Sea Grant College Program, and the nursery and landscape industry. It was established in 2004 to educate aquarium hobbyists, backyard pond owners, water garden enthusiasts, and others on how to prevent the spread of potential aquatic nuisance species. Its web site includes information on how non-native fish and plants can harm ecosystems, suggests environmentally sound alternatives to releasing unwanted aquatic plants and animals in the wild and offers tips on how to prevent accidental releases. The site offers promotional materials, signage and decals for participating retailers and manufacturers. The initiative offers a means for industry and the USFWS to work together to promote their shared interests in preventing AIS impacts.

Stop Aquatic Hitchhikers
www.protectyourwaters.com

The Stop Aquatic Hitchhikers web site is part of the ANSTF public awareness campaign. It is sponsored by the USFWS and the USCG. It functions as a reputable, central source of information about aquatic nuisance species affecting the United States. Resources include photos and descriptions of common nuisance species, how they impact ecosystems, boaters and anglers, and tips for preventing their spread. A news page features stories from major news outlets as well as government news releases related to AIS. Video and audio clips geared toward traveler information centers are available for download as are outreach materials such as posters, flyers, stickers for tackle boxes, banners and signs. Clubs, state and government agencies, and private entities are encouraged to join the campaign and pledge to prevent the spread of AIS. In California, partners include the DFG, California Trout, the City of Davis, Heal the Bay (Santa Monica), and the Santa Ana Zoo, among others.

SPECIES- & PLACE-SPECIFIC COALITIONS, INITIATIVES & NONPROFITS

100th Meridian Initiative, USFWS
(see Major National Education Campaigns)

California Sea Grant
(see Appendix B, NOAA – Sea Grant)

Channel Islands National Marine Sanctuary
(see Appendix B, NOAA – NMS)

Cordell Banks National Marine Sanctuary
(see Appendix B, NOAA – NMS)

Elkhorn Slough National Estuarine Research Reserve
(see Appendix B, NOAA – NERR)

Gulf of the Farallones National Marine Sanctuary
(see Appendix B, NOAA – NMS)

Invasive Spartina Project
(see Appendix C, State Coastal Conservancy)

Lower Colorado River Giant Salvinia Task Force
http://lcrsalvinia.org/salviniahome.asp

On August 4, 1999, the USFWS found giant salvinia in the Imperial National Wildlife Refuge on the Colorado River. Plants were also seen floating down the Colorado River, on the Cibola National Wildlife Refuge, and in Pretty Water and Three Finger lakes. Subsequent investigation determined that the source of the infestation was the West Side/Outfall Drain of the Palo Verde Irrigation District near Blythe, California. To ensure a coordinated response to the infestation, a task force was formed. Teams focused on accomplishing steps to control and/or eradicate giant salvinia in the lower Colorado River. Teams address issues relating to research, monitoring, rapid response, field implementation, regulation and compliance, outreach, and financial and international issues.

Monterey Bay National Marine Sanctuary
(see Appendix B, NOAA – NMS)

Morro Bay National Estuary Program (USEPA National Estuary Program)
(see Appendix B, USEPA – NEP)

San Francisco Bay National Estuarine Research Reserve
(see Appendix B, NOAA – NERR)

San Francisco Estuary Institute
www.sfei.org/bioinvasions

SFEI was founded as a non-profit organization in 1986 to foster the scientific understanding needed to protect and enhance the San Francisco Estuary. It is governed by a board composed of Bay Area scientists, environmentalists, regulators, local governments and industries. SFEI's Biological Invasions program conducts scientific and policy research and provides information and analyses on the introduction of exotic organisms into marine and freshwater ecosystems. In the last decade, the program has been actively working to improve understanding and management of invasive species, to document the status of invasive species in San Francisco Bay and the increasing rate of invasions. The program is also involved in helping develop regulatory standards for ballast water discharges. Most recently, SFEI is chairing the scientific advisory panel that is providing guidance from the research community to the government agencies responding to the recent discovery of quagga mussel in California and performing some of the research identified by the quagga mussel incident command.

San Francisco Estuary Project (USEPA National Estuary Program)
(see Appendix B, USEPA – NEP)

Santa Monica Bay Restoration Commission (USEPA National Estuary Program)
(see Appendix B, USEPA – NEP)

Southern California Caulerpa Action Team (SCCAT)
http://www.sccat.net/

SCCAT was established to respond quickly and effectively to the discovery of *Caulerpa* in Southern California. The group consists of representatives from local, state, and federal governmental entities and from private organizations. SCCAT's goal is to completely eradicate all infestations in Agua Hedionda Lagoon and Huntington Harbour and to prevent new infestations (see also Chapter 8, Case Study)

Tahoe Basin Weed Coordinating Group
(775) 784-4848

This group is coordinated through the University of Nevada Cooperative Extension to address the increasing aquatic weed problem in the two-state Lake Tahoe Basin. This group and local agencies have undertaken mechanical removal of Eurasian watermilfoil and efforts are now being expanded, incorporating a variety of removal methods (see also Case Study, Chapter 8).

Team Arundo
http://www.sawpa.org/arundo/

Team Arundo was formed in Orange County, California, in 1991 to control *Arundo* along the Santa Ana River, and has since become a statewide program. Chapters exist in the Bay Area, San Luis Obispo and surrounding counties, Greater Los Angeles County, and San Diego County.

Team Arundo Del Norte
http://ceres.ca.gov/tadn/

Team Arundo Del Norte is a forum of local, state and federal organizations dedicated to the control of *Arundo* in rivers, creeks and wetlands in Central and Northern California. The organization formed in the summer of 1996 and meets several times per year in the Sacramento area to explore opportunities for information exchange and partnerships in support of the ongoing work of eradicating Ar*undo*.

Tijuana River National Estuarine Research Reserve
(see Appendix B, NOAA – NERRS)

APPENDIX E: AIS PLAN DEVELOPMENT & PROCESS

An initial draft of this plan was developed for DFG several years ago with stakeholder input (see below). At that time the plan was not completed due to funding and staffing issues. In 2006, additional funding was awarded to SFEP from the OPC, through the SCC, to finish and begin implementation of the plan.

2006 Draft & Final Plan Process

The 2006 draft of the plan incorporated much of the text, research and public comments provided by the original 2004 draft (see below).

In early 2006, agency staff reviewed the 2004 version and suggested updates. The resulting draft was circulated two times for review and comment by AIS program managers within lead state and federal agencies. Two internal meetings – one in June, and one in July – were held to discuss the draft and documented in meeting notes. Revisions were made accordingly.

The resulting draft plan was posted for public review on August 22nd, 2006. Three public meetings were held in August and September 2006 in Oakland, Sacramento and Long Beach to review the draft plan. Public comments were reviewed and incorporated to the extent possible.

Attendees at one or more of 2006 internal interagency meetings included:

Susan Ellis, DFG
Abe Doherty, SCC
Julie Horenstein, DFG
Dan Wilson, DFG
Paul Ryan, DBW
Geoff Newman, DBW
Terri Ely, DBW
Marian Ashe, DFG/OSPR
Jeffrey Herod, USFWS
Marcia Carlock, DBW
Suzanne Gilmore, SLC
Tanya Veldhuizen, DWR
Lynn Takata, SLC
Ben Becker, NPS
Karen McDowell, SFEP
Maurya Falkner, SLC
Pat Akers, DFA

2006 Public Meetings Summary

Background

A Draft AIS Plan was publicly released in late August 2006 and three public meetings were held in August and September to solicit input. The following pages summarize the presentation used at all three meetings and present comments and questions raised by meeting attendees. In addition, the results from a "prioritization" exercise conducted at each meeting are presented.

Meeting Overview

The meetings were called to order by Austin McInerny, facilitator, from the Center for Collaborative Policy, California State University, Sacramento. After McInerny provided an overview of the meeting agenda, participants and staff involved in preparing the Draft AIS Plan, introduced themselves. Project staff participating in the meetings included:

- Susan Ellis, Invasive Species Coordinator, DFG
- Julie Horenstein, DFG
- Karen McDowell, Project Coordinator, SFEP
- Abe Doherty, Project Manager, SCC
- Paula Trigueros, SFEP (note taker)
- Debbi Egter Van Wissekerke, SFEP (logistics manager)

Karen McDowell provided a brief background and overview of the plan's development process and explained the need to complete the plan to qualify for federal funding. She further clarified that the plan is to provide a management framework for agency coordination and that the anticipated adoption timeline is very aggressive. She reviewed the required components of the plan and explained the proposed management framework and the Technical Advisory Panels. She highlighted the objectives, strategies and action items for implementation and noted the priority section would be completed following the public review process. She explained the appendices including the Rapid Response Plan. Next steps included posting updates on the website and including the public comments as an Appendix also to be posted on the web. The complete presentation is available online at:
http://sfep.abag.ca.gov/projects/invasive_species.html

Following the presentation, a short question and answer period was held to address questions on how the plan was developed. Then, meeting attendees provided feedback, comments, and questions regarding the Draft AIS Plan. Lastly, meeting attendees were asked to review the proposed Action Items proposed in the plan and identify what they believed were both "high" and "low" priority action items.

Comment forms were provided and copies of the Draft AIS Plan were available for review.

Public Meeting #1 (Sacramento) Summary

The meeting was held August 28 in the auditorium of the California Department of Food & Agriculture and had nearly 30 attendees. The following comments and questions were raised:

- Woody Schon, Sacramento/Yolo Mosquito & Vector Control District: Expressed concern with Action 2E4 regarding use of mosquito fish for mosquito control. His district uses fish to control mosquitoes in degraded habitats such as rice or agricultural fields that are not flowing into streams, rivers or vernal pools and does not want to see these fish excluded as a tool for mosquito control.

- Raynor Tsuneyoshi, Director, DBW: Would like to see Collaborative Center for AIS at a university. Concern with hull cleaning for small boats – it is 9 times more expensive to haul a boat out of the water for hull cleaning than to clean in the water. There is in-water technology for anti-fouling for large boats but not for small. Regarding cleaning stations, who would fund, and how would they be distributed around the state? Recommended the development of remedies for specific behaviors – fishing boats, trans-Pacific yacht racing. Recommends going slow to curtail copper based hull paint as it slows down hull fouling.

- Dave Breninger- General Manager Placer Co Water Agency; Director ACWA; Director RBOC: Concern with water quality issues (agricultural water and the delta). Need to link water agency and boating concerns (Objective 2I). His water district is plagued with non-natives. Need to eradicate in waterways. Likes use of native plants. Need to make recreational boaters part of the solution. *Egeria* should be eradicated. Need a positive way to put money into solution.

- Duane L. Schnabel, Primary State Biologist, DFA: Although the plan cites NEPA/CEQA in Appendix B there is no discussion of when an EIR will be done for the plan. People need to know if the actions will do more harm than good.

- Ted Grosholz, Dept. of Environmental Science & Policy, UC Davis: He is a cooperative extension researcher who developed the initial plan. The plan as written has an absence of university and research institution participation. The plan ignores non-agency participants in AIS work. Action 1A6 calling for a data base of AIS projects ignores already existing National Biological Species nodes at UC Davis and UC Santa Barbara. Actions 6A3-11 ignores cooperative extension and sea grant work in progress for years. Actions 7A1-2 to complete AIS studies ignores work under development at the universities. The plan needs to bring the University of California into the management plan. The Ocean Protection Council endorsed a university inter-agency center for AIS and the center is not included as part of this plan. The center needs to be part of the plan and needs to be stated explicitly.

- Rick Grosberg, Center for Population Biology, UC Davis: The threat of AIS was identified by the research community and not state agencies. The document completely ignores the contributions of the research community. UC Davis formed an AIS council that is not included or even mentioned. The management framework includes only agency leaders who will meet (When? For What?). The Document needs to integrate geographically and biologically. It does not provide a management framework for integration at all levels. There is a missing objective for coordination of research problems, ecological problems, biological problems; the structure for coordination is not listed as an objective. Document does a good job identifying problems but fails in coordination and development of policy.

- Rebecca Verity - UCOP: UCOP supports the University of California and CSU's disappointment at being left out of the plan. The state constitution designated the University of California as the research arm of the State of California. The university was told there would be an AIS Center for coordination of research, surveys and development of new tools. All faculty were told the bones of the center would be in the management plan. They are very disappointed it is not.

- Jodi Cassell, Sea Grant: Has been involved in outreach and applied research on AIS. Jodi herself has been involved for 8 years. They are also a funding source having funded $1,800,000 in AIS projects and outreach. They are very disappointed the plan ignores all non-state agency work related to AIS. Sea Grant is not mentioned at all in the plan although they have done extensive outreach on ballast water management, newsletters, research on hull fouling, transport vectors, establishing a network of advisors, etc. She feels the agency role should be to coordinate ongoing programs. DFG is not in outreach; outreach is not a strong component of their mandate. She felt the plan needed to use existing resources and not push them out of the management plan.

- Elaine Sledge, National Paint and Coatings Association: The association concurs with the plan findings on the threat of AIS. They support prevention vs. control and eradication. Coatings must have copper for anti-fouling. Inter-coastal vessels transport AIS. There are also non-ballast vectors. Non-biocide coatings are preferred. Written comments will provide additional information.

- Ron Eng, DFA: Action 2I1 proposes adding staff and hours at DFA Border Protection Stations with no indication of how this would be funded.

- Clint Meyer, Project Manager, Michael Brandman Associates: There is already a good regulatory program through CEQA. CEQA should be updated to address terrestrial and aquatic invasive species.

Public Meeting #2 (Oakland) Summary
The meeting was held August 30 in the Association of Bay Area Governments / Metropolitan Transportation Commission's conference room and had nearly 25 attendees. The following comments and questions were raised:

- Karl Malamud-Roam, Mosquito Ecologist, Contra Costa Mosquito VCD: He stated the regulatory aspects on control of public health were good. AIS present a huge problem. Insects and the diseases that come with them require continual surveillance and rapid response which the districts have in place. There is confusion in tone in the introduction; the plan treats non-native species and invasives as synonymous. The definition of invasives is not clear; the federal definition emphasizes harm (as stated in first paragraph) but the second paragraph treats all non-natives as invasive. It should not assume that non-native is detrimental; there are benefits of non-natives. The mosquito fish comments need correcting. There is a presumption that mosquito fish are known to harm; be careful of context of usage. They are a tool for resource management.

- Steve Hajik, Lake Co. Dept. of Agriculture: Spraying requires a permit from the regulatory water agency. County only allows licensed sprayers and inspects all applicators. His county passed an ordinance that lists banned weeds. He commented the plan should not forget agricultural commission offices.

- Caitlin Sweeney, SF Bay Conservation & Development Commission (BCDC): There is a critical omission of BCDC in the management plan. They have enforceable policies on fill, dredging, tidal marsh restoration projects and require eradication permits in their jurisdiction.

- Doug Johnson, California Invasive Plant Council: Plan needs to emphasize the impacts of chemical treatment as well as the impacts of all treatments. High level coordination under Strategy 1A should include agricultural and environmental groups; should be strengthened to advocate for AIS council not partitioned as aquatic, but all inclusive.

- Cathy McGowan, Office of Research, UCOP: Lawrence Coleman, Vice Provost will submit detailed comments in writing. Cathy read from a 4-page document (attached) with preliminary comments. Solutions must be cross-cutting; researchers, policy makers and managers must work together. There must be formation of a California Center for Invasive Species; UC supports this strongly and wants it added to the plan. The plan needs to include members of UC and Sea Grant on the CAAIST (1A2). The section on Education and Outreach needs to include the UC Riverside Aquatic Center and Sea Grant Extension outreach. The education of ongoing researchers needs to be added. Section 7 provides an excellent start but needs to be expanded to include an academic research center.

- Mike Connor, Executive Director, San Francisco Estuary Institute (SFEI): SFEI has been working on biological invasions for over a decade. The rate of invasions is increasing; at present they are working on a multi-agency rapid response effort to eradicate invasive oysters in the South Bay. The report needs three things; 1) transparency; 2) peer review; and 3) competitive funding. First, transparency, the public cannot figure out who is working on what and therefore cannot determine overall success. Second, there is no call for outside peer review, which is necessary to insure that implementation is up to date. This is crucial for incorporation into the report. Third, there should be provision for competitive funding of line items in the document. Funding should go through a competitive process to insure transparency and the best quality work.

- Cathy Roybal, Contra Costa Dept. of Agriculture: Local county agricultural offices need to be involved.

- Karl Malamud-Roam, Mosquito Ecologist, Contra Costa Mosquito VCD: Department of Health Services needs to be added to agencies; the Health & Safety Code needs to be added to statutes. Use of vector should be carefully defined; conventional use includes mosquito control. The Society of Wetland Scientists was the first concerned with invasive cord grass. Strong kudos for rapid response.

- Arthur Berlowitz, U.S. Department of Agriculture (USDA): Goal is to prevent invasive species if we can. USDA reviews plants for the aquarium trade. He does not see how USDA can interface with the plan; it is not clear how USDA fits in. Thinks a center is a great idea. Document should show who has jurisdiction over what part of invasive species control.

- Sarah Mannell, Mill Valley, CA: She wants to know who does the public contact about invasive species. There are large carp in Corte Madera Creek; a protected creek; with steelhead fry in their guts.

Public Meeting #3 (Long Beach) Summary

The meeting was held at the Port of Long Beach Board Room on September 1 and had eight attendees. While no comments were presented, meeting attendees did raise the following questions:

1. How does the plan articulate agricultural invasive plants?
   Answer: DFA is on the coordinating committee. The committee also worked with DPR.

2. For the Technical Advisory Committee, will there be one for the state, or will there be regional panels to focus on the issues for that region?
   Answer: Having regional coordinating panels is a good suggestion and will be considered during finalization and/or implementation of the plan.

3. How much public outreach was there for these public meetings? He did not see a full press announcement.
   Answer: There was targeted outreach to the OPC mailing list, stakeholder groups, web sites and DFG did a press release.

4. Is this a modification of an existing plan or a new plan?
   Answer: It is restructured and rewritten from an earlier draft.

5. How is the SFEP associated with the project?
   Answer: SFEP was contracted for one year by the SCC with funding from the Ocean Protection Council to finish the state AIS Plan.

6. Has there been outreach to shipping companies?
   Answer: SLC, which is in charge of the ballast water program, has been keeping shipping up to speed. The ballast water recommendations were taken from the proposed actions. The plan basically looks at vectors other than shipping.

Prioritization Exercise Results

At all three meetings, posters were provided on the walls for attendees to indicate which action items (as described in the Draft AIS Plan) they believed should be "high" and "low" priority. After the close of the public comment period, meeting attendees held informal conversations with project staff and added to the posters. The posters were brought to each subsequent meeting to allow attendees to see which action items other individuals had prioritized.

One action was identified as extremely important: 8A3. Pursue the authority for DFG and DFA to establish a Rapid Response Program.

The following information was collected. Some of the action numbers changed as comments were addressed and the draft plan was finalized. The action numbers below were updated to reflect the new numbers; some of the original actions were deleted or moved in the editing process. Some of the action language has been edited since this summary was made. A few actions are listed as both high and low priorities because of differing opinions among participants. For final priorities identified see Chapter 8.

Objective 1: Coordination & Collaboration

High Priority Actions

- 1A1. Develop an executive level consultation process.
- 1A2. Form the California Agencies AIS Team (CAAIST).
- 1A7. Identify lead state agencies for particular AIS, water bodies and invasion vectors.
- 1A8. Identify agency personnel required for AIS management.
- 1A9. Improve state websites related to AIS.
- 1A10. Assess effectiveness of and gaps in AIS programs.
- 1B4. Expand participation in local AIS efforts and task forces.
- 1B5. Expand participation in regional, national and international AIS task forces.
- 1B7. Participate in national and international conferences.
- 1C2. Establish stable, long-term funding to help implement this plan.
- 1C3. Provide state funding for the AIS positions.
- 1C4. Provide state funding for a rapid response program.
- 1C5. Hire a funding development specialist.
- 1C6. Provide new funding mechanisms.

Low Priority Actions

All remaining actions for this objective not shown as high priority above.

Objective 2: Prevention

High Priority Actions

- 2B1. Quantify the ballast water and hull fouling vectors and assess invasion risk.
- 2B2. Continue and improve state ballast water inspection and enforcement program.
- 2B3. Implement discharge standards for treated ballast water.
- 2B4. Identify and address gaps in the Marine Invasive Species Program.
- 2B7. Quantify and assess the role of commercial fishing vessels as AIS vector.
- 2C1. Quantify and assess the role of recreational boating as an AIS vector.
- 2C2. Develop a recreational boating outreach and management program.
- 2C3. Develop a watercraft inspection program for high priority boat launch sites.
- 2C4. Quantify and assess the role of recreational fishing as an AIS vector.
- 2C5. Develop a recreational fishing outreach and management program.
- 2C6. Develop guidelines for: disposal of invasive species, cleaning of gear disposal of live bait.
- 2D1. Quantify and assess live bait as an AIS vector.
- 2E1. Quantify and assess fisheries enhancement as an AIS vector.
- 2I1. Increase staffing and hours of operation at DFA Border Protection Stations.
- 2I2. Develop guidelines for border inspections.
- 2I3. Increase DFG enforcement of current regulations on prohibited and restricted species.
- 2I4. Ensure adequate staffing and cargo inspection guidelines at ports and airports.
- 2I5. Continue disease sampling for shipments and stocks of live aquatic species.
- 2I6. Identify mail order, online vendors selling CA prohibited and restricted species.

Low Priority Actions

- 2B3. Implement discharge standards for treated ballast water.
- 2B4. Identify and address gaps in the Marine Invasive Species Program.
- 2C All actions mandating hull cleaning and/or inspections.
- 2C10 Link activities to the national Stop Aquatic Hitchhikers campaign. (Action later deleted).
- 2E4. Weigh benefits of mosquito-fish introductions.

Objective 3: Early Detection & Monitoring

High Priority Actions

- 3A1. Assess current monitoring of the state waters for early detection opportunities.
- 3A3. Develop statewide approach to early detection.
- 3A4. Outreach to those regularly sampling state waters.
- 3A5. Create and train a statewide citizen monitoring network.
- 3B1. Assess long-term AIS monitoring of state waters.
- 3B3. Monitor locations with high invasion rates.
- 3B7. Review the efficacy of long-term monitoring systems.

Low Priority Actions

- 3B6. Include maps of existing AIS in California waters in DFG BIOS system.

Objective 4: Rapid Response & Eradication

High Priority Actions

- 4A1. Develop and implement a statewide rapid response plan.
- 4A2. Evaluate and coordinate existing systems for reporting AIS sightings.
- 4A3. Clarify among the agencies and organizations involved who is responsible for which areas and/or species. (This action from August ’06 draft has been deleted. It will be addressed through current actions 4A1 and 4A3).
- 4A4. Explore permanent funding to implement rapid response.
- 4B1. Review effectiveness of eradication programs.

4B2. Continue and complete current eradication efforts.
4B3. Standardize criteria for identifying priority species for eradication.
4B4. Develop a method to prioritize sites of AIS invasion concern.

Low Priority Actions

All remaining actions for this objective not shown as high priority above.

Objective 5: Long-Term Control & Management

High Priority Actions

5B All strategy action items; limit the dispersal of established AIS to new water bodies.
5C2. Coordinate entities to meet AIS protection and restoration objectives.
5C6. Assess guidelines for preventing AIS spread in habitat restoration and shoreline landscaping projects. (See 6C5)

Low Priority Actions

5B1. Establish boat washing stations and disposal facilities at infested water bodies.
5B3. Use volunteer monitors to conduct AIS inspections.

Objective 6: Education & Outreach

High Priority Actions

6A1. Inventory education and outreach efforts. Develop a state AIS communication strategy.
6A2. Partner with ongoing outreach campaigns.
6A4. Develop posters, brochures and articles for industry sectors and user groups.
6A5. Develop permanent interpretive displays at marinas, boat ramps, and fishing sites.
6A6. Work directly with industry trade shows to deliver the AIS message.
6A7. Present AIS information at public gatherings.
6A8. Include AIS information in state hunting, fishing and boating regulations and licenses.
6A9. Include AIS information in fishing and recreational publications.
6A10. Develop and distribute AIS identification cards
6A11. Encourage industries to offer noninvasive alternatives to AIS.
6A12. Partner with stakeholders and interest groups to broaden education efforts.
6A13. Educate waterfront and shoreline property owners about AIS.
6A14. Develop and offer AIS management classes for professional organizations.
6A15. Continue state education measures concerning ballast water.
6C2. Educate researchers on AIS containment, disposal methods and legal restrictions.
6C5. Disseminate guidelines to promote the use of native plants. (See 5C6)

Objective 7: Research

High Priority Actions

Note: suggestion was made to add “increase coordination of researchers and develop research agenda based on high priority research needs.”

7A1. Host workshops to develop AIS research priorities and identify gaps.
7A2. Assess, continue and complete current studies.
7A3. Develop a strategy to communicate and support research needs.
7C4. Identify opportunities for interagency funding of AIS management research.

Low Priority Actions

7C3. Consider test center to evaluate ballast water treatment technologies.

Objective 8: Policy

High Priority Actions

- 8A1. Establish a regulatory review committee.
- 8A2. Identify the potential for improved regulatory coordination.
- 8A3. Pursue the authority to establish an interagency rapid response program.
- 8A4. Explore the need for additional state authority for AIS management.
- 8A6. Review current system for regulating plant and animal importations. .

Low Priority Actions

None indicated

2006 California Invasive Species Management Plan Public Meeting Participants

Name	Affiliation	Email	*Mtg.
Alejandrino, Emily	Central Valley Water Board	ealejandrino@waterboards.ca.gov	Sac
Anderson, Tim P.	Friends of Seal Beach NNR	Tim@birdingbyboat.org	LB
Berge, John	PMSA	jberge@pmsaship.com	Sac
Berlowitz, Arthur	USDA/APHIS/PPQ	Arthur.berlowitz@aphis.usda.gov	Oak
Bohan, Drew	OPC	drew.bohan@resources.ca.gov	Sac
Breninger, Dave	Placer Co. Water Agency Recreational Boaters of CA	dbreninger@pcwa.net	Sac
Brockbank, Marcia	SFEP	mbrockbank@waterboards.ca.gov	Oak
Brusati, Elizabeth	Cal-IPC	edbrusati@cal-ipc.org	Oak
Carlock, Marcia	DBW	mcarlock@dbw.ca.gov	Sac
Cassell, Jodi	California Sea Grant	jlcassell@ucdavis.edu	Sac
Clamurro, Lori	Delta Protection Commission	loridpc@citlink.net	Sac
Coleman, Lawrence	University of California	Lawrence.coleman@ucop.edu	Oak
Connor, Mike	SFEI	mikec@sfei.org	Oak
Doherty, Abe	Coastal Conservancy	adoherty@scc.ca.gov	Sac Oak
Drill, Sabrina	UCCE	sldrill@ucdavis.edu	LB
El, Terri	DBW	tely@dbw.ca.gov	Sac
Ellis, Susan	DFG	sellis@dfg.ca.gov	Sac Oak LB
Eng, Ron	CDFA	reng@cdfa.ca.gov	Sac
Falkner, Maurya	CA State Lands Commission	falknem@slc.ca.gov	Sac
Fernandez, Linda	UC Berkeley – Dept. of Ag. & Resource Econ.	Linda.fernandez@ucb.edu	Oak
Fredrickson, Justin	Cal. Farm Bureau Federation	jfredrickson@cfbf.com	Sac
Fujioka, Kenn	Mosquito & Vector Control Assn. of Ca/San Gabriel Valley MVCD	kfujoika@sgvmosquito.org	LB
Gouvaia, John	Alameda Co. Dept. of Agric.	John.gouvaia@algov.org	Oak
Grosberg, Rick	UC Davis	rkgrosberg@ucdavis.edu	Sac
Grosholz, Ted	UC Davis	tedgrosholz@ucdavis.edu	Sac
Gurish, Jon	Coastal Conservancy	jgurish@scc.ca.gov	Oak
Hakjik, Steve	Lake Co. Ag. Dept.	Steveh@co.lake.ca.us	Oak
Hanson, Joel	SMBRC/F	jhanson@waterboards.ca.gov	LB
Horenstein, Julie	DFG	jhorenstein@dfg.ca.gov	Sac Oak LB
Jirik, Andrew	Port of Los Angeles	ajirik@portla.org	LB
Johnson, Doug	Cal-IPC	dwjohnson@cal-ipc.org	Oak
Karkanen, Kristie	Hanson Env./SWC	kkarkanen@hansonenv.com	Oak
Kolipinski, Dr. Mietek	National Park Service	Mietek-kolipinski@nps.gov	Oak
Liu, Marie	Senate Nat. Resources	Marie.liu@sen.ca.gov	Sac
Liu, Qinqin	DFG	qliu@dfg.ca.gov	Sac
Long, Dennis	MBSF	info@mbnmsf.org	Oak
Lynch, Michelle	SWRCB Clean Water Team	smlynch@waterboards.ca.gov	LB
Malamud-Roam, Karl	CCMVCD, AMCA	kmr@ccmvcd.net	Oak
Mannell, S.		sgarmanii@sbc.global.net	Oak

*Mtg. = meeting locations
Sac – Sacramento, August 28, 2006
Oak – Oakland, August 30, 2006
LB – Long Beach – September 1, 2006

2006 California Invasive Species Management Plan Public Meeting Participants

Name	Affiliation	Email	*Mtg.
McDowell, Karen	SFEP	kmcdowell@waterboards.ca.gov	Sac Oak LB
McLain, Susan	Stockton Sailing Club	manager@stocktonsc.org	Sac
Meyer, Clint	Michael Brandman Associates	cmeyer@brandman.com	Sac
Milton, Joe	Dept. of Fish & Game	jmilton@dfg.ca.gov	Sac
Magowan, Cathie	UC Office of the President	Cathie.magowan@ucop.edu	Oak
Noda, Gwen	UCLA	gwennoda@ucle.edu	LB
Noto, Dante	UC Office of the President	Dante.noto@ucop.edu	Oak
Rosales, Ava	CH2M Hill	Ava.rosales@ch2m.com	Oak
Roybal, Cathy	Contra Costa Dept. of Ag	croybal@ag.cccounty.us	Oak
Schnabel, Duane L.	CDFA	dschnabel@cdfa.ca.gov	Sac
Schon, Woody	Sac/Yolo Mosquito & Vector Control	wschon@fightthebite.net	Sac
Simpson, F.		fsimpson@rmc.ca.gov	LB
Sledge, Elaine	On behalf of Nat'l Paint & Coatings Assoc.		Sac
Smith, Larry	USACE		LB
Snyder, Barry	AMEC	Barry.snyder@amec.com	LB
Stephens, David	CA State Lands Commission		Oak
Stransky, Chris	Nautilus	chris@nautilusenvironmental.com	LB
Swanson, Lisa	Matson Navigation	lswanson@matson.com	Oak
Swauger, Troy	DFG	tswauger@dfg.ca.gov	Sac Oak
Sweeney, Caitlin	BCDC	caitlins@bcdc.ca.gov	Oak
Tamanaha, Miwa	SMBRC	mtamanaha@waterboards.ca.gov	LB
Tandoc, Tom	DOI OEPC	Tom.tandoc@gmail.com	Oak
Topel, Jack	SMBRC	jtopel@waterboards.ca.gov	LB
Torbett, Tim	USDA, APHIS	Timothy.J.Torbett@aphis.usda.gov	Oak
Tsuneyoshi, Roy	DBW	rtsuneyoshi@dbwq.ca.gov	Sac
Varghis, Jacob	USCG	Jacob.varghis@uscg.mil	LB
Veloz, MK	Northern California Marine Association	Ncma-gr@comcast.net	Oak
Verity, Rebecca	UC Office of the President	Rebecca.verity@ucop.edu	Sac
Vignolo, John	SJC Mosquito and Vector Control District		Sac
Young, Sara	USCG	Sara.e.young@uscg.mil	Oak

*Mtg. = meeting locations
Sac – Sacramento, August 28, 2006
Oak – Oakland, August 30, 2006
LB – Long Beach – September 1, 2006

2004 Draft Plan Process

The first draft of the AIS management plan included the valuable input of many dedicated individuals with expertise on a wide variety of topics relating to AIS in California and the region. Contributors ranged from local, state and federal agencies, to industry representatives, NGOs and other stakeholders.

Funding for the development of the first draft was provided by the DFG and USFWS. Susan Ellis, the Statewide Invasive Species Coordinator, developed a contract with the University of California, Davis, to develop an Aquatic Invasive Species Plan following the general outline provided by the Aquatic Nuisance Species Task Force. Ted Grosholz was the Principal Investigator for the contract. The deliverables for the contract included facilitated meetings to ensure that agency and stakeholder input was incorporated in the Plan.

In August of 2002, representatives of 14 agencies with a role in managing aquatic invasive species came together to participate in a State AIS Planning Workshop in Davis, CA. Results of that meeting included a draft set of goals and objectives for an AIS Plan and a brief summary of current AIS activities for some of the participating agencies. There was agreement that a state plan could help identify AIS of concern, and provide a framework for how to address AIS prevention, eradication, research, management and education and outreach in a more coordinated and comprehensive fashion.

Additional information for the plan was gathered from other state and federal plans, various websites, published papers, internal agency documents and through personal communication (phone and email).

The Plan's Review Committee (members listed below) commented on a first draft of the plan, which was then distributed to a broader group of Agency reviewers and for public review.

Review Committee for the 2004 Draft Plan

Lars Anderson, United States Department of Agriculture, Agricultural Research Service
Robert Leavitt, California Department of Food and Agriculture
Dale Steele, California Department of Fish and Game
Mark Sytsma, Portland State University
Erin Williams, United States Fish and Wildlife Service

Participation by Other Agencies and Groups

Courtney Albrecht, California Department of Food and Agriculture
Marcia Carlock, California Department of Boating and Waterways
Marina Carzola, California Coastal Commission
Jason Churchill, Lahontan Regional Water Quality Control Board
Nate Dechoretz, California Department of Food and Agriculture
Joseph DiTomaso, University of California, Davis
Maurya Falkner, California State Lands Commission
Connie Ford, State Water Resources Control Board
Joann Furse, California Sea Grant
Eric Gillies, California State Lands Commission
Bob Hoffman, National Marine Fisheries Service
Christina Johnson, California Sea Grant
Jaime Kooser, California Coastal Commission
Steve Lonhart, Monterey Bay National Marine Sanctuary
Karen McDowell, California Sea Grant
Cindy Messer, California Department of Water Resources
Julie Owen, California Department of Boating and Waterways
Bill Paznokas, California Department of Fish and Game
Stephen Phillips, Pacific States Marine Fisheries Commission
Carolyn Pizzo, U.S. Department of Agriculture

Jim Rains, California Department of Food and Agriculture
Steve Schoenig, California Department of Food and Agriculture
Jody Sears, California Department of Water Resources
Linda Sheehan, Pacific Regional Office, The Ocean Conservancy
Basia Trout, Bureau of Reclamation
Tanya Veldhuizen, California Department of Water Resources
Kim Webb, United States Fish and Wildlife Service
Katherine Zaremba, Invasive Spartina Project

2002-2003 Stakeholder Meeting Comments

Incorporating recommendations from a broad array of stakeholders contributes to a better and more responsive AIS plan for the State of California. In an effort to get input on concerns and perspectives regarding AIS during the plan's development, scoping meetings were held to get input from many organizations, businesses, industry representatives and individuals. A northern California stakeholder meeting was held in Sacramento on November 19, 2002. A southern California stakeholder meeting was held on March 20, 2003. Participants provided valuable comments, most of which have been incorporated into the management plan.

Northern California Stakeholder Comments

Invitations were sent to over 200 individuals and included representatives of many industries including the pet, aquarium, and nursery/landscaping trades, live bait and seafood dealers, and ports and marinas. The following individuals attended:

Drew Alden, Growers in Tomales Bay
John Berg, Pacific Merchant Shipping Association
Thomas Confal, IPM Specialist, Bitterroot Restoration, Inc.
John Cruger-Hansen, Harbor Master, City of Antioch
Daniel Garcia, Public Affairs, Marine Aquarists Roundtable of Sacramento
Jeff Hart, President, Habitat Assessment and Restoration Team, Inc.
James Kidder, President, Colombo Bait, Inc.
Karen McDowell, Project Coordinator, West Coast Ballast Outreach Project
James Mills, Vice President and Regional Manager, Westree Marinas
Fleur O'Neill, Policy Education Coordinator, Save Our Shores
John O'Sullivan, Curator of Field Operations, Monterey Bay Aquarium
Roger Phillips, Applied Research Manager, Monterey Bay Aquarium
Kirsten Upson, The Nature Conservancy
M.K. Veloz, Administrative Director, Northern California Marine Association

Mike Fraidenburg of Dynamic Solutions Group of Olympia, Washington facilitated the meeting. Susan Ellis (State Invasive Species Coordinator) explained the different roles and responsibilities of state agencies and current management activities for aquatic invasive species in California. Ted Grosholz (UCD) and Holly Crosson (UCD) discussed the process for the plan's development including future stakeholder and agency meetings as well as the current status of the plan. Mark Sytsma (Portland State University, Portland, Oregon) discussed Oregon's experience with writing a state management plan for aquatic invasive species as well as the uses and limits of state plans. The rest of the meeting was spent listening to concerns and suggestions presented by the stakeholders. Most of the comments could be divided into the categories of Education, Prevention, Best Management Practices, Regulation, State Invasive Species Council and General AIS Management Plan development suggestions.

EDUCATION

- Education about AIS should be a top priority.
- Educational tools should be used instead of legislation and regulations.
- A list of AIS experts should be made available to stakeholders.

- AIS information should be available at all bait shops, marinas, boat access areas, etc.
- It may take 20 years, but *all* of the public needs to be educated about AIS (example used was educational programs for dealing with issues such as recycling, littering, etc.).
- The public needs to know why they should care about AIS (i.e., the consequences of invasions).
- The public as well as industry needs to know the economic cost of AIS (cost/benefit analysis).
- Stakeholders are a resource and can help with education, such as public service announcements.
- Multiply educational efforts by identifying what industry sectors can do to help with AIS education and outreach (i.e., using Wal-Mart, Home Depot, PetSmart etc. to educate their customers about AIS).
- A database is needed that focuses on providing information about AIS outreach, education and research-based grants. Information on who is doing what on AIS should also be available and include efforts by NGO's, universities and industry.
- AIS hazards that exist in particular areas need to be identified and publicized before they spread.
- Cross-education between interest groups and government would help understanding of the issues and concerns for both groups.
- Education in the K-12 classroom is important; biologists should go into schools to talk about AIS.
- Aqua-culturists need current information to help avoid AIS introduction problems of the past.
- There should be guidelines developed to help groups "self-police" and educate their constituents.
- Coordination needs to be improved between state, regional and federal groups.
- Identify all educational and technical resources currently available and make them easily accessible.
- Identify where the information gaps are.

PREVENTION (including Early Detection and Rapid Response)

- A Rapid Response program requires extensive coordination but is critical.
- An AIS "hotline" is needed so new sightings can be reported immediately.
- Management of introduction pathways is important for AIS prevention.
- We should have the ethic of not transporting California's AIS elsewhere; include this in the plan.
- The largest percentage of funds should be spent on prevention since it is the most cost-effective.
- Early detection is key to successful AIS eradication and management.
- Each vector/pathway that is identified in the plan should have a lead agency listed as well as a stakeholder group.
- Look into whether funds from anti-terrorism sources could be tapped into (i.e. to address the intentional introduction of a devastating foreign, water-borne organism).

BEST MANAGEMENT PRACTICES (BMPs)

- Each industry should be actively involved in the development of the BMPs that relate to them.
- BMPs can be a tool for industry to understand and meet their obligations.
- Consider using a neutral third party or group (scientific panel) to offer advice and develop recommendations for BMPs instead of leaving development to agencies or industry alone.
- Investigate how "management" of a landscape (or lack thereof) affects the likelihood of invasion.

REGULATION

- The public and industry need to have an understanding of AIS laws and their history before they go into effect.
- We need more education and outreach on laws already passed so the public can abide by them.
- AIS laws and penalties need to be publicized in the DFG regulations right up front.
- Regulatory agencies need to "get on the same page"; inconsistencies confuse the public.
- There should be more opportunity for stakeholder input when new regulations are being written, especially when livelihoods are at stake (*Caulerpa* in southern California was example used).
- A patchwork of regulations makes coordination between state, regional and federal levels difficult.

- Inter-jurisdictional coordination needs improvement to make compliance easier.
- Guidelines need to be developed for meeting NPDES permit requirements.
- A process needs to be developed to authorize within-state transfer of approved live aquatic species.
- Laws, regulations and permits need to be more clear, consistent and effective.
- Enforcement needs to be more vigilant and consistent.
- Stakeholder input should be solicited when permitting procedures are being written.
- New legislation should be written with the help of stakeholders (ballast water example was used).
- Methods for complying with aquaculture regulations need to be clearer.
- Some stakeholders feel like they are working in a vacuum; they need guidelines to help them determine if the right thing is being done.
- Develop a mechanism for mandatory reporting of listed AIS.
- Make sure regulations that affect industry are feasible (shipping example was used).
- Use existing Department of Boating and Waterways (DBW) laws to make AIS introductions illegal.
- Create a single, central clearing house for information on all AIS laws and regulations.

STATE AQUATIC INVASIVE SPECIES COUNCIL (ISC)

- The ISC needs to have broader public representation; consider expanding it to include more stakeholder groups.
- Each industry should decide who will represent them on the ISC.
- The number of industry representatives should be equal to or higher than the number of government representatives on the ISC.
- DBW should not represent all boating interests on the ISC.

GENERAL AIS MANAGEMENT PLAN DEVELOPMENT

- Make the plan short and simple.
- Funding priorities in the plan should be delineated by the ISC or another representative group.
- Work together; don't have government on one side and resource users on the other.
- Stakeholders are interested in practical solutions.
- Use common names in addition to scientific names for AIS to make the plan more user-friendly.
- Limit use of acronyms or fully explain them.
- Prioritization of species within the plan is necessary.
- Develop a system to prioritize aquatic invasive species using the ISC or another representative group.
- Use assigned "Management Classes" as Oregon did rather than prioritizing species.
- Consider using DFA's ABC List of Noxious Weeds as a model.
- Develop a process to determine which method gets used to control or eradicate a species.
- Limit administrative overhead.
- Develop a process to resolve disputes.
- Make sure all groups are represented (include tribes, irrigation districts, bass anglers, boaters, etc.).
- The planning effort should take into account the target species as well as the environment.
- There is a concern that some may try to sidetrack the plan or use the plan to push their own agenda.
- Consider using AIS instead of ANS (the word "invasive" is perhaps better than "nuisance").
- Write into the plan that state and federal agencies coordinate through formal written agreements.
- High profile species should not take over concern for lesser-known problem species.
- Support for current AIS programs should be continued.
- Make sure limited resources go to on-the ground projects rather than getting lost in the bureaucracy.

Southern California Stakeholder Comments

Invitations were sent to over 450 individuals and included representatives of local water agencies and irrigation districts, tribes, various industries including the pet, aquarium, aquaculture and nursery/landscaping trades, live bait and seafood dealers, ports, marinas and shippers, and others with an interest in aquatic invasive species. The following individuals attended:

Douglas Ball, Los Angeles Department of Water and Power
Mark Baumann, Live Cargo Reptile and Fish/ San Diego Fish Society
Paul Brown, Project Analyst, Port of San Diego
Thomas Buckowski, Lake Biologist, Lake Mission Viejo Association
Larry Chapp, Vice President, Divisional Merchandise Manager, PETCO
Hugh Cobb, Pacific Coast Bait and Tackle
Tom Gass, Manager, El Pescado Caliente
Chris Graham, Lake Biologist, Lake Mission Viejo Association
Miguel Hernandez, Watermaster, Natural Resources Office, Pauma Band of Mission Indians
Annaliese Hettinger, The Diving Locker
Steve Lonhart, Monterey Bay National Marine Sanctuary
Marshall Meyers, Executive Vice President, Pet Industry Joint Advisory Council
Craig Parsons, Live Fish, Reptile, Bird and Small Animal Buyer, PETCO
Russell Moll, Director, California Sea Grant/ Scripps Institute of Oceanography (SIO)
Anandra Ranasinghe, Southern California Coastal Water Research Project
Freda Reid, San Dieguito Lagoon Committee and Research Associate (SIO)
Andi Shluker, The Nature Conservancy of Hawaii
Ed Smith, General Manager, Palo Verde Irrigation District

Mike Fraidenburg of Dynamic Solutions Group (DSG) of Olympia, Washington facilitated the meeting. Ted Grosholz (UCD) discussed the ecological and economic costs of aquatic invasive species and introduced the goals and purpose of the meeting. Susan Ellis (State Invasive Species Coordinator) explained the different roles and responsibilities of state agencies and current management activities for aquatic invasive species in California, and provided an update on the formation of the California Aquatic Invasive Species Council. Mark Sytsma (Portland State University, Portland, Oregon) discussed Oregon's experience with writing a state management plan for aquatic invasive species as well as the uses and limits of state plans. Holly Crosson (UCD) discussed the process for the California plan's development and progress on the plan thus far. The rest of the meeting was spent discussing concerns and suggestions presented by the stakeholders. Most of the comments could be divided into the categories of Education, Prevention, Best Management Practices, Regulation and General AIS Management Plan development. Below is a summary of specific comments made under each of these categories.

EDUCATION

- A comprehensive strategy for AIS Education and Outreach should be developed.
- Education should be used instead of new legislation and regulation.
- More AIS information needs to reach the public, retail stores, industry, schools, etc.
- Prioritize educational efforts based on risk associated with a given pathway.
- Piggyback onto current Agency educational programs.
- Consider "green labeling" to help consumers make the right choice; peer pressure will encourage appropriate behavior/decisions of others.
- Educational efforts need to take into account the multi-cultural nature of CA (signs, etc. need to be published in other appropriate languages besides English).
- Marketing experts should be used to get a single, common AIS message out across the region.
- The AIS message has to touch people personally (an impact on the quality of life or the pocketbook).
- Educational materials should be tailored to specific industry sectors (aquaculture, boaters, bait shops, pet/aquarium retailers, etc.).

- The public as well as industry needs to know the economic cost of AIS (pay now or pay more later).
- Stakeholders are a resource and can help with educational efforts (i.e., using Recreational Fisherman's Alliance, American Sportfishing Association, Diving or Tropical Fish Clubs, etc.).
- Multiply educational efforts by identifying what industry sectors can do to help with AIS education and outreach; partner with pet/aquarium and other industries.
- Develop better ways to get the AIS message out, for instance, don't just have a booth at trade shows but work directly with promoters of shows (example – Fred Hall Show).
- Publish articles in Western Outdoor News and similar magazines.
- Train people to use the AIS "Traveling Trunk" and have them take it "on the road".
- A comprehensive AIS species list should be developed and publicized with appropriate contacts listed for experts associated with each species.
- There should be guidelines developed to help groups "self-regulate" and educate their constituents.

PREVENTION (including Early Detection and Rapid Response)

- An AIS Prevention Program is key to success but is not foolproof.
- AIS Screening and Risk Assessment Programs should not be overly simplistic or arbitrary. They need to be based on the best available information and sound science.
- Volunteers can be an important piece in monitoring efforts for early detection of AIS.
- Training volunteers takes a lot of organization and keeping them motivated over the long term can be challenging
- Interaction with Watershed Councils is important.
- An AIS "hotline" is needed so new sightings can be reported immediately.
- Determine the economic consequences of pathway prevention.
- Look into funds available through "homeland security".

BEST MANAGEMENT PRACTICES (BMPs)

- Develop guidelines for acceptable, humane and environmentally safe ways to deal with unwanted aquatic organisms (whether it be proper disposal, returning the organism to the retailer, or being "adopted" by someone else).
- Industry and individuals need to accept a degree of economic liability and responsibility for their actions regarding AIS introduction and spread.
- Create industry standards to regulate and penalize the bad actors.
- Each industry should be actively involved in the development of their own BMP's. Weak industry initiative yields weak BMPs.
- Industry documentation is needed to support accountability.
- Determine if BMPs should be regulatory.
- Develop BMPs for Bass Tournaments.
- BMPs need to maintain some flexibility and an acknowledgement that "one size does not fit all".
- BMPs can help achieve buy-in, create institutional memory, give an outsider a way to monitor activities and are already an accepted process in industry (similar to ISO example).

REGULATION

- Enforce the laws and regulations we already have, rather than pass new ones.
- Provide positive incentives to encourage self-regulation.
- Provide better information about what AIS laws are currently in place and how to comply with them.
- A few bad apples are causing regulatory problems for all involved.
- Determine more effective ways to catch violators of current laws, including interstate transport.
- Improve current regulations. Piranhas and snakeheads were used as examples of species that are regulated but still are imported and released. We should learn from these experiences and attempt to prevent similar situations.

GENERAL AIS MANAGEMENT PLAN DEVELOPMENT

- Coordinate with the National Marine Sanctuaries on Plan development.
- Work with California Sea Grant to achieve success in plan implementation, especially with education and outreach strategies and actions.
- Be creative with funding and partnerships.
- Leverage resources by doubling up on surveys, inspections, etc. that are already being done.
- Continually evaluate and update the plan and make sure the plan's goals are being realized (develop a scorecard).
- Make sure the functioning of the California Aquatic Invasive Species Council is evaluated so it does not outlive its useful purpose. If changes are needed to make the council more effective, they should be able to be promoted through other agencies and the general public.
- Take steps to minimize the loss of dollars through overhead.
- Do not set the stage for failure by creating a timeline that cannot be met.
- Involve economists if possible (can a dollar figure be put on habitat/resources?).
- Make it clear who will determine priorities in the plan and what gets funded.
- Incorporate Watershed Councils in the planning effort.
- Make the relationship between the plan and AIS policy clear.
- Determine how plan implementers will interact with on-the-ground managers.
- Write the plan so that it facilitates funding for implementation. The plan should be user-friendly.
- Plans should promote accountability so that managers have an incentive to perform and meet commitments.

APPENDIX F: EXECUTIVE SUMMARY OF *BIOLOGICAL INVASIONS: RECOMMENDATIONS FOR U.S. POLICY AND MANAGEMENT*

Position Paper of the Ecological Society of America

Biological Invasions: Recommendations for U.S. Policy and Management

David M. Lodge, Susan L. Williams, Hugh MacIsaac, Keith Hayes, Brian Leung, Sarah Reichard, Richard N. Mack, Peter B. Moyle, Maggie Smith, David A. Andow, James T. Carlton and Anthony McMichael, 2006

Executive Summary

The spread of nonindigenous (non-native) species introduced into the United States is a significant and growing national problem, costing taxpayers hundreds of billions of dollars in environmental degradation, lost agricultural productivity, increased health problems and expensive prevention and eradication efforts. Some nonindigenous species are introduced intentionally and are highly valued by humans, e.g., agriculture, aquaculture, and ornamental species. Many other species are introduced as by-products of human activity, especially through the increasing global transportation of humans and commercial goods. A subset of introduced species spread widely, become abundant and cause harm. The definition of “harm” is a function of human values, which often differ in different regions and may change temporally. Nevertheless, harm is often unambiguous and the species from elsewhere that causes harm are referred to as invasive nonindigenous species. They are the focus of policy and management concern because of their serious and complex contributions to diseases of plants, animals and humans; reductions in native species; changes in ecosystem function; and financial losses.

Well known examples of invasive nonindigenous species include the vine kudzu (*Pueraria lobata*) in the southeastern U.S., cheat grass (*Bromus tectorum*) in the western U.S., and zebra mussel (*Dreissena polymorpha*) in the central U.S. More recent arrivals with large net negative impacts on the environment, agriculture, forestry, industry and human health include West Nile virus, the seaweed *Caulerpa* (*Caulerpa taxifolia*), Asian long-horn beetle (*Anoplophora glabripennis*), emerald ash borer beetle (*Agrilus planipennis*), sudden oak death (*Phytophthora ramorum*), monkeypox virus, and the SARS virus. Without management, the populations of these species grow and spread such that damages accelerate over time. In contrast to many other forms of pollution, such widespread invasions become irreversible because the technology often does not exist to selectively eradicate species. Relative to the economic and ecological costs of other forms of environmental pollution, the costs of nonindigenous species are therefore of particular concern because they are likely to be borne over very long time frames.

Despite the great diversity of invasive species and their impacts, an identified group of pathways transport species, and a common set of biological processes – introduction, establishment, spread, and impact – operate in all invasions. Policy and management solutions become clearer when these common pathways and processes are recognized. Nevertheless the possible management responses diminish as any invasion progresses. Prevention is possible only before a species arrives or at the point of entry. Thereafter, a narrow window of opportunity for eradication exists before some species spread so widely that it is impossible or infeasible to locate and kill all populations. Once a species is too widespread for eradication, only three management options remain: controlling populations in selected locations; active mitigation of impacts; or simply bearing the cost of the changes caused by the invader. U.S. policy, often by default, has largely adopted the last option, i.e., acceptance of often irreversible environmental and economic damage.

The only study to attempt a nationwide estimate of the economic costs to the U.S. of nonindigenous species concluded that annual costs exceed $120 billion (Pimentel et al. 2005), which

we regard as an underestimate because the majority of invasive species were not included in the study. Even this underestimate equates to costs of $1,100 per U.S. household per year, costs that will continue to grow unless prevention and management of invasive species improves. Yet, the U.S. has allowed invasions to continue and damages to increase.

A more cost-effective approach would include greater investments in prevention and other active management steps, including early detection, eradication and control. Recent scientific advances in our understanding of biological invasions make it clear that more effective options exist for these threats. Here, on behalf of the Ecological Society of America, we make six recommendations for government action that, if implemented, would substantially reduce the current and future damages to the U.S. from invasive species. We include proposals for cost-effective government actions that will address these problems with the understanding that other measures are important to complement governmental responses. Key challenges that require urgent government action include prevention, detection, eradication and control of harmful non-native species, and the coordination of these efforts at the state, federal and international levels. Table 1 summarizes the major recommendations, data and techniques for implementation, and proposed lead organizations.

Prevention

Recommendation 1. Use a combination of existing and new technologies, education strategies, industry codes of conduct, and government oversight to prevent introductions from pathways that already are well known to be major sources of nonindigenous species, and to monitor other pathways into the United States to better assess the degree of risk they pose.

Recommendation 2. Screen live organisms proposed for importation into the U.S. for environmental, economic and human health risk before a decision is made to allow entry. Risk analysis tools should be repeatable, transparent, supported by current scientific findings and applied to all pathways, across all agency jurisdictions.

Early Detection, Eradication and Control

Recommendation 3. Use new technology to improve active surveillance of invasive species to increase the success of rapid response and eradication efforts, in cooperation with existing web-based information networks in universities, herbaria, museums and state agencies.

Recommendation 4. Make legal authority and emergency funding available for eradication and control to proceed rapidly once a newly established potentially invasive species is detected. Current legal mechanisms and funding for responses to agricultural pests and parasites, and to human pathogens, should be extended to all potentially invasive species in all habitats, and employed commensurate with the threat.

Recommendation 5. Provide on-going funding and incentives for slowing the spread of established invasive species on public and private lands, in cooperation with the states and tribal governing bodies.

Establishing a National Center for Invasive Species Management

Recommendation 6. Expand existing authority of the National Invasive Species Council (NISC), including the establishment of a National Center for Invasive Species Management under NISC, to better coordinate policies among government agencies and with other countries. Current U.S. examples of intergovernmental cooperation include the National Interagency Fire Center and the Center for Disease Control and Prevention. Unless these or conceptually similar recommendations are adopted, the rate of damages to our environment, economy and health caused by invasive species will accelerate. These damages are spread across many stakeholders, and no strong, nationwide group has emerged to encourage industries that are pathways of introduction to reduce the threat. Hence the federal government must assume greater leadership to coordinate efforts by all levels of government. We recognize that the problem is complex and interdisciplinary, includes many pathways, a tremendous diversity of organisms that are invasive, and the vulnerability of all terrestrial, marine and freshwater ecosystems. Despite this complexity, and the consequent overlapping and sometimes conflicting state, federal and international policies involved, the six recommendations described in this paper provide sound guidance for the future. Recent scientific and interdisciplinary advances provide a strong basis for rapid implementation of these cost-effective solutions.

APPENDIX G: LIST OF REGULATED SPECIES IN CALIFORNIA

Aquatic invasive species are regulated by a number of state and federal regulations. The aquatic plant and animal species restricted in California, and the regulations that apply to each, are listed below.

ANIMALS

In California, the animal species considered detrimental to native wildlife, state agriculture or public health and safety are listed in California Administrative Code Title 14, Section 671. Importation, transportation and possession of the restricted animals on this list are unlawful except under permit issued by the California Department of Fish and Game. Animal species restricted by the federal government are considered "injurious wildlife" and named in the Lacey Act (50 CFR 16.11-16.15). The U.S. Fish and Wildlife Service has responsibility for regulating the live importation or shipment of these animals.

California's list of Restricted Animals
http://www.dfg.ca.gov/licensing/pdffiles/fg1518.pdf
Click on the following link: "Search for a Specific Regulatory Section"
Title: 14
Section: 671

Injurious Wildlife Species List (PDF)
U.S. Fish and Wildlife Service
http://www.invasivespeciesinfo.gov/laws/main.shtml

PLANTS

Certain aquatic invasive plants are listed as Noxious Weed Species in Title 3, Section 4500 of the California Administrative Code. Their eradication, control, and containment are regulated by the California Department of Food and Agriculture (DFA). Each species has been given a "pest rating" based on the economic risks it poses to the state. In addition, Division 3, Chapter 3.5, Section 2300 of the California Fish and Game Code restricts all species of the marine alga genus *Caulerpa*. Federally restricted invasive plants are listed in Noxious Weed Act P.L. 93-629.

CDFA Weed List
http://www.cdfa.ca.gov/phpps/ipc/encycloweedia/pdfs/noxiousweed_ratings.pdf

Federal Noxious Weed List (PDF)
http://www.aphis.usda.gov/ppq/weeds/weedlist2006.pdf

Appendix G
State and/or Federal Regulated Aquatic Invasive Animals

Scientific Name	Common Name	Group	Habitat	Regulated By
Mustelidae (Family)	All species except *Amblonyx cinerea*, Oriental small-clawed otter, *Aonyx capensis,* African clawless otter*, Pteronura brasiliensis,* giant otter and all species of genus *Lutra,* river otters.	Mammals	F	CA
Amiidae (Family)	bowfins	Fish	F	CA
Anguilla (Genus)	freshwater eels	Fish	F	CA
Aplodinotus grunniens (Species)	freshwater drum	Fish	F	CA
Astyanax fasciatus (Species)	banded tetra	Fish	F/B	CA
Belonesox belizanus (Species)	pike killifish	Fish	F	CA
Carcharhinus (Genus)	freshwater sharks	Fish	F	CA
Cetopsidae (Family)	whalelike catfishes	Fish	F	CA
Channidae (Family)	snakeheads	Fish	F	CA, US
Clariidae (Family)	labyrinth catfishes	Fish	F	CA*,US
Ctenopharyngodon idella (Species)	grass carp (permits may be issued for possession of triploid grass carp)	Fish	F	CA
Cyprinodon variegatus (Species)	sheepshead minnow	Fish	F/B	CA
Dorosoma cepedianum (Species)	gizzard shad	Fish	F	CA
Esocidae (Family)	pikes	Fish	F	CA
Heteropneustidae (Family)	airsac catfishes	Fish	F	CA
Hoplias malabaricus (Species)	tiger fish	Fish	F/B	CA
Hypophthalmichthys molitrix (Species)	silver carp	Fish	F	CA
Hypophthalmichthys nobilis (Species)	bighead carp	Fish	F	CA
Ictiobus (Genus)	buffalo suckers	Fish	F/M	CA
Lepisosteidae (Family)	gars	Fish	F	CA
Leuciscus idus (Species)	Ide	Fish	F	CA
Morone americana (Species)	white perch	Fish	F	CA
Morone chrysops (Species)	white bass	Fish	F	CA
Perca flavescens (Species)	yellow perch	Fish	F	CA
Potamotrygonidae (Family)	river stingrays	Fish	F/M	CA
Petromyzontidae (Family)	lampreys - all nonnative species	Fish	F/M	CA
Salmo salar (Species)	Atlantic salmon - restricted in the Smith River watershed	Fish	F/M	CA

* Only members of the Clarias, Dinotopterus, and Heterobranchus genera are prohibited by Title 14 section 671

Key

B Brackish
F Freshwater
M Marine

CA CDFG Restricted Species, Title 14, Section 671
US USFW Lacey Act 50 CFR 16.11-16.15

Appendix G
State and/or Federal Regulated Aquatic Invasive Animals

Scientific Name	Common Name	Group	Habitat	Regulated By
Salmonidae (Family)	live or dead uneviscerated salmonid fish, live fertilized eggs, or gametes of salmonids are prohibited unless accompanied by a certification that the ensures they are free of *Onocorhynchus masou* virus and the viruses causing viral hemorrhagic septicemia and infectious hematopoietic necrosis, and meet the conditions in 50 CFR 16.13	Fish	F/M	US
Serrasalmus (Genus)	piranhas (including genera Pygocentrus and Pygopristis, and invalid genera Serrasalmo, Taddyella, Rooseveltiella)	Fish	F	CA
Stizostedion vitreum (Species)	walleye	Fish	F	CA
Tilapia aurea (Species)	blue tilapia	Fish	F/M/B	CA
Tilapia nilotica (Species)	Nile tilapia	Fish	F/M/B	CA
Tilapia sparrmani (Species)	banded tilapia	Fish	F/M/B	CA
Tilapia zillii (Species)	redbelly tilapia (permits may be issued to a person or agency for importation, transportation, or possession in the counties of San Bernardino, Los Angeles, Orange, Riverside, San Diego, and Imperial)	Fish	F/M/B	CA
Trichomycteridae (Family)	parasitic catfishes	Fish	F	CA
Ambystoma (Genus)	tiger salamanders	Amphibian	F	CA
Bufonidae (Family)	toads (including *Bufo marinus,* cane toad, giant toad or marine toad; and invalid species, *Bufo paracnemis,* Cururu toad, and *Bufo horribilis,* other large toads from Mexico and Central and South America)	Amphibian	F/M	CA
Xenopus (Genus)	clawed frog	Amphibian	F	CA
Crocodilia (Order)	crocodiles, caimans, alligators and gavials	Reptile	F/M	CA
Chelydridae (Family)	snapping turtles	Reptile	F	CA
Cambaridae (Family)	crayfish - all species except *Procambarus clarkii* and *Orconectes virilis*	Invertebrate	F/M	CA
Eriocheir (Genus)	crabs	Invertebrate	F/M	CA, US
Dreissena (Genus)	zebra and quagga mussels	Invertebrate	F	CA, US **
Potamopyrgus antipodarum (Species)	New Zealand mudsnail	Invertebrate	M	CA
Transgenic Aquatic Animals	Freshwater and marine fishes, invertebrates, crustaceans, mollusks, amphibians and reptiles		F/M	CA

** Only the species Dreissena polymorpha is prohibited by the Lacey Act

Key

B	Brackish	CA	CDFG Restricted Species, Title 14, Section 671
F	Freshwater	US	USFW Lacey Act 50 CFR 16.11-16.15
M	Marine		

Appendix G
State and/or Federal Regulated Aquatic Invasive Animals

Scientific Name	Common Name	Habitat	Applicable Regulations/Pest Rating
Alternanthera philoxeroides	alligatorweed	F	A
Arundo donax	giant reed	W/U/R	B
Azolla pinnata	mosquito fern, water velvet	F	US
Cabomba caroliniana	fanwort	F	Q
Caulerpa taxifolia	Caulerpa	M	US, DFG
Caulerpa cupressoides	Caulerpa	M	DFG
Caulerpa mexicana	Caulerpa	M	DFG
Caulerpa sertulariodes	Caulerpa	M	DFG
Caulerpa floridana	Caulerpa	M	DFG
Caulerpa ashmeadii	Caulerpa	M	DFG
Caulerpa racemosa	Caulerpa	M	DFG
Caulerpa verticillata	Caulerpa	M	DFG
Caulerpa scapelliformis	Caulerpa	M	DFG
Eichhornia azurea	anchored water hyacinth	F	US
Hydrilla verticillata	hydrilla	F	US, A
Hygrophila polysperma	Miramar weed	F	US
Ipomoea aquatica	Chinese water spinach	F	US
Lagarosiphon major	oxygen weed	F	US
Limnobium spongia	spongeplant	F	Q
Limnophila indica	ambulia	F	Q
Limnophila sessiliflora	ambulia	F	US, Q
Lythrum salicaria	purple loosestrife	W/U	B
Melaleuca quinquenervia	broadleaf paper-bark tree	W	US
Monochoria hastata	monochoria	F	US
Monochoria vaginalis	heartshape false pickerelweed	F	US
Nymphaea mexicana	banana water lily	F	B
Ottelia alismoides	duck lettuce	F	US
Pistia stratiotes	water lettuce	F	B
Polygonum amphibium	swamp smartweed	F	C
Polygonum cuspidatum	Japanese knotweed	W/U/R	B
Sagittaria sagittifolia	arrowhead	F	US
Salvinia auriculata	salvinia	F	US, A
Salvinia biloba	salvinia	F	US, A*
Salvinia herzogii	herzog salvinia	F	US, A*
Salvinia molesta	giant salvinia	F	US, A*
Sparganium erectum	exotic bur-reed	F	US
Tamarix chinensis	Chinese tamarisk	U/R	B
Tamarix gallica	French tamarisk	U/R	B
Tamarix parviflora	smallflower tamarisk	U/R	B
Tamarix ramosissima	salt cedar	U/R	B

*DFA considers these species a synonym of Salvinia auriculata

Appendix G
State and/or Federal Regulated Aquatic Invasive Animals

Key for State and/or Federally Regulated Aquatic Invasive Plants

DFG	Regulated by CDFG Division 3, Chapter 3.5, Section 2300
F	Freshwater
M	Marine
R	Riparian
SM	Saltmarsh
U	Upland
US	**Regulated by the Federal Noxious Weed Act, P.L. 93-629.** For more details, see the discussion of the Noxious Weed Act in the subsection titled “Other Federal Authorities” in Appendix B of the California Aquatic Invasive Species Management Plan..
W	Wetland

Noxious Weed Ratings per California Department of Food and Agriculture Plant Industry Policy Letter 89-2, May 1, 1989. http://www.cdfa.ca.gov/cdfa/pendingregs/docs/PlantPestRatings.pdf

A	An organism of known economic importance subject to enforced action involving eradication, containment, rejection, or other holding action at the state-county level. Quarantine interceptions to be rejected or treated at any point in the state.
B	An organism of known economic importance subject to eradication, containment, control or other holding action at the discretion of the commissioner. OR an organism of known economic importance subject to state holding action and eradication only when found in a nursery.
C	An organism subject to state endorsed holding action and eradication only when found in a nursery; action to retard spread outside of nurseries at the discretion of the commissioner; reject only when found in a cropseed for planting or at the discretion of the commissioner.
Q	An organism requiring a temporary “A” action pending determination of a permanent rating. It is suspected to be of economic importance, but its status is uncertain because of incomplete identification or inadequate information.
D	Organisms determined to be of little or no economic importance

Inhibition of Giant Kelp Recruitment by an Introduced Brown Alga

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Richard F Ambrose
University of California, Los Angeles

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Inhibition of Giant Kelp Recruitment by an Introduced Brown Alga

R. F. Ambrose and Bobette V. Nelson

Department of Biology, University of California, Los Angeles, California 90024, USA

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Abstract

Following a natural disappearance of the native giant kelp *Macrocystis pyrifera*, an invasion of the introduced brown alga *Sargassum muticum* appeared to prevent giant kelp recruitment. Experimental removal of adult *S. muticum* resulted in a significant increase in giant kelp recruitment compared to nonremoval areas. Two requirements for the successful establishment of giant kelp appeared to be: 1) an absence of *S. muticum*, and 2) the presence of nearby giant kelp adults to supply sufficient spores. Higher densities of giant kelp in removal areas persisted throughout the period when *S. muticum* dies back to a perennial holdfast. Shading at a critical time in the giant kelp life cycle is suggested as a possible mechanism for the inhibition of giant kelp recruitment.

Introduction

The large kelps (Phaeophyta, Laminariales) comprise the majority of the subtidal canopy algal species in temperate marine communities (Mann 1973). Their ecological importance has long been recognized (Darwin 1860, North 1971). Dayton (1975) and Hruby (1976) have found that recruitment, growth, and development of several laminarians can be inhibited by competition with native algal species. In this paper, we examine the interactions between the introduced brown alga *Sargassum muticum* (Yendo) Fensholt (Order Fucales) and the native giant kelp *Macrocystis pyrifera* (L.) C. A. Agardh.

Sargassum muticum was introduced to the west coast of North America from Japan in the late 1940's (Scagel 1956). Initially restricted to the Pacific Northwest, it spread southward to Baja California by 1971 (Setzer and Link 1971) and was found for the first time in England in 1973 (Farnham, Fletcher and Irvine 1973). In spite of the rapid invasion of *S. muticum* and speculation of its potential influence on algal communities (Druehl 1973, Jones and Farnham 1973, Farnham and Jones 1974, Fletcher and Fletcher 1975, Norton 1976), its actual impact on native algae has not been studied. Our evidence suggests that *S. muticum* inhibits recruitment of the giant kelp *Macrocystis pyrifera* on Santa Catalina Island, California, USA.

Prior to 1976, a very dense bed of *M. pyrifera* existed near the east end of Bird Rock, a small island near Santa Catalina Island. This kelp bed, along with many others at Santa Catalina Island, disappeared in the summer of 1976 (see Coyer 1979). Elevated temperatures from mid-June to November 1976 at Santa Catalina (Coyer 1979) were the probable cause of the decline, since kelp beds in southern California deteriorate when water temperatures exceed 20 °C (North 1971, Abbott and North 1972). During the following winter, *S. muticum* appeared in high densities at Bird Rock for the first time, ultimately covering the entire east end. Even though *S. muticum* dies back to a perennial holdfast in early summer and does not resume vegetative growth until fall (Ambrose and Nelson, pers. obs.), there was essentially no *M. pyrifera* recruitment at Bird Rock in 1977 or 1978. Kelp abundance in other Santa Catalina kelp beds, where *S. muticum* had not become established, increased to predecline levels by August 1977 (Coyer 1979). These observations suggested that *S. muticum* might have been preventing the re-establishment of *M. pyrifera* at Bird Rock. We cleared several areas of *S. muticum* in 1979 to examine the possibility that *S. muticum* inhibited *M. pyrifera* recruitment.

Methods

Research was conducted near the east end of Bird Rock, a small island 0.5 km N of Big Fisherman's Cove on Santa Catalina Island (33° 27′ N, 118° 29′ W), 30 km S of Los Angeles, California, USA. The study site depth varies from 3 to 7 m below MLLW. Water temperature varies from 12°–14 °C in the winter to 20°–22 °C in the summer.

Sargassum muticum was removed by pulling up individual plants by hand along a corridor 2 m wide; no at-

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tempt was made to remove the perennial holdfast. Two areas were studied. Area 1 removal (15 m long) and its control (13 m long) were 2 m and 4 m away from a sharp dropoff to approximately 30 m ("the wall"), respectively. *Sargassum muticum* does not extend onto the wall, where many *Macrocystis pyrifera* persist. In Area 2 there were two removal areas (a and b) and one control, each 10 m long and located 13 m away from the wall. Removal areas were cleared monthly from January to June 1979, although not all areas were cleared every time; generally, an area was cleared as soon as *S. muticum* began to grow back noticeably. Nonmanipulated areas maintained high *S. muticum* cover until early June when *S. muticum* dies back to a perennial holdfast. *Sargassum muticum* densities were estimated by censusing 20 haphazardly placed 0.25 m^2 quadrats. Removal and control areas were censused by counting all juvenile *Macrocystis pyrifera* in contiguous 1 m^2 quadrats. The study site was censused in late June, approximately one month after the natural die-back of *S. muticum*, and in late September, one month before *S. muticum* resumed vegetative growth, to distinguish between the following hypotheses: 1) *Macrocystis pyrifera* recruitment is delayed until *S. muticum* dies back, and 2) *S. muticum* prevents the recruitment of *M. pyrifera*. Differences between areas were examined using the Wilcoxon two-sample test.

Results

In 1979 the *Sargassum muticum* density near the east end of Bird Rock averaged 56.9 plants/m^2 (range 8/m^2 to 136/m^2); plant height was 3–4 m. In June, following the *S. muticum* die-back, juvenile *M. pyrifera* density was significantly higher in removal areas 1 and 2a than their respective controls ($p < 0.001$; Tab. I). Density was not significantly greater in removal 2b than its control. In general, areas near the wall had higher recruitment than their counterparts away from the wall. Recruitment in removal area 1 was significantly higher than removal areas 2a and 2b ($p < 0.01$). The greater juvenile *M. pyrifera* density in control area 1 versus control area 2 was not significant.

Supplementary observations in June of an isolated adult *M. pyrifera* plant 10 m away from the wall, where *S. muticum* was not removed, failed to reveal any juvenile *M. pyrifera* around the adult.

Juvenile *M. pyrifera* density in September 1979, although lower than in June, was still significantly higher in removal areas 1 and 2a than their respective controls ($p < 0.001$ and $p < 0.01$, respectively). Density was marginally significantly greater in removal area 2b than its control ($0.05 < p < 0.10$). Recruitment in removal area 1, near the wall, was significantly higher than removal areas 2a and 2b ($p < 0.01$ and $p < 0.001$, respectively). The difference in juvenile *M. pyrifera* density between control area 1 and control area 2 was marginally significant ($0.05 < p < 0.10$).

Tab. I. Juvenile *Macrocystis pyrifera* density in *Sargassum muticum* removal quadrats and in unmanipulated controls. Censuses were conducted in June 1979, one month after the natural dieback of *S. muticum*, and in September 1979, one month before *S. muticum* resumed growth. N = 30 for area 1 removal, N = 26 for area 1 control, and N = 20 for area 2 removals and control. ** and * indicate removal significantly different from control at $p < 0.001$ and $p < 0.01$, respectively. + indicates removal marginally significantly different from control at $0.05 < p < 0.10$

Area	Distance from wall (m)	*Macrocystis* Density Mean (s.d., range) (Plants/m^2) *Sargassum* Removal		Control
June 1979				
1	2	5.0 (5.91, 0–32)	**	0.4 (0.63, 0–3)
2a	13	1.9 (1.38, 0–12)	**	0.2 (0.37, 0–1)
2b	13	0.4 (0.75, 0– 3)		
September 1979				
1	2	1.9 (2.06, 0– 7)	**	0.1 (0.31, 0–1)
2a	13	0.4 (0.60, 0– 2)	*	0.0 (–)
2b	13	0.1 (0.31, 0– 1)	+	

Discussion

The *Macrocystis pyrifera* juveniles growing in the *S. muticum* removal areas represent the first significant *M. pyrifera* recruitment near the east end of Bird Rock since the establishment of *S. muticum* 3 years earlier. However, *S. muticum* removal did not invariably result in greater numbers of juvenile *M. pyrifera*. One treatment, removal area 2b, was statistically indistinguishable from its nonremoval control. Low recruitment in area 2b may result from the limited distance of *M. pyrifera* dispersal (Anderson and North 1966). Only one adult *M. pyrifera* was within a few meters of removal area 2b. Limited dispersal may also explain the differences between areas 1 and 2, which were 2 m and 13 m away from the wall, respectively. Tidal currents could more easily disperse spores from the numerous adult *M. pyrifera* plants growing on the wall to areas near the wall (area 1) than to area 2, where adult *M. pyrifera* were sparse.

Of the many possible mechanisms by which *S. muticum* may reduce *M. pyrifera* recruitment, shading is perhaps the most likely. The dense *S. muticum* bed (mean of 56.9 plants/m^2) very effectively lowered light levels. Since dense kelp canopies can prevent the development of juvenile *M. pyrifera* (Anderson and North 1969), recruitment under the *S. muticum* canopy seems unlikely. Shading by *S. muticum* may occur at a critical time in the *M. pyrifera* life cycle. In southern California the peak *M. pyrifera* recruitment occurs in early spring (Anderson and North 1969), after which recruitment is normally very low. The absence of *M. pyrifera* juveniles in the control areas approximately 4 months after the *S. muticum* die-back indicates that *S. muticum* did not simply cause the delay of *M. pyrifera* recruitment, but effectively prevented recruitment.

Sargassum muticum is an extremely successful introduced species, having spread through England and the west coast of the United States in a remarkably short time. Our observations suggest that there is intense competition between *M. pyrifera* and *S. muticum*. Both species utilize the same basic resourse and both form canopies. Although *S. muticum* was present at Santa Catalina Island since 1971 (Setzer and Link 1971), it did not invade the east end of Bird Rock until the massive *M. pyrifera* die-off in 1976, suggesting that the local distribution of *S. muticum* was restricted by competition with *M. pyrifera*. Once *S. muticum* became established at Bird Rock, *M. pyrifera* did not reinvade. Kelp forests are regularly exposed to natural as well as man-made disturbances (North and Pearse 1970, North 1971, 1976, Rosenthal *et al.* 1974). If our observations are generally true, it is possible that by exploiting these opportunities, *S. muticum* may have a substantial impact on *Macrocystis pyrifera* distribution in southern California.

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References

Abbott, I. A. and W. J. North. 1972. Temperature influences on floral composition in California coastal waters. *Proc. Internat. Seaweed Symp. 7*: 72–79.

Anderson, E. K. and W. J. North. 1966. *In situ* studies of spore production and dispersal in the giant kelp, *Macrocystis. Proc. Internat. Seaweed Symp. 5*: 73–86.

Anderson, E. K. and W. J. North. 1969. Light requirements of juvenile and microscopic stages of giant kelp, *Macrocystis. Proc. Internat. Seaweed Symp. 6*: 3–15.

Coyer, J. A. 1979. The invertebrate assemblage associated with *Macrocystis pyrifera* and its utilization as a food resource by kelp forest fishes. Ph. D. dissertation, Univ. Southern Calif. 364 pps.

Darwin, C. 1860. *The Voyage of the Beagle*. The Natural History Library Edition, 1962. Doubleday & Co., New York, USA.

Dayton, P. K. 1975. Experimental studies of algal canopy interactions in a sea otter-dominated kelp community at Amchitka Island, Alaska. *Fish. Bull. 73*: 230–237.

Druehl, L. D. 1973. Marine transplantations. *Science 179*: 12.

Farnham, W. F. and E. B. Jones. 1974. The eradication of the seaweed *Sargassum muticum* from Britain. *Biol. Conserv. 6*: 57–58.

Farnham, W. F., R. L. Fletcher and L. M. Irvine. 1973. Attached *Sargassum* found in Britain. *Nature (London) 243*: 231–232.

Fletcher, R. L. and S. M. Fletcher. 1975. Studies on the recently introduced brown alga *Sargassum muticum* (Yendo) Fensholt. I. Ecology and reproduction. *Bot. Mar. 18*: 149–156.

Hruby, T. 1976. Observations of algal zonation resulting from competition. *Estuarine and Coast. Mar. Sci. 4*: 231–233.

Jones, E. B. and W. F. Farnham. 1973. Japweed: a new threat to British coasts. *New Scient. 60*: 394–395.

Mann, K. H. 1973. Seaweeds: Their productivity and strategy for growth. *Science 182*: 975–981.

North, W. J. 1971. Introduction and background. In: (J. Cramer, ed.) *Giant kelp beds (Macrocystis) in California*. Lehre, Germany, pp. 1–97.

North, W. J. 1976. Aquacultural techniques for creating and restoring beds of giant kelp, *Macrocystis* spp. *J. Fish. Res. Board Can. 33*: 1015–1023.

North, W. J. and J. S. Pearse. 1970. Sea urchin population explosion in southern California coastal waters. *Science 167*: 209.

Norton, T. A. 1976. Why is *Sargassum muticum* so invasive? *British Phyc. J. 11*: 197–198.

Rosenthal, R. J., W. D. Clarke and P. K. Dayton. 1974. Ecology and natural history of a stand of giant kelp, *Macrocystis pyrifera*, off Del Mar, California. *Fish. Bull. 72*: 670–684.

Scagel, R. F. 1956. Introduction of a Japanese alga, *Sargassum muticum*, into the Northeast Pacific. *Fish. Res. Papers, Wash. Dept. Fish 1*: 49–58.

Setzer, R. and C. Link. 1971. The wanderings of *Sargassum muticum* and other relations. *Stomatopod 2*: 5–6.

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Outplanting large adult green abalone (*Haliotis fulgens*) as a strategy for population restoration

Nancy L. Caruso*

Get Inspired, Inc., 6192 Santa Rita Ave., Garden Grove, CA 92845, USA (NLC)

**Correspondent: nancy@getinspiredinc.org*

Wild abalone populations are in decline around the globe. Given their high market value, abalone have been targeted for restoration in many areas where they were once abundant. Efforts to restore California green abalone (*Haliotis fulgens*) have had limited success for species recovery. This study aimed to use large (>14cm) adult green abalone as a strategy for restoration. Abalone of this size have few predators and are generally emergent, making them more visible during surveys. Sixty-nine large (average size 16.2 cm) farm raised abalone were outplanted in three batches (May, July and August) in Newport Beach, California, on natural reef structure at a depth of 8.4 m, monitored for 15 months, and then recaptured. Using multiple tagging devices and rigorous monitoring resulted in 40% survival at the end of the study, with 61% of the mortalities occurring within the first 30 days of outplanting, and 46% of the August outplants surviving to the end of the study period. Most of the trackable abalone movements, throughout the study, were confined to a 10 m radius of outplanting areas and 79% (22) of the surviving abalone stayed within 8 m of the outplant areas.

Key words: abalone, adult abalone, *Haliotis fulgens*, outplanting, restoration, restocking, size, stock enhancement

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Abalone populations worldwide have been in decline for many decades (Campbell 2000). Over fishing, illegal harvest, disease and habitat degradation are thought to be the primary causes (Cook 2014). California once supported fisheries for five species of abalone (black, green, pink, red, white) and by 1998 all commercial and recreational fisheries were closed south of San Francisco bay. Rogers-Bennett et al. (2004) found that adult abalone densities in southern California were two orders of magnitude below the estimated minimal viable population of 2000 individuals/ha and at that point, abalone recruitment in southern California had declined 20-fold over the previous decade. Despite 20 years of closed fisheries, populations of all five of these abalone species have yet to rebound on coastal reefs in southern California indicating a need for restoration activities. McCormick et al. (1994) suggested that seeding areas with hatchery raised abalone may be the only means of increasing coastal abalone stocks on a time scale meaningful to fishery managers.

The challenges facing abalone restoration include: captive spawning and rearing, protecting aggregated or outplanted animals from poaching, tracking reproduction, quantifying survival, and maximizing survival of captive-reared abalone in the wild (Henderson et al. 1988, Tegner and Butler 1989, Tegner 1992, Rogers-Bennett and Pearse 1998, Tegner 2000). Reseeding or outplanting projects have most often involved larvae and juveniles (0-100 mm) and have had mixed results around the globe with Japan and New Zealand reporting higher than 50% survival for some projects (Saito 1984, Schiel 1993, Kojima 1981). Results for reseeding or outplanting juveniles in southern California report much lower recovery rates ranging from 0-6% (Tegner and Butler 1985, McCormick et al. 1994, Davis 1995, Chick et al.2013). Quantifying recovery rates is a challenge for comparisons of efforts across time, species and different geographic areas.

Green abalone, (*Haliotis fulgens; Philippi*), are native to southern California and range from Point Conception, California, USA, to Magdalena Bay, Baja California, Mexico, and include the offshore islands (Cox 1962). They were once part of a large recreational and commercial fishery, and have previously been a target for species recovery. The green abalone is listed as a federal Species of Concern (NOAA 2004) and based on historic landings, is estimated to be at less than 1% of its baseline density (Rogers-Bennett et al. 2002). The major threat to remaining populations is their low densities and the possibility of reduced reproduction resulting from the Allee effect (Allee 1931). Low densities of broadcast spawners can lead to poor fertilization and recruitment failure because of the distances between males and females (Babcock & Keesing 1999). Remnant populations are comprised primarily of solitary abalone, many of which may not be contributing to reproduction and are thus functionally sterile (Taniguchi et al. 2013). Results from a drift tube study by Tegner and Butler (1985) indicated that in the absence of local broodstock, a fishery closure alone would not be an effective management policy for the recovery of green abalone populations on the mainland in southern California.

There have been several attempts at restoration of green abalone beginning in the 1970s. Most attempts have involved outplanting small hatchery reared animals generally due to costs associated with raising this slow growing mollusk. Seeding or outplanting results are affected by many variables including condition of the abalone at release, size, planting method, season, as well as site specific conditions including habitat type, food availability, predation, and topography (Saito 1984, Schiel 1993, McCormick et al. 1994). Because of the cryptic and mobile nature of small abalone it is difficult to estimate survival in most studies (Breen 1992, Shepherd & Breen 1992). Juveniles are highly cryptic and are found during daylight hours beneath rocks or in the recesses and crevices; they move freely at night and seldom return to the same location as the preceding day (Leighton 2000). Outplanting activities in Baja California with approximately 20 mm (shell length) green and pink abalone have yielded recovery rates ranging up to 4.7% (Sercy-Bernal et al. 2013). In summary, abalone outplanting has many variables to consider and there has been no formula for "success" that works for all species in all locations.

Translocation of abalone involves aggregating wild animals into one location with the aim of increasing reproductive success. A recent trial involving the translocation of adult California green (*H. fulgens*), and pink (*H. corrugata*), abalone showed that green abalone were not a good candidate for this restoration technique because they exhibited site infidelity (Taniguchi et al. 2013). A previous trial of 4,453 translocated green abalone on the Palos Verdes Peninsula, California was inconclusive due to poaching of the aggregated animals in the second year of the project (Tegner 1992).

Natural mortality of juvenile abalone may vary with location, time, and generally declines with age (Tegner and Butler 1985, Prince et al. 1988, Shepherd and Daume 1996). Initial mortality rates for outplanted juvenile abalone species are quite high and the rates decrease as the abalone grow to larger sizes (Schiel 1993). Saito (1984) found that survival of outplanted abalone increased with seed size in the range of 10 to 50 mm. Outplanting large adults in high densities on isolated reefs seems to be more effective (Coates et al. 2013).

Studies conducted in the 40 years before this project noted issues with the following: tagging (tags falling off, not identifiable); tracking (outplanted animals were not surveyed with enough frequency, were too cryptic, or emigrated off study site); predation (the size of the outplanted animals were vulnerable to multiple predators); poaching; and mortalities from transport shock. With historically limited success in green abalone restoration utilizing juveniles, the aim of this study was to use large (>14 cm) adult abalone for outplanting as a possible restoration strategy and to quantify their survival. This project aimed to also address some of the previous noted issues by using multiple tags, surveying with greater frequency, minimal handling in transport, and removing sea star predators. The use of large animals may act as a model for other abalone species including the endangered white (*H. sorenseni*) and black abalone (*H. cracherodii*) as recommended by Davis et al. (1998). The results are compared with previous restoration studies to determine if larger (>14 cm) outplants yield higher survival rates. The premise is that, large abalone have fewer predators and they are more easily detected and tracked.

Materials and Methods

Study site.—The green abalone outplant site was located in Crystal Cove State Park, Orange County, California, with coordinates 33° 34' 6.528" N, 33° 34' 6.528" W. The study site was chosen because it was familiar to the author, too far from shore for shore divers to reach, and was not a well-known recreational dive spot minimizing opportunities for poachers. Surveys were conducted to characterize the composition of the reef, describe the topography, and assess the predator population. Predators of large abalone (>14 cm) in Orange County include octopus (*Octopus sp.*), sea stars (*Pisaster sp.*), and the bat ray (*Myliobatis californica*). The surveys were conducted using two different methods. In one method, an observer conducted two 30 x 2 m band transect surveys and the other method included 30 random 1-m^2 quadrats along two 30-meter transects. Each surveyor collected information on reef composition (continuous reef, boulder, sand, or cobble on every meter), changes in rugosity (change in height of the reef at every meter), percent cover (sessile invertebrates, algal species), the presence of wild abalone, and presence/absence of predators.

The 450 m^2 reef was roughly rectangular and was divided into eight quadrants (approximately 9 x 6 m) using plastic clothesline stretched out across the reef and tied off to cinderblocks. Each quadrant was labeled with floating numbers to make the process of mapping the locations of abalone easier for volunteers. The large Pisaster stars were removed before outplanting and continuously removed during the project period. No octopus were removed from the reef but were present during the entire study, and two bat rays were observed near the reef, one before and one during the study.

Tagging.—Seventy adult abalone were purchased ($38 each) from The Cultured Abalone, a commercial farm in Goleta, California. The average size of the abalone was 16.2 cm (max 17.9 cm, min 14.6 cm). These animals were used as broodstock on the farm and thought to be at least 10 years old. They were shipped in three batches to a holding facility in

San Pedro, California in moist foam and oxygen filled bags and held for up to thirteen days to tag, monitor, and reduce stress from transport. Upon arrival, the animals were measured, sexed, affixed with tags using Splash Zone marine epoxy or cyanoacrylate (Super Glue), and photographed. Of the 69 abalone tagged, 87% (60) were identified as female (Table 1). Since abalone are known for choosing crevices, ledges, and overhangs for their home scars multiple tags were used to make the identifiers visible from any angle. The tags identified which outplant batch the animal was from and had both a unique number identifier (Major Tag) and several auxiliary tags (Minor Tag). Each animal was given a "Major" tag with a number, a color coded zip tie, and up to four other "Minor" tags (Figure 1). The Major tags consisted of a 1.5 cm stainless steel disk with etched numbers; a 2.5 cm white plastic square with printed black numbers; or a 4 cm brass disk with printed black numbers. All of the abalone had a colored zip tie secured through the first or second respiratory pore. PIT (passive integrated transponder) tags were epoxied on the shells of 32 of the animals for the purposes locating the animals using a PIT tag reader. Minor tags consisted of one or more of the following: blue aluminum tree tags with etched numbers; colored plastic bottle caps; white plastic beads with black letters; red plastic key tags with white numbers; stainless steel washers; plastic chain links; and metallic painted plastic jewelry (shiny). No two animals had the same combination of tags. The white lettered beads were the only tag affixed with cyanoacrylate. Knowing that the abalone would be cryptic to the observing volunteer divers, the objects used for tagging were meant to help spot the animals and the combinations of tags helped to identify the animals in hard to see places.

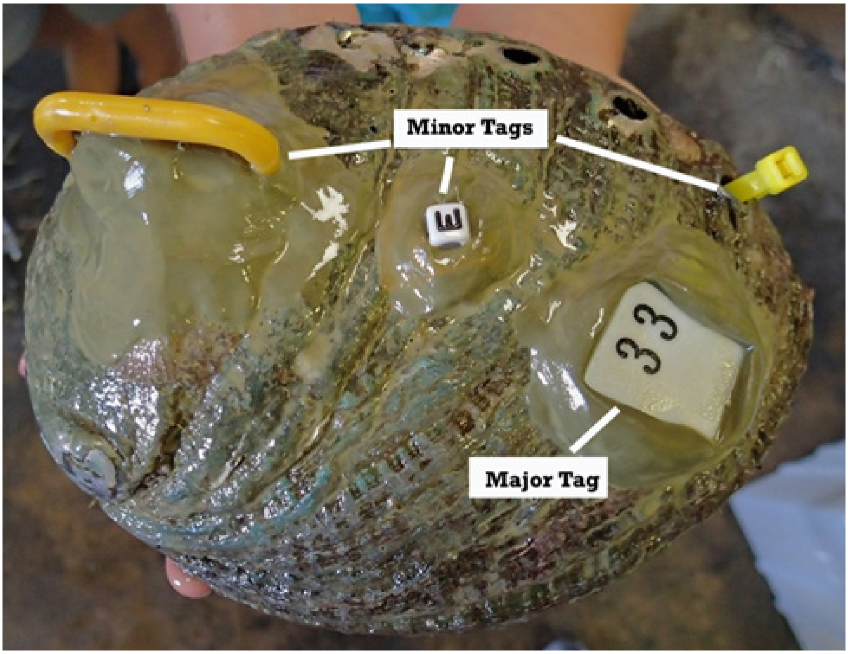

FIGURE 1.—Example of multiple tagging methods for green abalone outplants illustrating "Major" and "Minor" tags. Recorded as Major tag: #33, Minor tags "E", yellow chain link, yellow zip tie, and PIT tag # (in the epoxy).

Following the tagging activity, the animals were placed in rectangular plastic milk crates and submerged in a recirculating seawater holding systems (18 °C) for up to 13 days. The top of the milk crate was covered with plastic mesh so the animals could not crawl out. There was one mortality while in the holding tanks presumably due to stress related to shipment.

Outplanting.—Sixty-nine green abalone were outplanted in three batches in May 2013, July 2013, and August 2013 (Table 1). The animals were monitored for survival for one year after the last outplanting (until August 2014). On the day of outplanting, the animals were checked for health and for any tag loss, the milk crates were put into large coolers with seawater from the holding tanks and transported to the outplant site by car and then by boat. They were in transport for approximately three hours. While on board the boat, fresh ocean water was exchanged with the water in the cooler by bucket. Divers descended to the reef with the milk crates. When on the bottom, the milk crates were turned on their side and four half-sized cinder blocks were zip- tied to each milk crate to weigh them down. The first and third outplant sites offered more ledges and overhangs while the second outplanting area was on the top of the reef just above the other two. All of the locations chosen to place the crates on were within 5 m of each other on the west end of the reef (Figure 2). In accordance with the outplanting permit, as many abalone as possible were recovered from the test site at the end of the study. All animals were measured at the beginning of the study and emergent animals were measured at the end of the study. Volunteers were asked to not share the outplanting location with anyone. Temperature loggers (Hobo) were deployed from 01 April 2013 to 25 March 2014.

Monitoring.—Monitoring began with the first outplanting in May 2013 and concluded one year after the last outplanting in August 2014, representing a 15-month study period. Rigorous monitoring was required to track the newly released animals as they were very mobile. In order to track this movement, the program utilized volunteers. In total, 28 volunteers were trained as abalone observers. Each dive was led by the Get Inspired project biologist and assisted by up to four other volunteer divers. During each dive, a diver was assigned a quadrant number within which to survey the reef for abalone. Every visible tag

Table 1.—Proportion, by sex, of green abalone that were outplanted in three batches and their survival in Crystal Cove State Park, Orange County, California. Average size 16.2 cm.

Outplanted			
	Batch 1 5/26/13	**Batch 2 7/22/13**	**Batch 3 8/11/13**
Females	17	21	22
Males	2	1	6
Total	19	22	28
Survival 8/11/14			
Females	7	7	8
Males	1	0	5
Total	8	7	13

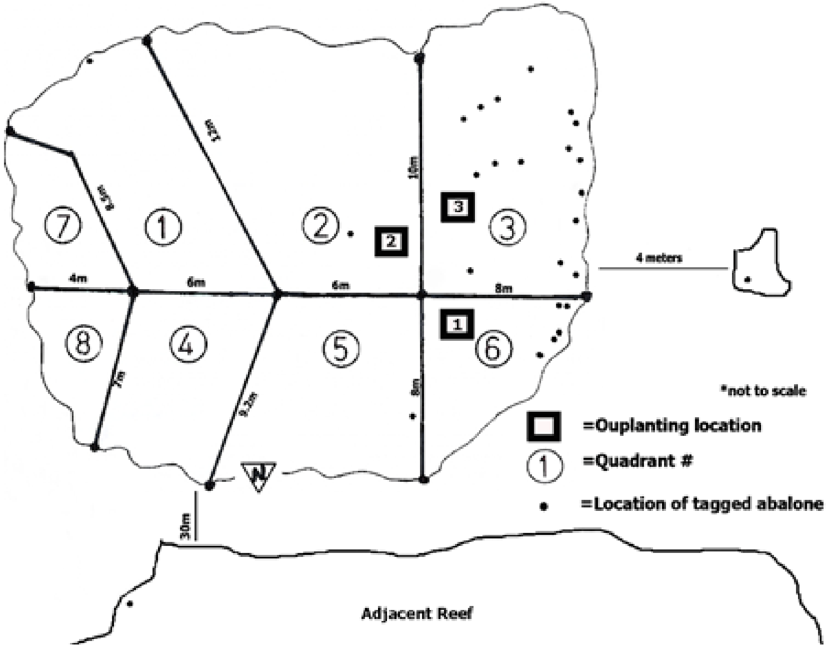

Figure 2.—Map of the relative locations of the surviving abalone created 11 August 2014.

on the animal was recorded and the shells and tags were cleaned with a toothbrush to reduce encrusting organisms. By recording every observable tag, even if a "Major" tag could not be seen, the combinations of other visible tags usually lead to the positive identification of a specific animal. If an abalone could not be positively identified, it was not counted that day. Empty shells and shell fragments were also collected for positive identification.

Over the 15-month (60 week) study period, 64 monitoring dives (approximately 45 min each) were made totaling 260 dive hours. Dives were conducted after each out-planting every 48-hours for approximately two weeks to track the immediate movements of the animals. Monitoring tapered off from every 48-hours to every four days, then once per week, then once every 10 days by the end of the study period. Telescoping mirrors and flashlights were used to look under ledges and in deeper crevices for abalone. A map of the location of each abalone was created/updated after each monitoring dive. An animated map was created, at the end of the project, to illustrate relative movements of the animals throughout the study period. Survival was calculated by finding and counting the actual live animals that were positively identified at the end of the study period.

Results

Site Survey.—The study site is composed of continuous rocky reef approximately 450 m^2 in size and surrounded by sand. The reef is composed of bedrock and roughly rect-angular with dimensions approximately 18 m wide by 25 m long, with the highest point being approximately 2 m from the sand that surrounds it. Changes in contour are minimal on the top of the reef with rugosity being less than 1 m. The south and north ends of the reef are composed of ledges, the west end gently slopes down toward the sand, the east end of the reef is a wall that drops 2.5 m vertically to the sand. The reef was at a relatively uniform depth of 8.4 m on the top of the reef and it slopes on each side to a maximum depth of 11.5 m to the sand on the east end. Due to sea urchin removal activities during a giant kelp restoration project conducted on the reef by the author 10 years earlier, sea urchin densities were low with lots of crevice and ledge space available.

Both site survey methods provided similar results with mature giant kelp (*Macrocystis pyrifera)* covering 10% of the reef providing a 30% canopy, reaching the surface over the reef. Approximately 15% of the reef was covered with pink crustose coralline algae, and articulated coralline algae covered 10% of the reef. Subtidal algae (*Cystoseira osmundacea)* covered 5% of the reef surface and other low lying red and brown alga covered 15% of the reef. The remaining 45% of the reef was occupied by sessile invertebrates including tunicates, bryozoans, worms (Serpulorbis sp.), gorgonians, anemones, and sponges. There were no wild abalone observed on this reef before outplanting. The average temperatures on the reef during outplating were as follows: May-18 °C, July-17.5 °C, August-15.8 °C

Tagging.—With continuous cleaning, the multiple tagging strategy worked well for the study period. Although the abalone routinely were wedged up and under rocks and ledges, the multi tag method allowed for identification of the animals from any angle. Only four of the major tags were lost due to poor epoxy application but the animals could still be identified by their minor tags. By the end of the project period, the brass tags (Major Tag) had tarnished making the numbers unreadable although we could still tell they were brass and coupled with the minor tags, each individual could still be identified. None of the zip ties or cyanoacrylate affixed tags were lost during the project period.

Monitoring and movements.—The milk crates allowed for the abalone to attach to something that could easily be moved, placed in a cooler, and transported to the study site with minimal stress to the animal. Upon release, most of the animals immediately moved out of the crates and even within the period of the dive (approximately 45 minutes) they moved up to 2 m away. All of the abalone left the milk crates within 48-hours of outplanting. Some made their immediate homes inside the cinderblocks that weighted down the milk crates so after the first outplanting batch we covered the cinderblocks so the abalone would be forced out onto the reef. All the abalone were released on the west end of the reef and subsequently 96% of the animals stayed on the west side of the reef within a 10 m radius of their release site, either under ledges or oriented at the sand reef interface during the project period. The farthest distance moved by an abalone was 44 m and the shortest distance moved was <1 m, both of which survived until the end of the project (Figure 2).

The PIT tag reader was only used once and was not effective at locating abalone during that one use. An animated map was created from each survey by compiling location information allowing us to see the relative movements of the animals over the course of the study. This animated map is available from the author.

Survival.—Mortality was closely associated with outplanting events with 61% of mortalities (17) occurring within the first 30 days of being outplanted and 9% (6) mortalities occurring in the first week of outplanting. Being out and on top of the reef (emergent) was not the key factor in mortality because several animals survived through the entire project while in conspicuous places on top of the reef. No direct predation was observed, although we did remove a giant sea star (*Pisaster giganteus*) from the shell of a live abalone. Thirteen mortalities were observed with crushed shells (Figure 3) and the meat gone, with the shell

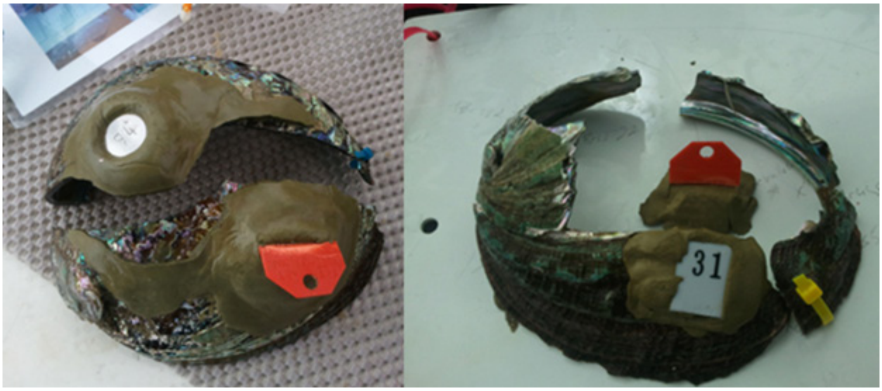

Figure 3.—Example of crushed shells which resulted in 13 mortalities, predator unknown.

fragments found in the same location that the live animal had been previously observed. The shell crushing predator was never observed.

During this 15-month study period, 28 animals (40%) survived (Table 1). We searched adjacent reefs and boulders off the study site. Two abalone were found on a boulder 4 meters away from the outplant reef. They migrated there independently over a two month period. Another abalone ventured across 10 m of sand, across 20 m of reef, then across another 4 m of sand to another adjacent reef. There were 13 animals or 19% of the original 69 that were missing and not accounted for at the end of the project. Some of these animals presumably could have survived. Of the 13 missing animals, seven went missing within 30 days of outplanting and were never seen again. Three of those abalone were missing from the first week of outplanting.

After observing the habitat preferences of the first two batches of outplanted abalone, we chose the third outplanting site to match that of the first. It was 5 m away from the first on the edge of the west end of the reef with many overhangs and ledges. The last batch of abalone (28), outplanted in August, had 46% survival (Table 1). At the end of the 15-month period, eight abalone were retrieved in accordance with CDFW permits. The other 20 were not retrievable due to their positioning on the reef. The average growth of those eight surviving and retrieved abalone was 2.2 mm over the study period. Two of the 13 missing abalone were found dead two months after the end of the study period.

Discussion

Based on findings from Tanaguchi et al. (2013), that green abalone expressed site infidelity when translocated; this survey site was specifically chosen because it was surrounded by sand. It was a disproven assumption that sand would act as a barrier and deter abalone movements. This finding presents a problem for future studies and may shed some light on previous studies where recapture rates were low. Green abalone will leave study sites even if it means crossing expanses of sand. It is possible more abalone emigrated from the survey site and these represent a proportion of the missing animals. Abalone movements and migrations are still poorly understood and continues to be a problem for abalone outplanting/reseeding efforts. Current telemetry will add new knowledge to this question.

Juvenile abalone of all species may move tens of meters, but this tendency decreases with age (Cox 1962, Tutschulte 1976). Adult abalone generally have very limited movements (Shepherd 1973, Tutschulte 1976). Abalone have been known to move considerable distances which has made previous restocking projects challenging and often ineffective (Shepherd 1986, Ault & DeMartini 1987, Tegner & Butler 1989). The majority of the abalone that survived until the end of this project appeared to move very little during the project period, though this also made them easier for divers to find repeatedly. After each survey, a map of the relative locations of the abalone was created. From this, we noted that 22 (79%) of the surviving abalone were within an 8 m radius of the release sights at the end of the project (Figure 2). Many did not appear to move at all from these scars during the entire study. This may be an advantage of using large adult green abalone. In a telemetry study, Coates et al. (2013) mentions a "flight" response when pink abalone were translocated, this was thought to occur within the first 20 days after moving the animals. The reported 61% of the abalone mortalities from this study, occurred in the first 30 days and may have been due to this "flight" response in the initial phase after outplanting.

The fact that the abalone used for this study were farm raised has not been shown to be a factor in their ability to hide (Tegner and Butler 1985, Schiel and Weldon 1987). It appears that abalone have home scars and possibly home ranges for localized movements (Ault & DeMartini 1987, Tutschulte and Connel 1988). Some of the abalone in this study found their home scars right away while others seemed to "roam" throughout the study period. The challenge is to determine how long it takes for introduced/outplanted large emergent adult abalone to get acclimated to their outplanted reef so they "settle" in fast and find a home scar. Ideally, it would be most advantageous to be able to place abalone directly onto their preferred home scar location in hopes that they would stay there when outplanted.

There were at least 13 known abalone mortalities which involved crushed shells and there were many more shell fragments found that could not be identified. Given that these abalone were large with a shell thickness of at least 3 mm, the list of possible predators was small. Very large bat rays and humans are capable of such crushing forces. Giant seabass are capable of both "sucking" them off the reef and inflicting the force necessary to crush the shells (L. Allen, California State University Northridge, personal communication). Often the crushed shell would be found with all the pieces in the same spot that the live abalone was seen just 48 hours before. In October 2013, suspecting poaching as the possible cause of the crushing mortalities, floating signs were posted around the reef warning humans that they were under surveillance and that they were violating the law by taking or killing the animals. It should be noted that within 30 days of the signs being put up, the crushing mortalities stopped. This could be coincidence. It should be noted, that in January 2014 a mortality event (sea star wasting disease), which affected the west coast of North America, resulted in a die-off of all sea star species observed on the reef (Hewson et al. 2014). Sea stars, therefore, were not a predator of concern during much of this study.

Difficulties involved in quantifying the results of outplanting and reseeding efforts make it difficult to make comparisons between studies (McCormick et al. 1994). A summary of abalone outplanting projects around the world, their duration, and percent survival was compiled by Chick et al. (2013). In comparison with those studies, this study has notable survival rates for the project duration (>1 year) and species outplanted, and also used the largest size abalone. Of the studies conducted with larger red and green abalone (40-100 mm) in southern California, survival rates were only as high as 2.8% and the researchers claimed they found no evidence of size differential in survival (Tegner and Butler 1985, Tegner and Butler 1989, Davis 1995). Although survival may be quantified using several different methods, it is important to note that the survival rates reported for this study are actual, not estimates. Each animal counted as a survivor was physically observed.

The frequency with which the animals in this study were surveyed was an advantage for monitoring their survival and it may have been the key to the high recapture rates. We were able to observe their movements regularly (at most every 10 days). With the success of tracking and survival of the animals in this study, it is evident that the strategy of using larger animals for restocking green abalone is worthy of further study. The survival rate for this project is notable and far exceeds survival rates in other studies with green abalone. The animals used in this study were estimated to be at least 10 years old (ranging in size from 14.6 cm to 17.9 cm) by the farmer from whom they were purchased. The costs associated with raising them to this size may be great but there have been decades of attempts to restock. One expensive project may be worth 30 or more failed larval or juvenile outplanting attempts. Perhaps, outplants could be clustered to create reproductive "colonies". The animals used in this study seem to be the largest used in a California abalone restocking/outplanting study. We are currently spawning wild abalone to repeat this test in a future study in several different locations and may include animals 10 cm to 14 cm.

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References

Allee, W. C. 1931. Animal Aggregations: A Study in General Sociology. University of Chicago Press, Chicago, USA.

Ault, J. S., and J. D. DeMartini. 1987. Movement and dispersion of red abalone, *Haliotis-rufescens*, in Northern California. California Fish and Game 73(4):196-213.

Babcock, R. C., and J. Keesing. 1999. Fertilization biology of the abalone *Haliotis laevigata*: laboratory and field studies. Canadian Journal of Fisheries and Aquatic Sciences 56:1668-1678.

Breen, P. A. 1992. A review of models used for stock assessment in abalone fisheries. Pages 253-275 *in* S. A. Shepherd , M. J. Tegner, and A. Guzman del Pro´o, editors. Abalone of the world: biology, fisheries and culture. Fishing News Books, Oxford, United Kingdom.

Campbell, A. (Editor). 2000. Workshop on rebuilding abalone stocks in British Columbia. Canadian Special Publication of Fisheries and Aquatic Sciences 130:1-150.

Chick, R. C., D.G. Worthington, and M. J. Kingsford. 2013. Restocking depleted wild stocks - Long term survival and impact of released Blacklip abalone (*Haliotis rubra)* on depleted wild populations in New South Wales, Australia. Reviews in Fisheries Science 21:3-4, 321-340.

Coates, J. H., K. A. Hovel, J. L. Butler, A. P. Klimley, and S. G. Morgan. 2013. Movement and home range of pink abalone *Haliotis corrugata*: implications for restoration and population recovery. Marine Ecology Progress Series 486:189-201.

Cook, P. A. 2014. The Worldwide Abalone Industry. Modern Economy. 5:1181-1186. Available from: http://dx.doi.org/10.4236/me.2014.513110.

Cox, K.W. 1962. California abalones, family Haliotidae. California Fish and Game, Fish Bulletin 118:1-133.

Davis, G. E. 1995. Recruitment of juvenile abalone (*Haliotis spp*) measured in artificial habitats. Marine and Freshwater Research 46:549-554.

Davis, G. E., P. L. Haaker, D.V. Richards. 1998. The perlious condition of white abalone, *Haliotis sorenseni* Bartsch 1940. Journal of Shellfish Research 14:871-876.

Henderson, K. C., D. O. Parker, and P. L. Haaker. 1988. The survival and growth of transplanted adult pink abalone, *Haliotis corrugata*, at Santa Catalina Island. California Fish and Game 74:82-86.

Hewson, I., J. B. Button, B. M. Gudenkauf, B. Miner, A. L. Newton, J. K. Gaydos, J. Wynne, C. L. Groves, G. Hendler, M. Murray, S. Fradkin, M. Brieitbart, E. Fahsbender, K. D. Lafferty, A. M. Kilpatrick, C. M. Miner, P. Raimondi, L. Lahner, C. Friedman, S. Daniels, M. Haulena, J. Marliaye, C. A. Burge, M. E. Eisenlord, and C. D. Harvell. 2014. Densovirus associated with sea star wasting disease and mass mortality. Proceedings of the National Academy of Sciences of the United States of America 111 (48) 17278-17283.

Kojima, H. 1981. Mortality of young Japanese black abalone *Haliotis discus discus* after-transplantation. Bulletin for the Japanese Society for the Science of Fish 47:151-159.

Leighton, D. 2000. The biology and culture of the California abalones. Dorrance Publishing, Pittsburg, Pennsylvania, USA.

McCormick, T. B., K. Herbinson, T. S. Mill, and J. Altick. 1994. A review of abalone seeding, possible significance and a new seeding device. Bulletin of Marine Science 55(2-3):680-693.

National Oceanic and Atmospheric Administration (NOAA). 2004. Endangered and Threatened Species; Establishment of Species of Concern List, Addition of Species to Species of Concern List, Description of Factors for Identifying Species of Concern, and Revision of Candidate Species List Under the Endangered Species Act. Federal Register /Notices/Vol. 69, No. 73, Doc. # 04-8593, 19975 -19979.

Prince, J. D., T. L. Sellers, W. B. Ford, S. R. Talbot. 1988. Confirmation of a relationship between the localized abundance of breeding stock and recruitment for *Haliotis rubra Leach* (Mollusca: Gastropoda). Journal of Experimental Marine Biology and Ecology. 122:91-104.

Rogers-Bennett, L., and J. S. Pearse. 1998. Experimental seeding of hatchery reared juvenile red abalone in northern California. Journal of Shellfish Research 17:877-880.

Rogers-Bennett, L., P. L. Haaker, T. O. Huff, and P. K. Dayton. 2002. Estimating baseline abundances of abalone in California for restoration. California Cooperative Oceanic Fisheries Investigations Report 43:97-11.

Rogers-Bennett, L., B.L. Allen, and G.E. Davis. 2004. Measuring abalone (*Haliotis Spp.*) recruitment in California to examine recruitment, overfishing, and recovery criteria. Journal of Shellfish Research Vol 23-4, 1201-1207.

Saito, K. 1984. Ocean ranching of abalones and scallops in Northern Japan. Aquaculture 39:361-373.

Schiel, D. R. 1993. Experimental evaluation of commercial-scale enhancement of abalone *Haliotis iris* populations in New Zealand. Marine Ecology Progress Series 97:167-181.

Schiel, D.R. and B. C. Weldon. 1987. Responses to predators of cultured and wild red abalone *Haliotis rufescens* in laboratory experiments. Aquaculture 60:173-188.

Sercy-bernal, R., C. Anguiano-Beltran, J. A Espinoza-Montes, and Eugenio Carpizo-Ituarte. 2013. Restocking of Abalone populations (*Haliotis Spp.*) in Mexico. Journal of Shellfish Research 32:189-195.

Shepherd, S. A. 1973. Studies on southern Australian abalone (Genus *Haliotis*). Ecology offive sympatric species. Australian Journal of Marine and Freshwater Research 24:217-257.

Shepherd, S. A. 1986. Movement of the Southern Australian abalone *Haliotis levitates* in relation to crevice abundance. Australian Journal of Ecology 11:295-302.

Shepherd, S. A., and P. A. Breen. 1992. Mortality in abalone: its estimation, variability and causes. Pages 276-304. in S. A. Shepherd, M. J. Tegner, and A. Guzman del Pro´o, editors. Abalone of the world: biology, fisheries and culture. Fishing News Books, Oxford United Kingdom.

Shepherd, S. A. and S. Daume. 1996. Ecology and survival of juvenile abalone in a crustose coralline habitat in South Australia. Pages 297-313. in Y. Watanabe, Y. Yamashita, and Y. Oozeki, editors. International Workshop: Survival strategies in early life stages of marine resources. Balkema, Rotterdam, Netherlands.

Taniguchi, I. K., D. Stein, K. Lampson, and L. Rogers-Bennett. 2013. Testing translocation as a recovery tool for pink (*Haliotis corrugata*) abalone in southern California. Journal of Shellfish Research 32:209-216.

Tegner, M. J. 1992. Brood-stock transplants as an approach to abalone stock enhancement. Pages 461-473 in S. A. Guzman del Pro´o, editor. Abalone of the world: biology, fisheries and culture. Fishing News Books, Cambridge, Massachusetts, USA.

Tegner, M. J. 2000. Abalone (*Haliotis spp*.) enhancement in California: What we've learned and where we go from here. Canadian Special Publication of Fisheries and Aquatic Sciences 130:61-71.

Tegner, M. J. and R. A. Butler. 1985. Drift-tube study of the dispersal potential of green-abalone (*Haliotis fulgens*) larvae in the southern California Bight: Implications for recovery of depleted populations. Marine Ecology Progress Series 26:73-84.

Tegner, M. J. and R. A. Butler. 1989. Abalone seeding. Pages 157-182 *in* K. Hahn, editor. Handbook of culture of Abalones and other Gastropods. CRC Press, Boca Raton, Florida USA.

Tutschulte, T. C. 1976. The comparative ecology of three sympatric abalone. Ph.D. dissertation, University of California, San Diego, USA.

Tutschulte T.C. and J. H. Connell. 1988. Feeding behavior and algal food of three species of abalones (*Haliotis*) in southern California. Marine Ecology Progress Series 49:57–64.

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Research Article

Distribution patterns of the non-native seaweeds *Sargassum horneri* (Turner) C. Agardh and *Undaria pinnatifida* (Harvey) Suringar on the San Diego and Pacific coast of North America

Nikolas John Kaplanis*, Jill L. Harris and Jennifer E. Smith
Scripps Institution of Oceanography, University of California, San Diego, USA
**Corresponding author*
E-mail: nikokaplanis@gmail.com

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Abstract

Here we report the occurrence of the two non-native brown macroalgal species *Sargassum horneri* (Turner) C. Agardh and *Undaria pinnatifida* (Harvey) Suringar in San Diego County and describe expansions in their ranges and new invasions on the California and Baja California coasts. Both species have exhibited characteristics of successful invaders: establishing in new areas, spreading locally, and persisting through multiple generations in areas that have been invaded. These species now occur primarily in harbors, but have also invaded open coast sites, suggesting that they can invade areas with relatively high wave action and with well-established native benthic communities. The rapid and uncontrolled spread of these species to date has serious implications for their expansion along the west coast of North America. The ecological and economic consequences of these invasions require further research.

Key words: invasive algae, macroalgae, California, Channel Islands, Cabrillo National Monument

Introduction

Marine algal invasions have become a pervasive problem. Diverse impacts include reductions in biodiversity and the abundance and performance of native species as well as changes in community structure and function (Walker and Kendrick 1998; Thresher 2000; Inderjit et al. 2006; Schaffelke et al. 2006; Valentine et al. 2007). Marine algal invasions can also threaten economically important species and industries such as aquaculture and tourism (Schaffelke et al. 2006). However, relatively few studies have comprehensively analyzed these invasions or addressed their effects (Nyberg and Wallentinus 2005; Inderjit et al. 2006; Schaffelke et al. 2006; Johnson and Chapman 2007; Schaffelke and Hewitt 2007; Valentine et al. 2007; Smith 2011). As a result, many gaps exist in our current knowledge of how specific non-native seaweeds affect indigenous ecosystems and the economies that depend on them.

Despite the fact that hundreds of species of non-native seaweeds have been documented around the world, research to date has largely focused on a small fraction of these species and a limited number of invasion locations, or has simply documented occurrence without analyzing patterns of distribution or change over time (Inderjit et al. 2006; Johnson and Chapman 2007; Williams and Smith 2007). Consequently, very little is known about the natural history of non-native algal species in their invaded environments and their interactions with recipient environments, both important elements known to influence invasion success (Valentine et al. 2007). Studies that document species-and-region-specific patterns of establishment, spread, and persistence are a crucial first step in closing major gaps in our knowledge of the invasion process. Further, because invasions often proceed rapidly it is important to gain a better understanding of how new invaders spread in the early stages of establishment.

Southern California and the surrounding coastline have received multiple high-profile invasive algal species, but little information is available about the invasion dynamics of these taxa. A recent review by Miller et al. (2011) reports 27 non-native seaweed species in California and 11 in Baja California, 9 of which are common to both areas. Most of these have been discovered in the last 30 years, and while the rate of introductions may not necessarily be increasing, climate change may increase the establishment of non-native species in Southern California and Baja California (Carlton 2000; Harley et al. 2006; Miller et al. 2011). This area has been invaded by some of the most high profile algal invaders in the world. *Caulerpa taxifolia* (M.Vahl) C.Agardh was first detected in two locations in Southern California in 2000 but was contained and successfully eradicated by 2006 (Jousson et al. 2000; Anderson 2005; Smith 2011). Other successful invaders include *Undaria pinnatifida* (Harvey) Suringar, first noted in 2000 (Silva et al. 2002), the globally invasive alga *Sargassum muticum* (Yendo) Fensholt, which was first noted in the 1970's and which has since become naturalized in this area (Norton 1981; Miller et al. 2007), and *Sargassum horneri* (Turner) C.Agardh, first noted in 2003 (Miller et al. 2007). Despite the long invasion history of this area, the dynamics and ecology of the non-native seaweeds in this region remain relatively unexplored.

Undaria pinnatifida is an aggressive invader worldwide, having colonized Argentina, New Zealand, Australia, Atlantic Europe, and the Mediterranean Sea (Silva et al. 2002; Nyberg and Wallentinus 2005). Its alarming rate of spread and ability to occupy and alter a variety of native systems have made this species one of only two algae on the International Union for the Conservation of Nature (IUCN) list of 100 most invasive species on the planet (Lowe et al. 2000). *Undaria pinnatifida* exhibits opportunistic life history traits that contribute to its successful establishment in new areas: a short, annual life span (Schaffelke et al. 2005; Miller and Engle 2009), high growth rate and fecundity, (Schaffelke et al. 2005; Valentine et al. 2007), and both a small and large dispersal shadow (Forrest et al. 2000). Serious negative ecosystem effects of this species - including reductions in native seaweed diversity- have been documented in shallow coastal communities elsewhere (Casas et al. 2004; Farrell and Fletcher 2006; Schaffelke and Hewitt 2007; Williams and Smith 2007). Because of the lack of knowledge of *U. pinnatifida* on the Pacific coast of North America and the potential for significant impacts of its further spread, we document the current distribution of this species in this region in the early stages of invasion.

In the early 20th century, *Sargassum muticum* was introduced to North America from northeast Asia and quickly spread throughout the west coast, reaching southern California in the early 1970's (Miller et al. 2007). This species is a highly successful invader worldwide and is considered to be naturalized in intertidal and subtidal communities throughout southern California (Harries et al. 2007; Miller et al. 2007). Some of the ecological effects of this species, such as reduction of native algal abundance and inhibition of native kelp recruitment have been assessed in Washington, California, and Baja California (Norton 1977; Ambrose and Nelson 1982; Espinoza 1990; Aguilar-Rosas and Machado Galindo 1990; Britton-Simmons 2004). Yet despite its widespread presence in southern California, there have been few studies examining the effects of this naturalized species in this area (Deysher and Norton 1982; Miller et al. 2011) or its current distribution.

Sargassum horneri was first discovered in Long Beach Harbor in 2003 (Miller et al. 2007), the first instance of this species outside of its native range (Miller et al. 2007). *Sargassum horneri* is one of the most abundant members of the algal community in temperate areas of Japan and Korea (Choi et al. 2003; Pang et al. 2009). This alga is an ecosystem engineer in these areas, growing up to 5 m tall in dense forests that provide habitat and spawning grounds for a diverse assemblage of organisms (Choi et al. 2003; Choi et al. 2008). *Sargassum horneri* is known for its high reproductive capacity, ability to rapidly colonize new areas, and fast growth rate (3–5 m in 10 months) (Choi et al. 2003). Due to its life history characteristics and its rapid spread in the short time frame since its original introduction, *S. horneri* is recognized as having the potential to be highly invasive in Southern California, Baja California, and other areas along the west coast of North America (Nyberg and Wallentinus 2005; Miller et al. 2011). Despite the rapid invasion of *S. horneri*, little is known about its current distribution and ecological impacts in southern California and Baja California.

The goal of this study was to provide detailed information on the distribution of *S. horneri* and *U. pinnatifida* on the San Diego County coast, and to analyze patterns of establishment, spread, and persistence of these seaweeds along the California and Baja California coasts. Specifically, our first goal was to describe the distribution of these non-native algae in San Diego County. Second, we documented how the presence of these species has changed with regard to: the number of locations they have become established; spread of populations within invaded sites; and persistence of populations. Third, we compared invasion locations to ascertain whether certain habitats appear to be more invasion prone than others. Finally we assess the occurrence of these species in San Diego County within the context of the invasion of the broader California and Baja California coastlines.

Methods

We used three approaches to describe the distribution, abundance, and invasion patterns of non-native macroalgae in San Diego and the broader region: broad-scale qualitative presence/absence surveys; smaller-scale quantitative benthic community surveys; and a synthesis of published and unpublished literature.

Site selection

Thirty-two sites (10s of m in extent) in eight locations (1–10 km apart, Figure 1) in San Diego County were assessed (n=1–7 sites per location, depending on availability of suitable habitat within each location). Surveys were initially conducted in January 2012 at Mariner's Cove, Mission Bay, where the first population of *S. horneri* was discovered. Four additional sites with rip-rap substrate similar to Mariner's Cove were surveyed between February and July 2013 (Supplementary material Table S1). In July 2013, permanent sites for qualitative and quantitative surveys were established. These sites were located between Oceanside Harbor and San Diego Bay. All sites were then surveyed during summer 2013 (23 July 2013 – 7 August 2013), winter 2013 (8 December 2013 – 20 December 2013), and summer 2014 (2 July 2014 – 1 August 2014).

Survey locations were grouped into three site types based on site characteristics: harbors (n=3), open coast jetties (n=2), and natural open coast locations (n=3). Harbor locations included San Diego's three main harbors: Oceanside Harbor, Mission Bay, and San Diego Bay. The two open coast jetties, Ponto Jetty and Del Mar Rivermouth were located between Oceanside Harbor and Mission Bay. Open coast locations were La Jolla Cove in the Matlahuayl State Marine Reserve, Bird Rock in the South La Jolla State Marine Reserve, and the Cabrillo National Monument State Marine Reserve. Because it is an area of special ecological and management interest, Cabrillo National Monument was surveyed five times: fall 2013 (20 October 2013) and spring 2014 (2 April 2014) and the three survey rounds listed above.

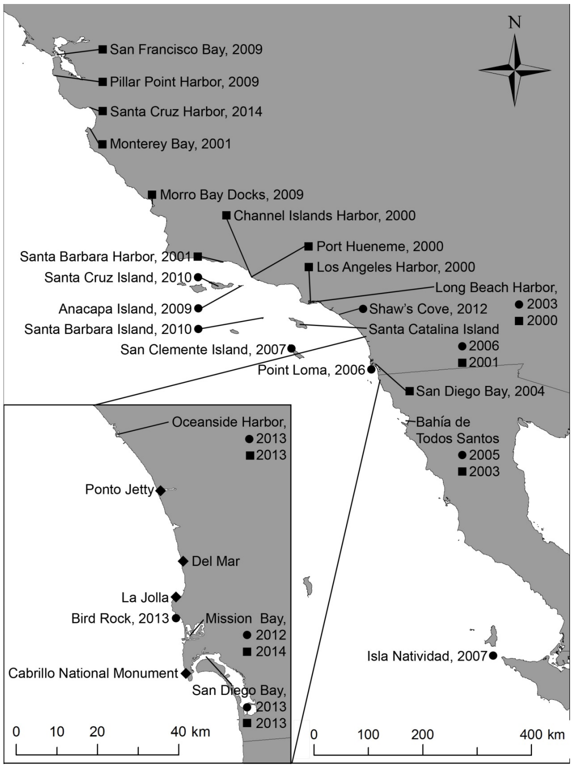

Figure 1. Map of locations where the non-native algae: *S. horneri* (circles) and *U. pinnatifida* (squares) have been documented; diamonds indicate locations where no non-native seaweeds were documented. The larger map presents results from our literature review and from herbarium collections while the inset map presents results from our survey of San Diego County. The year where each species was first documented is also shown for each location.

Within each of the eight locations, survey sites were established on hard bottom substrate suitable for the growth of macroalgae. Harbor and jetty sites were established on rip-rap rock that typically terminated in sand at maximum depths of 5 m. For open coast locations, survey sites were chosen from a habitat map generated in ArcGIS with LIDAR data. Fifteen stratified random coordinates in each open coast location were generated then ground-truthed for suitability (hard substrate, depths from 0–5m). From these, three points in each location were randomly selected as survey sites.

Qualitative surveys

Rapid qualitative surveys were conducted at 32 sites across all eight locations (Table S1) to note the establishment of populations at new sites and to describe how established populations were

Table 1. Summary information from presence-absence surveys with estimated peak abundance (# stipes / site) of non-native brown macroalgae at survey sites for all sampling rounds (Winter / Summer 2012–2014). Sites that were not sampled are shown with "ns", white indicates absence of non-native macroalgae, light grey indicates *S. horneri* was found, dark grey indicates *U. pinnatifida* was found, and black indicates both species were found concurrently. Categorical abundances are shown as follows: absent (-); 1–10 stipes (+); 11–100 stipes (++); 101–1000 stipes (+++); >1000 stipes (++++).

Location	Site	Winter 2012	Spring 2013	Summer 2013	Winter 2013	Summer 2014	*S. horneri*	*U. pinnatifida*
Oceanside Harbor	Oceanside Harbor North	ns	ns				-	+
	Oceanside Harbor, Marker 6	ns					-	++
	Oceanside Harbor, Marker 4	ns					+	++
	Oceanside Harbor Docks	ns					-	++
Ponto Jetty	Ponto Jetty	ns					-	-
Del Mar	Del Mar Rivermouth	ns					-	-
	9th Street	ns	ns				-	-
	Flat Rock, Torrey Pines	ns	ns				-	-
La Jolla	Dike Rock, Scripps	ns	ns				-	-
	La Jolla Cove East	ns					-	-
	La Jolla Cove West	ns					-	-
	La Jolla Cove Central	ns					-	-
	Boomers Cove	ns	ns				-	-
	Casa Cove	ns	ns				-	-
	Marine Street	ns	ns				-	-
Bird Rock	Bird Rock North	ns	ns				-	-
	Bird Rock Central	ns	ns				++++	-
	Bird Rock South	ns	ns				++++	-
Mission Bay	Mission Point						++++	-
	Hospitality Point	ns	ns				++++	-
	Vacation Island	ns	ns				++++	-
	Quivira Basin	ns	ns				++++	++
San Diego Bay	Harbor Island East	ns	ns			ns	-	+
	Harbor Island Central	ns	ns				-	+
	Harbor Island West	ns					-	-
	Shelter Island North	ns					++++	-
	Shelter Island South	ns	ns				++++	-
	Marina Park, Seaport Village	ns	ns				-	-
	Coronado Ferry Terminal	ns	ns				-	++
Cabrillo Natl. Monument	North Cabrillo	ns	ns				-	-
	Central Cabrillo	ns	ns				-	-
	South Cabrillo	ns	ns				-	-
	# locations where non-native seaweeds found:	1	4	3	10	13	9	8

spreading in spatial extent through time for large swaths of coastline. At each site, we searched for *S. horneri* and *U. pinnatifida* at depths of 0–5 m along as much of the coastline as possible, using SCUBA in some sites to access deeper reefs. Hard bottom substrates in harbors, including harbor breakwalls and jetties, rip-rap, and along docks and dock pilings, were searched. At open coast sites (including jetties), hard bottom substrata was searched, with a special focus on areas of low wave exposure.

Presence-absence and relative abundance (<10, 11–100, 101–1000, >1000 stipes per site) of *S. horneri* and *U. pinnatifida* were recorded. When either of these species was encountered, habitat characteristics (depth, substrate type, exposure to current and waves) and size and reproductive status of the algae also were recorded.

Quantitative surveys

Quantitative surveys were conducted at twenty sites across all eight locations (Table S1) to describe changes in non-native algal density through time and to determine if patterns of density and distribution existed with respect to benthic composition of survey locations. At each site, three 5 m transects were set 5 to 10 m apart, perpendicular to shore from 0–5 m depth. In five 1-m^2 quadrats placed on alternating sides of each transect line, brown macroalgal taxa (> 10 cm tall) were identified to species and the number of stipes was counted. In each quadrat, visual estimates of percentage of substrate covered were also made to the functional group level, which included all abiotic (bare rock, sand, shell), and biotic (articulated coralline algae, crustose coralline algae, fleshy crust, turf algae, brown, green and red fleshy macroalgae, seagrass, and sessile benthic invertebrates) components of the benthic community. Quadrats that contained substrate unsuitable for the growth of macroalgae (100% sand) were removed from the data set so that densities were reported per area of available hard bottom habitat.

Statistical analysis

Our hierarchical sampling scheme was designed to allow comparisons of non-native algal populations at the site, location, and site type (harbor versus open coast) level. To compare densities of native, non-native, and non-native naturalized brown algae (*S. muticum*) among sites, mean site-level stipe densities (# stipes / m^2) were calculated for each site and sampling round. To compare non-native algal abundance between site types, a three-factor analysis of variance (ANOVA) was used with site type and sampling round as fixed effects and location as a random effect nested within site type. Jetties were not included in the comparison among site types due to the low number of jetty sites (n=2). To explore how algae may use space in different habitats, we plotted native versus non-native site-level mean stipe densities for each sampling round.

Benthic cover data from quantitative surveys were examined using principal components analysis (PCA). Scores along the first PC axis were used to examine if densities of native, non-native naturalized or non-native taxa were related to benthic composition across our data set. Statistical analyses were performed using SigmaPlot 13 (Systat Software Inc., San Jose, California, USA) and JMP 12 (SAS Institute Inc., Cary, North Carolina, USA).

Literature review and synthesis

To provide an updated regional distribution for both species, all published and unpublished accounts of *S. horneri* and *U. pinnatifida* on the Pacific coast of North America were gathered from ISI Web of Science and Google Scholar, the University of California Herbarium database (https://webapps.cspace.berkeley.edu/ucjeps/publicsearch/publicsearch/), and personal correspondence with researchers. Web of Science and Google Scholar were searched using the key words: Baja California, California, distribution, invasive algae, *Sargassum horneri*, and *Undaria pinnatifida*. Discovery dates, identifier, location, latitude/longitude, and any depth, habitat and density information were recorded.

Results

San Diego County distribution

Sargassum horneri was found at 28% of the thirty-two sites and *U. pinnatifida* was found at 25% of the sites (Table 1). In all cases, non-native algae were found at sites where they had not previously been documented. Overall, non-native algae occurred in 43.75% of San Diego sites surveyed, and occurred disproportionately in harbor sites, with 86.7% of harbor sites having non-natives present at some point during sampling. These two invaders were found at 13.3% of open coast sites and never found to occur in jetty sites. Both species occurred together at two of San Diego's three harbors, Oceanside Harbor, and Mission Bay. In general, native brown macroalgal species dominated at our survey sites, contributing 56.7 ± 1.94% (mean ± SE) of all macroalgal stipes. The non-native naturalized alga (*S. muticum*) made up 29.1 ± 1.74%, and non-native brown macroalgae made up 14.2 ± 1.31% of stipes. For the individual non-native macroalgal species, *S. horneri* contributed 12.4 ± 1.26%, and *U. pinnatifida* made up 1.8 ± 0.47% of macroalgal stipes across all study sites.

Establishment of new populations in San Diego through time

The number of sites where *S. horneri* was found increased during our study from one to nine sites (Table 1). On 15 January 2012, *S. horneri* was discovered at a single site at Mission Point in Mission Bay. Spring 2013 surveys documented no new populations of *S. horneri,* though a second survey of Mission Point revealed a persistent, dense and localized population. All *S. horneri* populations discovered during our survey effort persisted throughout the duration of the study. During our first comprehensive survey of thirty-two sites (summer 2013), *S. horneri* was found at two new sites, in Bird Rock South, an open coast site in Bird Rock, and on the south end of Shelter Island in San Diego Bay (Table 1). At Bird Rock, juvenile *S. horneri* thalli were found in the 3–5 m depth range on cobble coated in crustose coralline algae. This was the only open coast location to have *S. horneri* throughout our survey. At Shelter Island, *S. horneri* was found growing at depths of 1–5 m along the rip-rap breakwall on the south end of the island near the marina in an area of high boat traffic.

During the winter 2013 survey, *S. horneri* was found at five new sites (Table 1). The species appeared intermingled with native algae in a small patch near the mouth of Oceanside Harbor (Oceanside Harbor North). The previously localized population at Bird Rock South spread to the Bird Rock Central site. *Sargassum horneri* was also found at three new sites in Mission Bay: at Hospitality Point, in the boat marina at Quivira Basin, and on a rip-rap breakwall near the boat ramp at Vacation Island.

During our final comprehensive sampling round, summer 2014, *S. horneri* was found at one new site, Shelter Island North. While in past surveys the species was localized at Shelter Island South, during this final survey it was observed growing along the entire length of the harbor breakwall.

Overall, we found *U. pinnatifida* at eight sites in San Diego County, and the number of sites in which it was present increased through time (Table 1). *Undaria pinnatifida* was first found at three sites in Oceanside Harbor in spring 2013: near the mouth of the harbor on a rip-rap breakwall (Oceanside Harbor, Marker 6), deeper in the harbor on rocks surrounded by soft muddy substrate, (Oceanside Harbor, Marker 4), and attached to the underside of 10–15 docks within the marina (Oceanside Harbor Docks). *Undaria pinnatifida* was not found at any site during the summer 2013 survey, including the Oceanside Harbor sites. During the winter 2013 survey, *U. pinnatifida* was found at the eastern end of Harbor Island and at the Coronado Ferry Terminal. At Harbor Island we found a group of large isolated thalli (approx. 1–2 m length) on a rip-rap breakwall, a cement breakwall, and on pilings. In Coronado, *U. pinnatifida* was observed on the underside of the ferry landing docks. In summer 2014, *U. pinnatifida* reappeared in Oceanside Harbor at the same three sites it was previously found and was found at Quivira Basin in Mission Bay and the central part of Harbor Island.

Spatial spread at sites through time

Within established sites, *S. horneri* consistently increased its spatial extent through time. At Mission Point in Mission Bay, this species was initially confined to a small section of protected rip-rap within Mariner's Cove growing on bare rock in an area sparsely populated by *S. muticum* and the native species *Dictyopteris undulata* Holmes and *Dictyota flabellata* (F.S. Collins) Setchell and N.L. Gardner. Further west on the harbor breakwall, where tidal current flows are much higher, and where native kelps (e.g. *Macrocystis pyrifera* (Linnaeus) C.Agardh, *Egregia menziesii* (Turner) Areschoug, and *Eisenia arborea* (Areschoug) occur in higher density than on the inner breakwall, no *S. horneri* was found. This population remained localized between January 2012 and spring 2013, but in summer 2013 the length of the breakwall occupied by *S. horneri* had expanded by roughly 0.33 km, with new recruits occurring in patches moving outward toward the mouth of Mission Bay. During winter 2013, these recruits developed into mature and fertile adult thalli, which then produced another cohort of recruits approximately 0.6 km further west on the breakwall in summer 2014.

A clear pattern of population expansion with each recruitment cycle was also observed at other sites. At Hospitality Point the population on the inner breakwall spread westward toward the mouth of the harbor with each recruitment cycle. At Shelter Island, the species spread from the south end of the island north, eventually reaching the north end by winter 2013. At Bird Rock, the population was discovered in a small patch at the center of the cove in summer of 2013, but eventually occupied the majority of the cove by winter 2013, again spreading with each recruitment event.

In contrast, *Undaria pinnatifida* occurred in low density populations that remained localized through time. At all sites where it was observed, densities were highest in spring to late summer, following the annual pattern of recruitment and development seen in native populations (Saito 1975) and previously observed in Santa Barbara Harbor (Thornber et al. 2004) and at Santa Catalina Island (Miller and Engle 2009). While other populations die off entirely in the late summer or early fall (Miller and Engle 2009), mature reproductive adults were observed in low densities year round in San Diego locations.

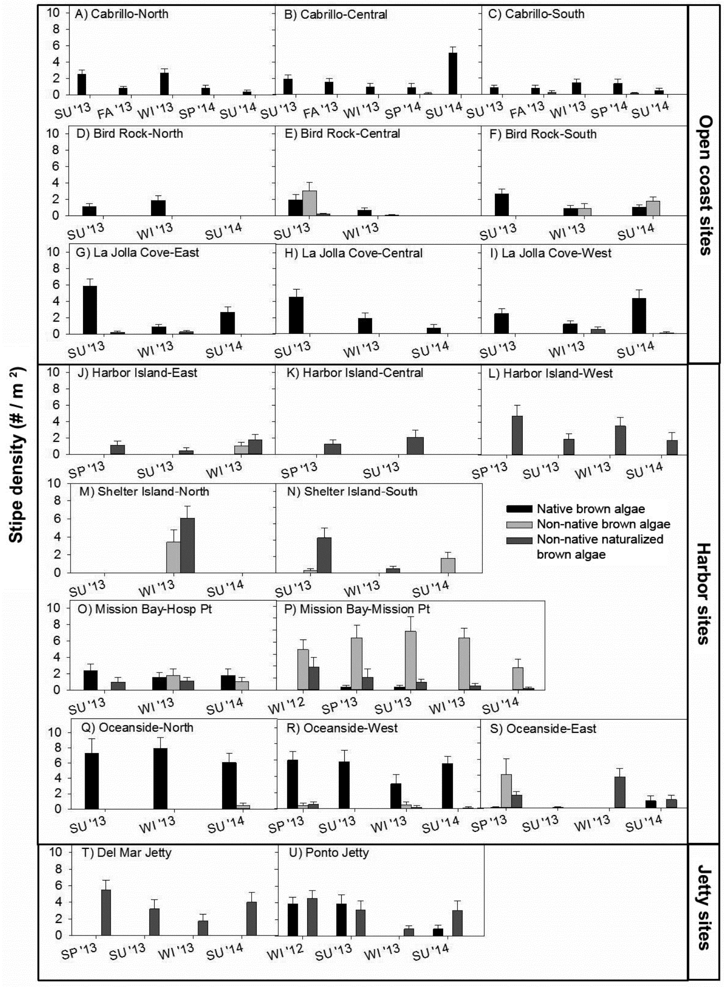

Figure 2. Mean density (± SE) of native (black), non-native (*S. horneri* and *U. pinnatifida,* light grey), and non-native naturalized (*S. muticum,* dark grey) brown macroalgae at quantitative survey sites in San Diego County during each survey round (Winter 2012, Spring 2013, Summer 2013, Fall 2013, Winter 2013, Spring 2014, Summer 2014 (abbreviated in figure)) and grouped by site type.

Changes in density through time

Despite an increase in both the number of sites where *S. horneri* and *U. pinnatifida* were present, and in the spatial extent of their populations, the density at each site did not increase for either species (Figure 2). At Bird Rock central and Bird Rock south (Figure 2E and F), the open coast sites where *S. horneri* was found, populations were patchy and densities were consistently low. Harbor sites had persistent but consistently low density populations of *S. horneri* (Shelter Island North and South, Figure 2M and N, and Hospitality Point, Figure 2O) and *U. pinnatifida* (Harbor Island East, Figure 2J). Finally, at Mission Point (Figure 2P) *S. horneri* densities were consistently higher than any other site, with the mean density ranging between 4.31 ± 1.54 stipes/m^2 (summer 2014) and 10.08 ± 1.53 stipes/m^2 (winter 2013).

Habitat type and benthic composition

Mean stipe densities of non-native species were significantly higher at harbors than at open coast sites (Table 2). Overall mean stipe densities (stipes / m^2 ± SE) for the Summer 2013, Winter 2013, and Summer 2014 survey rounds were 1.03 ± 0.97, 1.91 ± 1.10 and 1.11 ± 0.56 for harbors, and 0.0 ± 0.0, 0.47 ± 0.35, and 0.20 ± 0.20 for open coasts. There was significant variation in density of non-native species among sites within locations and among locations within site type. There were no differences in non-native species densities among sampling rounds, nor was there an interaction between site type and sampling round. Harbor sites exhibited either high native stipe densities or high non-native stipe densities, and no site had high densities of both concurrently (Figure 3). Open coast sites had low densities of non-native species and a range of densities of

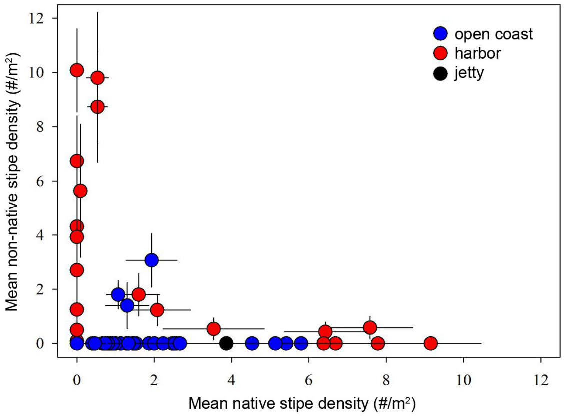

Figure 3. Mean (± SE) native vs. non-native algal stipe density (stipes/m^2) for open coast sites (blue circles), harbor sites (red circles), and jetty sites (black circles).

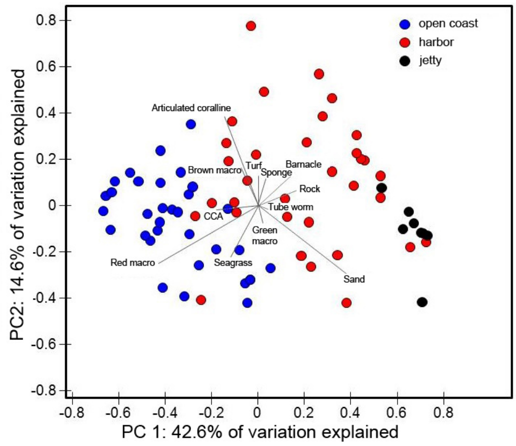

Figure 4. Principal component analysis (PCA) of major benthic groups from all sites with benthic cover survey data (n = 32 (open coast, blue), n = 34 (harbor, red), n= 8 (jetty, black)).

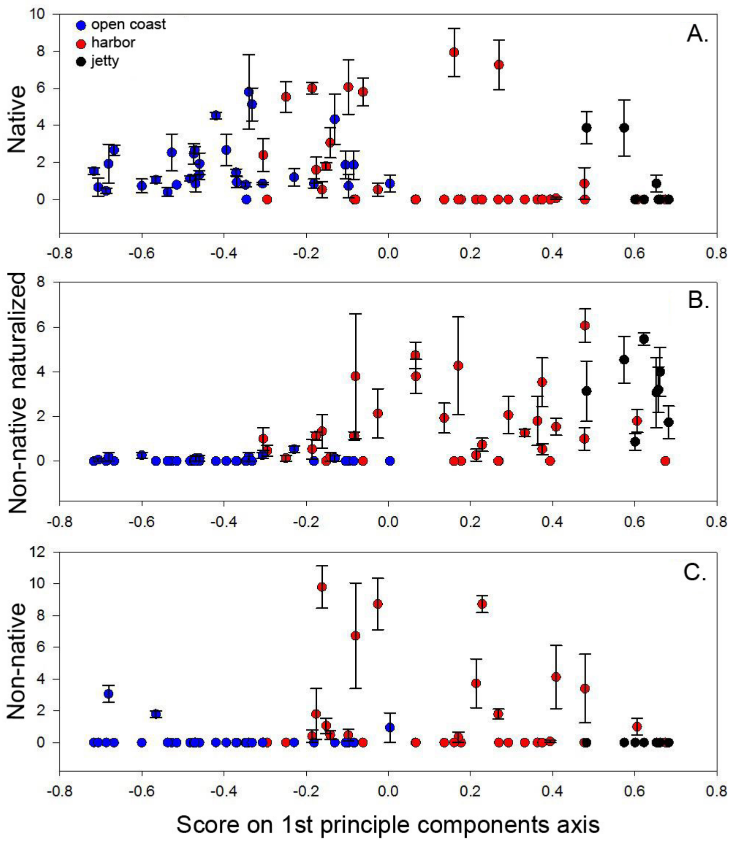

Figure 5. PC1 vs. native (A), non-native naturalized (B), and non-native (C) mean stipe densities at survey sites (n = 32 (open coast, blue), n = 34 (harbor, red), n= 8 (jetty, black).

native algae. Jetty sites had intermediate densities of native species and lacked non-natives entirely. When examining benthic community composition across all sites surveyed in this study (Figure 4), the first two principal component axes (PC1 and PC2) described over 50% of the variation in the data (with PC1 explaining 42.6% of variation). Sites within each site type clustered together along PC1 (left to right from open coast to jetty, Figure 4) suggesting that each site type was

Table 2. Results from three-way ANOVA testing for differences in mean non-native stipe densities across location nested within site type, site type (open coast versus harbor) and survey round.

Source	*df*	MS	SS	F	*p*
Site [Location, Site Type]	13	6.2331	81.0301	4.8074	0.0002
Site Type	1	26.5361	26.5361	20.4663	< 0.0001
Location [Site Type]	4	20.7358	82.9432	15.9947	< 0.0001
Site Type x Survey Round	2	0.4742	0.94833	0.3657	0.6968
Survey Round	2	1.8880	3.77605	1.4562	0.2491
Error	30	1.29658	38.8973		
Total	52				

Table 3. Summary of *S. horneri* and *U. pinnatifida* documentations on the Pacific Coast of North America from published sources and University of California Herbarium (Berkeley, California) database specimens.

Species	Year	Location	Source	Latitude	Longitude
S. horneri	2003	Long Beach Harbor	Miller 2007	33º 42.0' N	118º 14.0' W
	2005	Todos Santos Bay	Aguilar-Rosas 2007	31º 43.2' N	116º 40.2' W
	2006	Santa Catalina Island	Miller 2007	33º 24.3' N	118º 22.0' W
	2006	Point Loma	UC Herbarium	32º 41.2' N	117º 16.0' W
	2007	San Clemente Island	UC Herbarium	32º 58.7' N	118º 32.3' W
	2007	Isla Natividad	Riosmena-Rodriguez 2012	27º 27.8' N	115º 9.00' W
	2009	Anacapa Island	D. Kushner, US Natl. Park Service	34º 0.91' N	119º 22.5' W
	2010	Santa Cruz Island	D. Kushner, US Natl. Park Service	34º 2.61' N	119º 42.9' W
	2010	Santa Barbara Island	D. Kushner, US Natl. Park Service	32º 28.7' N	119º 24.2' W
	2012	Mission Bay	this study	32º 45.7' N	117º 14.8' W
	2012	Shaw's Cove	UC Herbarium	33º 32.6' N	117º 47.9' W
	2013	Oceanside Harbor	this study	33º 12.4' N	117º 23.6' W
	2013	San Diego Bay	this study	32º 42.4' N	117º 14.1' W
	2013	Bird Rock	this study	32º 48.9' N	117º 16.5' W
U. pinnatifida	2000	Los Angeles Harbor	Silva 2002	33º 42.9' N	118º 17.0' W
	2000	Long Beach Harbor	Silva 2002	33º 45.7' N	118º 12.0' W
	2000	Channel Islands Harbor	Silva 2002	34º 9.71' N	119º 13.4' W
	2000	Port Hueneme	Silva 2002	34º 9.17' N	119º 12.5' W
	2001	Santa Barbara Harbor	Silva 2002	34º 18.5' N	119º 41.4' W
	2001	Santa Catalina Island	Silva 2002	33º 24.2' N	118º 22.1' W
	2001	Monterey Bay	Silva 2002	36º 36.2' N	121º 53.3' W
	2003	Isla Todos Santos	Aguilar-Rosas 2004	31º 48.1' N	116º 47.3' W
	2004	San Diego Bay	Miller 2009	32º 42.5' N	111º 10.4' W
	2009	Morro Bay Docks	UC Herbarium	35º 22.2' N	120º 51.4' W
	2009	San Francisco Bay	Zabin 2009	37º 46.8' N	122º 23.1' W
	2009	Pillar Point Harbor	Zabin 2009	37º 30.1' N	122º 28.9' W
	2013	Oceanside Harbor	this study	33º 12.4' N	117º 23.6' W
	2014	Santa Cruz Harbor	H. Fulton- Bennett, Moss Landing Marine Laboratory	36º 57.8' N	122º 0.08' W
	2014	Mission Bay	this study	32º 45.7' N	117º 14.8' W

characterized by distinct benthic functional groups. The major loadings on PC1 were fleshy red macroalgae and crustose coralline algae in the direction of open coast sites and sand and bare rock in the direction of jetties. Sites within each classification spread along PC2, which had major loadings of articulated coralline algae, brown macroalgae, turf algae, sponges, and seagrass. This spread indicates that cover of these benthic functional groups was variable at sites within the three site types.

Densities of native, non-native naturalized, and non-native stipes were clearly grouped along PC1 based on site type (Figure 5). Native brown algal stipe densities (Figure 5A) were high in open coast sites characterized by native fleshy red macroalgae and articulated coralline algae and low in harbor and jetty sites. Harbor and jetty sites had consistently high stipe densities of non-native naturalized *S. muticum* (Figure 5B). Non-native macroalgae (Figure 5C) were found almost exclusively in harbor sites that were characterized by turf algae, articulated coralline algae, sponges, and barnacles.

Regional abundance and current distribution

In the relatively short invasion history of *S. horneri* and *U. pinnatifida* on the Pacific coast of North America, each species has spread rapidly to occupy a range of different habitats in multiple biogeographic regions with different environmental conditions (Figure 1, Table 3). Both species have been documented on man-made and natural substrates in protected harbors, open mainland coasts, and on offshore islands.

Since its discovery in Long Beach Harbor in 2003, *S. horneri* has shown a general southward spread, remaining in the southern California Bight and expanding southward down the coast of Baja California, Mexico (Figure 1, Table 3). In this time, it has expanded its range approximately 200 km north and 750 km south, from Santa Barbara, California to Isla Natividad, Central Baja California, Mexico.

While the first documentation of *Sargassum horneri* was in a harbor, this species has been found in few harbor locations since then. In 2010, *S. horneri* was found growing in the Port of Ensenada. In this study we report the occurrence of *S. horneri* in Oceanside Harbor, Mission Bay, and San Diego Bay. *Sargassum horneri*'s greatest invasion success has been on offshore islands along the coasts of California and Baja California. *Sargassum horneri* was first discovered at Santa Catalina Island in April 2006, and it was reported at San Clemente Island in May 2007. It has since spread to Anacapa and Santa Cruz Islands. In the south, the species has been found from the Coronado Islands in 2015 (N. Kaplanis, pers. obs.), to Isla Natividad, a small island off of the central Pacific coast of Baja California, Mexico in 2007. *S. horneri* has also successfully invaded open coast mainland locations in California and Baja California, Mexico. In 2005, *Sargassum horneri* was first reported as drift wrack at La Jolla, Baja California and growing at Rancho Packard in Todos Santos Bay, Ensenada B.C. In 2006, the first population in San Diego County was discovered at New Hope Rock, Point Loma. It has since been found in isolated populations along the southern California coast in Santa Barbara (D. Reed, University of California Santa Barbara, Santa Barbara, CA, pers. comm.), Laguna Beach, and Crystal Cove, Orange County. Our study adds a total of nine sites to the list of locations where this species is now present.

Undaria pinnatifida has primarily spread northward since its discovery in Los Angeles Harbor in March 2000, growing almost exclusively on man-made structures in protected harbor locations (Figure 1, Table 3). *Undaria pinnatifida* was reported in rapid succession at harbors throughout the California coast: Port Hueneme and Santa Barbara Harbor in November 2000 and April 2001, respectively; and as far north as Monterey Harbor by August 2001. In 2004 it was first found in San Diego Bay, and by 2009 the species was also found at Morro Bay Harbor, at Pillar Point Harbor in Half Moon Bay, and marinas in San Francisco Bay. *Undaria pinnatifida* was then found on floating structures in two marinas within the Bahía Todos Santos in April of 2012, and most recently was discovered in Santa Cruz Harbor in June of 2014 (H. Fulton-Bennett, Moss Landing Marine Lab, Moss Landing, CA, pers. comm.). In two instances *U. pinnatifida* has been found on natural substrates in island locations. In June of 2001, a deep water population was found in Button Shell Cove, an open-coast location on Santa Catalina Island. This documentation represents the first and only instance of *U. pinnatifida* occurring on a natural reef on the open coast in California. In September 2003, *U. pinnatifida* was found at Isla Todos Santos, the first documentation of this species on the Pacific coast of Mexico. *Undaria pinnatifida* has not yet been documented growing on a natural reef on the mainland Pacific coast of California. In Baja California though, populations have been observed in a natural reef setting at Punta Banda, Bahía Todos Santos (Aguilar-Rosas 2014). Here we document eight new sites from San Diego harbors where *U. pinnatifida* is present.

Discussion

We investigated the presence, establishment, spread and persistence of *S. horneri* and *U. pinnatifida* in San Diego County. Both species are well established, occurring throughout the county in multiple locations characterized by distinct habitats. Further, both species appear to be spreading locally within a short time frame to an increasing number of sites where they are found. Finally, the persistence of both species at invasion locations through multiple generations indicates that these species are established.

Sargassum horneri has proven to be a successful invader in San Diego, rapidly colonizing new areas, forming dense thickets and spreading quickly within invasion sites. This suggests that it is competitively equal to, or dominant over, native macroalgal species when conditions are right. The life history characteristics of this species may explain its success as an invasive species. Like in its native range, in invasion locations *S. horneri* grows very rapidly between November and July, reaching full size (3–5 m in length) and reproductive maturity in nine to ten months (L. Marks, University of California Santa Barbara, Santa Barbara CA, pers. comm.; N. Kaplanis pers. obs.). *Sargassum horneri* is an annual species (Gao and Hua 1997) and is capable of persisting through multiple generations because it is monoecious and extremely fecund (Miller and Engle 2007). Once released, *S. horneri* eggs have the potential to be fertilized for up to 48 hours, a window of viability much longer than related species (Pang et al. 2009). In San Diego, mature senescent thalli bearing reproductive conceptacles have been observed in spring of 2014 and 2015 throughout the county as beach wrack and as drift (N. Kaplanis, pers. obs.). Whether these drifting thalli are capable of releasing viable embryos is unknown, but it appears likely that *S. horneri* is capable of local dispersal even without a human transport vector.

Undaria pinnatifida has remained a relatively inconspicuous invader in San Diego. Its spread has been slow, has been mostly confined to man-made substrates, and no obvious ecological effects of its colonization have yet been observed. However, this survey provides only a snapshot of *U. pinnatifida* in a relatively early stage of a potential invasion. More detailed studies that investigate the interactions of this invader with the native benthic community are needed to better understand and track the progress of this invasion along the Pacific coast of North America.

Both non-native species investigated here were found almost exclusively in harbors in San Diego County. In these harbors, densities of non-native macroalgae are high when densities of native macroalgae are low and vice-versa. This pattern may result from occupation by the non-native species of an open niche that is not suitable for the growth of native macroalgae, or may be due to competitive displacement by the invaders. The disproportionate presence of these species in harbors may be a result of these locations being initial points of introduction, suggesting boats as a vector for long distance transport. Once present in harbors, the invaders may remain restricted to these habitats or they may spread into adjacent open coast sites. Whether the rocky reefs of our study area are more resistant to invasion than harbors, or whether they have simply not been exposed to propagules of the non-native species remains to be determined. However, it appears that several offshore islands in southern California and in Baja California are highly susceptible to invasion. Whether these new open coast invasions are the result of El Niño associated conditions that have negatively impacted kelp communities, potentially opening space for invader colonization, is yet to be determined. More long-term monitoring in conjunction with experimental manipulations are needed to better understand the dynamics and potential impacts of these invaders along the Pacific coast of North America.

The results of our surveys also provide valuable insight into the distribution of the naturalized invader *S. muticum*, which was abundant at nearly every survey site. Unlike *S. horneri* and *U. pinnatifida, S. muticum* was abundant on open-coast jetties year round. *Sargassum muticum* was also abundant in low energy environments throughout San Diego's harbors, as well as high energy wave-swept intertidal and subtidal areas along the open coast. Further, *S. muticum* was found both in areas devoid of other macroalgae and intermingled with native macroalgal species. While *S. muticum* was ubiquitous, it was never found in dense canopy-forming stands, as it is observed in its native range (Deysher and Norton 1982) and was observed during its initial invasion of San Diego in the 1970's (P. Dayton, Scripps Institution of Oceanography, San Diego, CA, pers. comm., Ambrose and Nelson 1982). At present, it appears as though *S. muticum* has become naturalized in San Diego but little is known about how this species interacts with native benthic communities or the new invaders over time. Continued monitoring is needed to better understand the invasion ecology of these three non-native species.

Comparing patterns of invasion of these macroalgal species along the San Diego County coast to the broader coastal region provides important context to understanding patterns of spread. In San Diego County, *S. horneri* grows in large meadows in the local harbors. These harbor populations are similar to the extensive populations now observed on the leeward side of Santa Catalina Island, though their spatial extent is more confined by limited availability of suitable hard substrate. On the open coast of San Diego, *S. horneri* remains contained in small localized populations with small spatial coverage and lower densities. In the wave and current exposed areas along the west and southern coasts of Santa

Catalina, the Northern Channel Islands, and the southern California mainland, *S. horneri* has also not yet been observed to form large or persistent meadows. The mechanisms driving these patterns of establishment remain unclear but may be tied to wave and current exposure.

Despite *U. pinnatifida*'s reputation as an aggressive invader, the colonization pattern for San Diego, as with the rest of the Pacific coast of North America, has shown that *U. pinnatifida* is largely restricted to man-made structures in harbors. This is strikingly different from other invasion locations such as Australia and New Zealand, where widespread invasion on the open coast has prompted aggressive removal and control programs (Lonhart and Bunzel 2009). Instances where *U. pinnatifida* has invaded natural substrates on the open coast of California and Baja California remain rare despite fears that these observed populations are the beginning of a widespread and devastating invasion. The pattern of colonization along the Pacific coast of North America may be a result of a limited temperature tolerance (Aguilar-Rosas et al 2004; Miller and Engle 2009), an inability to become established in areas of high wave exposure (Miller and Engle 2009), or an inability to compete with native macroalgae for settlement space on the benthos – but these mechanisms have yet to be explored.

The spread of *S. horneri* and *U. pinnatifida* along the Pacific Coast of North America in the past two decades has been swift and reveals that these two species are capable of becoming invasive in a range of habitats within this region. Colonization of areas far from their native ranges indicates that these species are capable of utilizing a human-mediated transport vector. Distribution patterns suggest hull fouling of large commercial vessels as a likely vector for initial introduction and fouling of smaller recreational vessels as a vector for secondary spread. Further, their capability to spread locally from these initial points of introduction may also suggest secondary spread through sexual and asexual propagation. These two species have also proven to be highly versatile. While *S. horneri* has remained confined to the southern California Bight and the Baja California Coast, it has successfully colonized a wide range of habitat types in this region. *Undaria pinnatifida* has also proven capable of invading a variety of habitat types, and has expanded its range from Baja California to northern California, spanning across multiple distinct biogeographic provinces. Finally, the persistence of both species since their initial introductions indicates they are also able to withstand competition and with native algal species and grazing pressure from native herbivores.

The ecological and economic impacts of these seaweed invaders have yet to be explored. In its native range, *S. horneri* is known to influence a variety of different coastal environmental parameters including dissolved oxygen concentration, water flow, pH, and light conditions (Komatsu et al. 2007). It is also known to play an important ecological role in offshore waters, forming large, dense, drifting mats (Komatsu et al. 2007). In its native range, this species is an important biofilter that removes inorganic nutrients from mainland effluent discharges (Pang et al. 2009). The impacts of the large invasive stands and drifting mats of this species on the Pacific coast of North America on coastal environmental conditions and nutrient distributions remains unknown. Few studies have assessed the impacts of *U. pinnatifida* on native communities in other areas, and ecological effects of *U. pinnatifida* on native species have been variable based on invasion location. Further, little is known about how this species may affect the rocky reef communities of the Pacific coast of North America if it spreads further (Lonhart and Bunzel 2009).

The coastal communities of the Californias are currently undergoing invasion by multiple non-native macroalgae. The majority of these species have appeared in the past 30 years, and species such as *S. horneri* and *U. pinnatifida* are still in the early stages of the invasion process, providing the opportunity to gain insight into the early stages of algal invasions. Further, environmental shifts associated with climate change, including increases in the frequency and intensity of ENSO events, may be making the California and Baja California coasts more susceptible to invasion by non-native algal species through creating more space and reducing natural resistance (Miller et al. 2011). While the current distributions of these species may be confined by latitudinal temperature barriers, with the North Equatorial Current possibly confining the spread of *U. pinnatifida* south, and the California Current possibly confining the spread of *S. horneri* north, temperature shifts associated with climate change could potentially alter these barriers and allow for further spread of these species. Identifying the underlying mechanisms that facilitate or inhibit further spread is the next logical step in advancing our knowledge of the invasion ecology of these species.

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References

Aguilar-Rosas LE, Aguilar-Rosas R, Kawai H, Uwai S, Valenzuela-Espinoza E (2007) New record of *Sargassum filicinum* Harvey (Fucales, Phaeophyceae) in the Pacific Coast of Mexico. *Algae* 22: 17–21, http://dx.doi.org/10.4490/ALGAE.2007.22.1.017

Aguilar-Rosas LE, Núñez-Cebrero F, Aguilar-Rosas CV (2013) Introduced marine macroalgae in the Port of Ensenada, Baja California, Mexico: biological contamination. *Procedia Environmental Sciences* 18: 836–843, http://dx.doi.org/10.1016/j.proenv.2013.04.112

Aguilar-Rosas LE, Pedroche FF, Zertuche González JA (2014) Algas Marinas no nativas en la costa del Pacífico Mexicano. In: Mendoza R, Kpleff P (eds), Especies acuáticas invasoras en México. Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, México, pp 211–222

Aguilar-Rosas R, Machado Galindo A (1990) Ecological aspects of *Sargassum muticum* (Fucales, Phaeophyta) in Baja California, Mexico: reproductive phenology and epiphytes. *Hydrobiologia* 204–205: 185–190, http://dx.doi.org/10.1007/BF00040232

Aguilar-Rosas R, Aguilar-Rosas LE, Ávila-Serrano G, Marcos-Ramírez R (2004) First record of *Undaria pinnatifida* (Harvey) Suringar (Laminariales, Phaeophyta) on the Pacific coast of Mexico. *Botanica Marina* 47: 255–258, http://dx.doi.org/10.1515/BOT.2004.028

Ambrose RF, Nelson BV (1982) Inhibition of giant kelp recruitment by an introduced brown alga. *Botanica Marina* 25: 265–267, http://dx.doi.org/10.1515/botm.1982.25.6.265

Anderson LWJ (2005) California's reaction to *Caulerpa taxifolia*: a model for invasive species rapid response. *Biological Invasions* 7: 1003–1016, http://dx.doi.org/10.1007/s10530-004-3123-z

Britton-Simmons KH (2004) Direct and indirect effects of the introduced alga *Sargassum muticum* on benthic, subtidal communities of Washington State, USA. *Marine Ecology Progress Series* 277: 61–78, http://dx.doi.org/10.3354/meps277061

Carlton JT (2000) Global change and biological invasions in the oceans. In: Mooney HA, Hobbs RJ (eds), Invasive species in a changing world, Island Press. Covelo, CA, pp 31–53

Casas G, Scrosati R, Piriz ML (2004) The invasive kelp *Undaria pinnatifida* (Phaeophyceae, Laminariales) reduces native seaweed diversity in Nuevo Gulf (Patagonia, Argentina). *Biological Invasions* 6: 411–416, http://dx.doi.org/10.1023/B:BINV.0000041555.29305.41

Choi CG, Kim HG, Sohn CH (2003) Transplantation of young fronds of *Sargassum horneri* for construction of seaweed beds. *Korean Journal of Fisheries and Aquatic Sciences* 36: 469–473, http://dx.doi.org/10.5657/kfas.2003.36.5.469

Choi HG, Lee KH, Yoo HI, Kang PJ, Kim YS, Nam KW (2008) Physiological differences in the growth of *Sargassum horneri* between the germling and adult stages. *Journal of Applied Phycology* 20: 729–735, http://dx.doi.org/10.1007/s10811-007-9281-5

Deysher L, Norton TA (1982) Dispersal and colonization in *Sargassum muticum* (Yendo) Fensholt. *Journal of Experimental Marine Biology and Ecology* 56: 179–195, http://dx.doi.org/10.1016/0022-0981(81)90188-X

Espinoza J (1990) The southern limit of *Sargassum muticum* (Yendo) Fensholt (Phaeophyta, Fucales) in the Mexican Pacific. *Botanica Marina* 33: 193–196, http://dx.doi.org/10.1515/botm.1990.33.2.193

Farrell P, Fletcher RL (2006) An investigation of dispersal of the introduced brown alga *Undaria pinnatifida* (Harvey) Suringar and its competition with some species on the man-made structures of Torquay Marina (Devon, UK). *Journal of Experimental Marine Biology and Ecology* 334: 236–243, http://dx.doi.org/10.1016/j.jembe.2006.02.006

Forrest BM, Brown SN, Taylor MD, Hurd CL, Hay CH (2000) The role of natural dispersal mechanisms in the spread of *Undaria*. *Phycologia* 39: 547–553, http://dx.doi.org/10.2216/i0031-8884-39-6-547.1

Gao K, Hua W (1997) In-situ growth rates of *Sargassum horneri* (Fucales, Phaeophyta). *Phycological Research* 45: 55–57, http://dx.doi.org/10.1111/j.1440-1835.1997.tb00062.x

Harley C, Hughes AR, Hultgren KM, Miner B, Sorte CJB, Thornber CS, Rodriguez LF, Tomanke L, Williams SL (2006) The impacts of climate change in coastal marine systems. *Ecology Letters* 9: 228–241, http://dx.doi.org/10.1111/j.1461-0248.2005.00871.x

Harries DB, Harrow S, Wilson JR, Mair JM, Donnan DW (2007) The establishment of the invasive alga *Sargassum muticum* on the west coast of Scotland: a preliminary assessment of community effects. *Journal of the Marine Biological Association of the UK* 87: 1057–1067, http://dx.doi.org/10.1017/S0025315407057633

Inderjit, Chapman D, Ranelletti M, Kaushik S (2006) Invasive marine algae: an ecological perspective. *The Botanical Review* 72: 153–178, http://dx.doi.org/10.1663/00068101(2006)72[153:IMAAEP]2.0.CO;2

Johnson CR, Chapman ARO (2007) Seaweed invasions: Introduction and scope. *Botanica Marina* 50: 321–325, http://dx.doi.org/10.1515/BOT.2007.037

Jousson O, Pawlowski J, Zaninetti L, Zechman FW, Dini F, Di Guiseppe G, Woodfield R, Millar A, Meines A (2000) Invasive alga reaches California. *Nature* 408: 157–158, http://dx.doi.org/10.1038/35041623

Komatsu T, Matsunaga D, Mikami A, Sagawa T, Boisnier E, Tatsukawa K, Aoki M, Ajisaka T, Uwai S, Tanaka K, Ishida K, Tanoue H, Sugimoto T (2007) Abundance of drifting seaweeds in eastern East China Sea. In: Borowitzka MA, Critchley AT, Kraan S, et al. (eds), Nineteenth International Seaweed Symposium. Springer Netherlands, pp 351–359

Lonhart S, Bunzel R (2009) Final report to NOAA community-based restoration program Monterey Bay, pp 1–51

Lowe S, Browne M, Boudjelas S, DePoorter M (2000) 100 of the world's worst invasive alien species, a selection from the global invasive species database. Published by The Invasive Species Specialist Group (ISSG) a specialist group of the Species Survival Commission (SSC) of the World Conservation Union (IUCN), 12 pp

Miller KA, Engle JM, Uwai S, Kawai H (2007) First report of the Asian seaweed *Sargassum filicinum* Harvey (Fucales) in California, USA. *Biological Invasions* 9: 609–613, http://dx.doi.org/10.1007/s10530-006-9060-2

Miller KA, Engle JM (2009) The natural history of *Undaria pinnatifida* and *Sargassum filicinum* at the California Channel Islands: non-native seaweeds with different invasion styles. Proceedings of the 7th California Islands Symposium, pp 131–140

Miller KA, Aguilar-Rosas LE, Pedroche FF (2011) A review of non-native seaweeds from California, USA and Baja California, Mexico (Reseña de algas marinas no nativas de California, EUA y Baja California, México). *Hidrobiológica* 21: 365–379

Norton TA (1977) The growth and development of *Sargassum muticum* (Yendo) Fensholt. *Journal of Experimental Marine*

Biology and Ecology 26: 41–53, http://dx.doi.org/10.1016/0022-0981(77)90079-X

Norton TA (1981) Gamete expulsion and release in *Sargassum muticum, Botanica Marina* 24: 465–470, http://dx.doi.org/10.1515/botm.1981.24.8.465

Nyberg CD, Wallentinus I (2005) Can species traits be used to predict marine macroalgal introductions? *Biological Invasions* 7: 265–279, http://dx.doi.org/10.1007/s10530-004-0738-z

Pang SJ, Liu F, Shan TF, Gao SQ, Zhang ZH (2009) Cultivation of the brown alga *Sargassum horneri*: sexual reproduction and seedling production in tank culture under reduced solar irradiance in ambient temperature. *Journal of Applied Phycology* 21: 413–422, http://dx.doi.org/10.1007/s10811-008-9386-5

Riosmena-Rodríguez R, Boo GH, López-Vivas JM, Hernández-Velasco A, Sáenz-Arroyo A, Boo SM (2012) The invasive seaweed *Sargassum filicinum* (Fucales, Phaeophyceae) is on the move along the Mexican Pacific coastline. *Botanica Marina* 55: 547–551, http://dx.doi.org/10.1515/bot-2012-0120

Saito Y (1975) *Undaria*. In: Tokida JHH (ed), Advances of Phycology in Japan. Junk Publishers, The Hague, pp 304–320

Schaffelke B, Campbell ML, Hewitt CL (2005) Reproductive phenology of the introduced kelp *Undaria pinnatifida* (Phaeophyceae, Laminariales) in Tasmania, Australia. *Phycologia* 44: 84–94, http://dx.doi.org/10.2216/0031-8884(2005)44[84:RPOTIK]2.0.CO;2

Schaffelke B, Smith JE, Hewitt CL (2006) Introduced macroalgae - a growing concern. *Journal of Applied Phycology* 18: 529–541, http://dx.doi.org/10.1007/s10811-006-9074-2

Schaffelke B, Hewitt CL (2007) Impacts of introduced seaweeds. *Botanica Marina* 50:397–417, http://dx.doi.org/10.1515/BOT.2007.044

Silva PC, Woodfield RA, Cohen AN, Harris LH, Goddard JHR (2002) First report of the Asian kelp *Undaria pinnatifida* in the northeastern Pacific Ocean. *Biological Invasions* 4: 333–338, http://dx.doi.org/10.1023/A:1020991726710

Smith JE (2011) Algae. In: Simberloff D, Rejmanek M (eds), Encyclopedia of Biological Invasions. University of California Press, Berkeley and Los Angeles, pp 11–15

Thornber CS, Kinlan BP, Graham MH, Stachowicz JJ (2004) Population ecology of the invasive kelp *Undaria pinnatifida* in California: environmental and biological controls on demography. *Marine Ecology Progress Series* 268: 69–80, http://dx.doi.org/10.3354/meps268069

Thresher RE (2000) Key threats from marine bioinvasions: a review of current and future issues. In: Pederson J (ed), Marine Bioinvasions, Proceedings of the First National Conference, January 24–27, 1999. Massachusetts Institute of Technology, Sea Grant College Program, Boston, pp 24–36

Valentine JP, Magierowski RH, Johnson CR (2007) Mechanisms of invasion: establishment, spread and persistence of introduced seaweed populations. *Botanica Marina* 50: 351–360, http://dx.doi.org/10.1515/BOT.2007.040

Walker DI, Kendrick GA (1998) Threats to macroalgal diversity: marine habitat destruction and fragmentation, pollution and introduced species. *Botanica Marina* 41: 105–112, http://dx.doi.org/10.1515/botm.1998.41.1-6.105

Williams SL, Smith JE (2007) A global review of the distribution, taxonomy, and impacts of introduced seaweeds. *Annual Review of Ecology Evolution and Systematics* 38: 327–359. http://dx.doi.org/10.1146/annurev.ecolsys.38.091206.09

Zabin C, Ashton G, Brown C, Ruiz G (2009) Northern range expansion of the Asian kelp *Undaria pinnatifida* (Harvey) Suringar (Laminariales, Phaeophyceae) in western North America. *Aquatic Invasions* 4: 429–434, http://dx.doi.org/10.3391/ai.2009.4.3.1

The following supplementary material is available for this article:

Table S1. Summary of surveys in San Diego County.

This material is available as part of online article from:
http://www.aquaticinvasions.net/2016/Supplements/AI_2016_Kaplanis_etal_Supplement.xls

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Rapid Communication

Range expansion of a non-native, invasive macroalga *Sargassum horneri* (Turner) C. Agardh, 1820 in the eastern Pacific

Lindsay M. Marks[1,2]*, Paulina Salinas-Ruiz[2], Daniel C. Reed[2], Sally J. Holbrook[1,2], Carolynn S. Culver[2,3], John M. Engle[2], David J. Kushner[4], Jennifer E. Caselle[2], Jan Freiwald[5], Jonathan P. Williams[6], Jayson R. Smith[7], Luis E. Aguilar-Rosas[8] and Nikolas J. Kaplanis[9]

[1]*Department of Ecology, Evolution and Marine Biology, University of California Santa Barbara, Santa Barbara, California 93106-6150, USA*
[2]*Marine Science Institute, University of California Santa Barbara, Santa Barbara, California 93106-6150, USA*
[3]*California Sea Grant, Scripps Institution of Oceanography, University of California San Diego, 9500 Gilman Drive, La Jolla, California 92093-0232, USA*
[4]*Channel Islands National Park, 1901 Spinnaker Drive, Ventura, California 93001, USA*
[5]*Reef Check Foundation, 13723 Fiji Way, B-2, Marina del Rey, California 90292, USA*
[6]*Moore Laboratory of Zoology, Occidental College, Los Angeles, California 90041, USA*
[7]*Department of Biological Sciences, California State Polytechnic University, Pomona, California 91768, USA*
[8]*Instituto de Investigaciones Oceanológicas, Universidad Autónoma de Baja California, Carr. Transpeninsular Ensenada-Tijuana, 3917. Frac. Playitas, Ensenada, Baja California, México. C.P. 22860*
[9]*Scripps Institution of Oceanography, University of California San Diego, 9500 Gilman Drive, La Jolla, California 92093-0202, USA*
**Corresponding author*
E-mail: marks@lifesci.ucsb.edu

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Abstract

Sargassum horneri (Turner) C. Agardh, 1820 is a fast growing brown alga native to shallow reefs of eastern Asia. It has spread aggressively throughout southern California, USA, and Baja California, México since it was discovered in the eastern Pacific in 2003 and poses a major threat to the sustainability of native marine ecosystems in this region. Here we present a chronology of the rapid geographic expansion of *S. horneri* in the eastern Pacific and discuss factors that potentially influence its spread.

Key words: introduced species, invasion, distribution, seaweed, *Sargassum filicinum*, southern California, Baja California

Introduction

Introductions of marine non-native species continue worldwide and are expected to increase with the expansion of global trade. The spread and ecological effects of newly-established non-native species can vary; some proliferate and compete vigorously in their introduced range and are considered "invasive" (Miller et al. 2011). Introduced marine macroalgae are no exception, although detailed records of the geographic expansion of introduced marine macroalgae are rare (Lyons and Scheibling 2009) despite there being at least 277 introduced seaweed species globally (Williams and Smith 2007). Documenting the spread of these species can be challenging given the logistical difficulties associated with sampling in subtidal habitats where they occur (e.g. time- and depth-limitations when using scuba and the expense of accessing remote sites). Yet such studies are valuable for not only documenting their distributions but also providing insight into the mechanisms influencing the spread of non-native species.

Here we present the chronology of the geographic expansion of the non-native macroalga *Sargassum horneri* (Turner) C. Agardh, 1820 (Fucales) along the southern region of the Pacific

Figure 1. *Sargassum horneri* morphology and life cycle. (A) Recruit, (B) Mature thallus with reproductive receptacles indicated by arrow, (C) Thick canopy on a shallow reef. Photo credits: Jessie Alstatt (A), Dan Richards (B), Tom Boyd (C).

coast of North America, where it has spread rapidly since it was first detected in Long Beach Harbor, California, USA, in 2003 (Miller et al. 2007). We also discuss potential factors influencing the spread of this species and the implications of its invasion to native ecosystems.

Study area

The study area encompassed the shallow coastal waters of the eastern Pacific Ocean from northern California, USA, to the southern tip of Baja California, México. Much of this coast is actively monitored by government and academic researchers and citizen scientists, and is therefore an ideal region in which to document the spatio-temporal dynamics of the spread of an invasive macroalga.

Study species

Miller et al. (2007) initially identified the introduced population of *Sargassum* discovered in Long Beach, California as *S. filicinum* (Harvey, 1860). This annual brown alga is monoecious, with ellipsoidal pneumatocysts, and has a narrow geographic range on the coast of western Japan (Yoshida et al. 1983; Tseng et al. 1985) and southern Korea (Lee and Yoo 1992). On the basis of molecular population studies, Uwai et al. (2009) merged *S. filicinum* with *S. horneri*, a dioecious species with spherical pneumatocysts that is widespread in the warmer waters of eastern Asia (Tseng et al. 1985). Therefore, we refer to the eastern Pacific population as *S. horneri*.

The morphology of *S. horneri* changes throughout its annual, diplonic, life cycle. Embryos develop into small plants with lateral fern-like branches anchored by a common holdfast (Figure 1A). Plants give rise to a single erect frond up to several meters in length that bears numerous vegetative blades buoyed by many small gas bladders (Yoshida 1983). Eventually, the frond ceases vertical growth and develops hundreds of reproductive receptacles (Figure 1B). Fertilization occurs when sperm penetrate an egg inside a conceptacle positioned on the surface of a receptacle. The resulting embryo is released and settles to the bottom. After embryos are shed the frond senesces and the entire thallus dies, completing the life cycle. Sexual reproduction is the only known means of propagation.

Miller et al. (2007) recorded the presence of *S. horneri* in the eastern Pacific in southern California shortly after it was first discovered in 2003. Rapid communication, coupled with the species' conspicuous morphology and widely distributed information on its identification, facilitated the subsequent monitoring of *S. horneri* by many researchers in California and Baja California.

Methods

We compiled records of *S. horneri* from herbaria, publications, government and academic groups and trained citizen scientists monitoring subtidal and intertidal reefs in California and Baja California (Supplementary material Table S1). Its presence or absence was recorded during ecological surveys by observers trained to identify the species. Because this region is extensively and regularly monitored by many trained observers, the spread of *S. horneri* can be described with high spatial and temporal resolution. Using these data, we present a timeline of *S. horneri* spread in southern California and Baja California.

Results

Since 2003 when *S. horneri* was first detected in Long Beach Harbor, it has spread north and south along the mainland coast and westward across several nearshore islands (Supplemental material Table S2, Figure 2). The geographic expansion of *S. horneri* is characterized by isolated introductions to new islands and locations on the mainland widely separated from existing populations, followed by the steady colonization of surrounding areas.

In 2005, just two years after *S. horneri* was first detected in Long Beach, it was found drifting on the surface 260 km south in Todos Santos Bay, Baja California, México. One year later it was confirmed to be growing on natural reefs there, and along the coast of San Diego and the leeward side of Santa Catalina Island, California. Since then it has progressively spread north in southern California and south in Baja California. By 2007, *S. horneri* had spread to Isla Natividad in Baja California, 500 km south of the nearest known population. In 2013, the northern range of *S. horneri* reached Santa Barbara, California, 186 km northwest of Long Beach. The known northern and southern limits of the range of established populations have not changed since 2013, though additional populations were recorded within the previously established range. However, individual thalli were found floating at the surface west of the current range at Santa Rosa and San Miguel Islands in 2012 and 2015 respectively, and at multiple islands near the southern end of its range in 2015.

The abundance and persistence of the recorded populations varied. Many reports consisted of only a few individuals or groups of individuals in small patches, often at sites where *S. horneri* had not previously been recorded. Patchy distribution continued in subsequent years at many sites, and occasionally *S. horneri* was recorded at a site but not found there again. However, in some areas, such as Santa Catalina and Anacapa Islands, *S. horneri* spread profusely and was persistent, covering large portions of reefs with adult densities > 100 m^{-2} and recruit densities > 1000 m^{-2} for multiple years (e.g. Figure 1C).

Discussion

Invasive traits

Sargassum horneri has several life history characteristics that make it well adapted for colonizing distant areas and rapidly populating an area once it is established. Thalli are buoyed by gas bladders and are capable of self-fertilization, making the establishment of new populations from long-range dispersal of a single floating thallus possible. Indeed, floating *S. horneri* thalli have been observed frequently off southern California and Baja California and are estimated to remain afloat for several weeks before decomposing (Yatsuya 2008). Local population growth can occur quickly because *S. horneri* is a fast-growing (4.46% day^{-1} adult blade weight maximum relative growth rate; Choi et al. 2008) and highly fecund alga (up to 50% of the biomass of a mature individual is composed of reproductive tissue; L. Marks unpublished data). Furthermore, the patchy distribution and reoccurrence of dense aggregations of *S. horneri* in successive years (Figure 1C) may be explained by the heavy embryos of *S. horneri* which, like other fucoid algae, are thought to have limited capacity for dispersal.

Dispersal vectors

The distribution and rapid spread of *S. horneri* is likely influenced by both natural and human-mediated dispersal. Reproductive thalli can become dislodged naturally if severed from their holdfast by grazers or strong wave action and carried to new sites on ocean currents. Divers may also dislodge thalli accidentally or intentionally, inadvertently contributing to its dispersal by either freeing them to float away or transporting them elsewhere. Boaters can dislodge thalli when setting and retrieving anchors lying in *S. horneri*-populated areas. *Sargassum horneri* is also adept

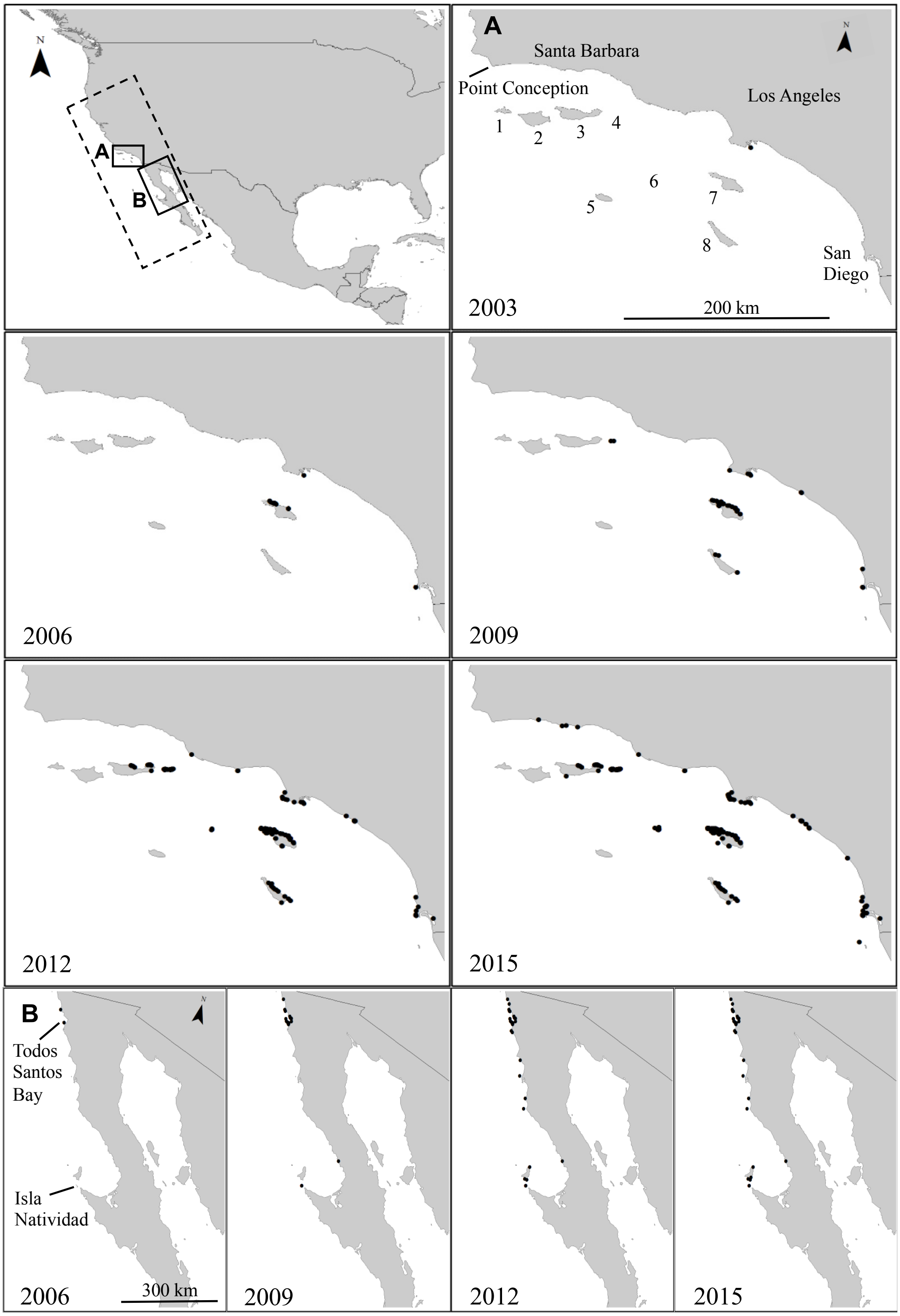

Figure 2. Chronology of geographic expansion of *S. horneri* in the southern California, USA (A) and Baja California, México (B) regions. Each dot identifies a location where *S. horneri* was found attached to the substrate at least once. Each map includes observations from all previous years to display the distribution of *S. horneri* at each interval. The California Channel Islands are identified by number as follows: 1. San Miguel, 2. Santa Rosa, 3. Santa Cruz, 4. Anacapa, 5. San Nicolas, 6. Santa Barbara, 7. Santa Catalina, 8. San Clemente. The entire study area is outlined by the dashed line. Maps were created by P. Carlson.

at growing on a variety of both natural and man-made surfaces, so vessels fouled with *S. horneri* may be an effective means of transporting it to new locations as suggested by Miller and Engle (2009). The current distribution of this seaweed includes many sites that are frequently visited by boaters and divers, such as harbors or anchorages, supporting the idea that *S. horneri* is being transported regionally by recreational and commercial vessels.

Potential for further spread

Sargassum horneri has expanded significantly further south along the eastern Pacific coast than north, spanning 6.18 and 0.76 degrees latitude from the initial detection site in Long Beach Harbor, respectively. The thermal tolerances of *S. horneri* may play an important role in determining range limits in the eastern Pacific. Sea surface temperatures in its native range in western Japan and southern Korea average between about 18–22° C (Chu et al. 1998). Baja California water temperatures typically range between 14–22° C on the Pacific coast (Zaytsev et al. 2003), so the continued expansion of *S. horneri* southward along this peninsula is likely. Warmer average temperatures in the Gulf of California and mainland México will likely prevent expansion beyond the peninsula. Ocean temperatures north of Point Conception rarely exceed 18°C, which may prevent *S. horneri* from spreading further north under present ocean climate conditions. However, predictions for a warmer ocean in the future may serve to increase the northward expansion of *S. horneri* in the eastern Pacific.

Implications of S. horneri invasion

Sargassum horneri can be locally very abundant and highly persistent. Therefore, its continued expansion in the eastern Pacific may pose a major threat to the sustainability of native marine ecosystems. Its high growth rates and long, floating thalli may provide a competitive advantage over other macrophytes. In addition, it appears to be avoided by most herbivores (Navarro 2009; Vogt 2010), possibly due to high concentrations of phenolic compounds that have been shown to deter grazing in other fucoid algae (Steinberg 1985). Mesoinvertebrates that use macroalgae as biogenic habitat and the fish that depend on these invertebrates may also be affected by the *S. horneri* invasion. Research investigating the interactions between *S. horneri* and ecologically important species is critically needed to understand how its invasion may be altering the structure and functioning of existing ecosystems of the eastern Pacific.

Continued monitoring of *S. horneri* distribution is essential to identify environmental factors influencing its spread and prioritize management actions. Researchers and citizen scientists can contribute to this effort by reporting observations of *S. horneri* occurrence to an online database and map designed to help track its spread (Marine Invasive Species Tracking website 2015).

Conclusion

The range of *S. horneri* has expanded rapidly in the eastern Pacific since it was first detected in 2003. Its expansion to the south has been more extensive and occurred more quickly than to the north, suggesting that it may be better suited to warmer southern waters. The prevalence of *S. horneri* at popular boating and diving destinations suggests that its spread is the result of multiple introductions. The life history of this species allows distant areas to be colonized by a single individual, which facilitates its spread. The high abundance and persistence of *S. horneri* in novel areas has heightened the awareness of its invasion potential and raised concerns about its possible adverse effects on existing ecosystems. Future research aimed at determining the environmental factors affecting its spread and the ecological and economic consequences of *S. horneri* invasion will provide much needed insight into the cost and need for human intervention in controlling its invasion.

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References

Choi GH, Lee KH, Hyun IY, Kang PJ, Kim YS, Nam KW (2008) Physiological differences in the growth of *Sargassum horneri* between the germling and adult stages. *Journal of Applied Phycology* 20: 729–735, http://dx.doi.org/10.1007/s10811-007-9281-5

Chu PC, Chen Y, Lu S (1998) Temporal and spatial variabilities of Japan Sea surface temperature and atmospheric forcings. *Journal of Oceanography* 54: 273–284, http://dx.doi.org/10.1007/BF02751702

Lee K, Yoo S-A (1992) Korean species of *Sargassum* subgenus *Bactrophycus* J. Agardh (Sargassaceae, Fucales). In Abbott IA (ed) Taxonomy of Economic Seaweeds, Vol 3. California Sea Grant College, La Jolla, California, pp 139–147

Lyons DA, Scheibling RE (2009) Range expansion by invasive marine algae: rates and patterns of spread at a regional scale. *Diversity and Distributions* 15: 762–775, http://dx.doi.org/10.1111/j.1472-4642.2009.00580.x

Marine Invasive Species Tracking (2015) The University of California Santa Cruz Marine Invasive Species Tracking website, http://www.marineinvasives.org

Marks LM, Salinas-Ruiz P, Reed DC (2015) Records of *Sargassum horneri* occurrence in the eastern Pacific. Santa Barbara Coastal LTER; Long Term Ecological Research Network, http://dx.doi.org/10.6073/pasta/63012c4e436214239ebed11ee57cbe03

Miller KA, Engle JM, Uwai S, Kawai H (2007) First report of the Asian seaweed *Sargassum filicinum* Harvey (Fucales) in California, USA. *Biological Invasions* 9: 609–613, http://dx.doi.org/10.1007/s10530-006-9060-2

Miller KA, Engle JM (2009) The natural history of *Undaria pinnatifida* and *Sargassum filicinum* at the California Channel Islands: non-native seaweeds with different invasion styles. Proceedings of the 7th California Islands Symposium. Institute for Wildlife Studies, Arcata, California, pp 131–140

Miller KA, Aguilar-Rosas LE, Pedroche FF (2011) A review of non-native seaweeds from California, USA and Baja California, Mexico. *Hidrobiológica* 21: 365–379

Navarro CA (2009) Feeding rates of native herbivores on introduced and native seaweeds. M.S. Thesis, California State University, Fullerton, 59 pp

Riosmena-Rodríguez R, Boo GH, López-Vivas JM, Hernández-Velasco A, Sáenz-Arroyo A, Boo SM (2012) The invasive seaweed *Sargassum filicinum* (Fucales, Phaeophyceae) is on the move along the Mexican Pacific coastline. *Botanica Marina* 55: 547–551, http://dx.doi.org/10.1515/bot-2012-0120

Steinberg PD (1985) Feeding preferences of *Tegula funebralis* and chemical defenses of marine brown algae. *Ecological Monographs* 53: 333–349, http://dx.doi.org/10.2307/1942581

Tseng CK, Yoshida T, Chiang YM (1985) East Asiatic species of *Sargassum* subgenus *Bactrophycus* J. Agardh (Sargassaceae, Fucales), with keys to the sections and species. In: Abbott IA, Norris JN (eds), Taxonomy of Economic Seaweeds, Vol 1. California Sea Grant College Program, La Jolla, California, pp 1–15

Uwai S, Kogame K, Yoshida G, Kawai H, Ajisaka T (2009) Geographical genetic structure and phylogeography of the *Sargassum horneri/filicinum* complex in Japan, based on the mitochondrial *cox3* haplotype. *Marine Biology* 156: 901–911, http://dx.doi.org/10.1007/s00227-009-1136-y

Vogt SC (2010) Consumer food choices for native or non-native seaweeds from southern California waters. M.S. Thesis, California State University, Fullerton, 48 pp

Williams SL, Smith JE (2007) A global review of the distribution, taxonomy, and impacts of introduced seaweeds. *Annual Review of Ecology, Evolution, and Systematics* 38: 327–359, http://dx.doi.org/10.1146/annurev.ecolsys.38.091206.095543

Yatsuya K (2008) Floating period of Sargassacean thalli estimated by the change in density. *Journal of Applied Phycology* 20: 797–800, http://dx.doi.org/10.1007/s10811-007-9293-1

Yoshida T (1983) Japanese species of *Sargassum* subgenus *Bactrophycus* (Phaeophyta, Fucales). *Journal of the Faculty of Science, Hokkaido University. Series 5, Botany* 13: 99–246

Zaytsev O, Cervantes-Duarte R, Montante O, Gallegos-Garcia A (2003) Coastal upwelling activity on the Pacific shelf of the Baja California Peninsula. *Journal of Oceanography* 59: 489–502, http://dx.doi.org/10.1023/A:1025544700632

Supplementary material

The following supplementary material is available for this article:

Table S1. Sources for records of *Sargassum horneri* occurrence.

Table S2. Records of the occurrence of *Sargassum horneri* in California, USA, and Baja California, México, since 2003, the year it was first discovered in the eastern Pacific.

This material is available online for download from Long Term Ecological Research Network Data Portal (see Marks et al. 2015, http://dx.doi.org/10.6073/pasta/63012c4e436214239ebed11ee57cbe03)

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Research Article

Assessment of control methods for the invasive seaweed *Sargassum horneri* in California, USA

Lindsay M. Marks[1,]*, Daniel C. Reed[2] and Adam K. Obaza[3]

[1]*Department of Ecology, Evolution and Marine Biology, University of California Santa Barbara, Santa Barbara, California 93106-6150, USA*
[2]*Marine Science Institute, University of California Santa Barbara, Santa Barbara, California 93106-6150, USA*
[3]*Ocean Associates Inc., 4007 N. Abingdon Street, Arlington, Virginia 22207, USA*
E-mail addresses: lindsay.marks@lifesci.ucsb.edu (LMM), dan.reed@lifesci.ucsb.edu (DCR), adam.obaza@noaa.gov (AKO)
**Corresponding author*

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Editor's note:
This study was first presented at the 9th International Conference on Marine Bioinvasions held in Sydney, Australia, January 19–21, 2016 (http://www.marinebioinvasions.info/previous-conferences). Since their inception in 1999, ICMB series have provided a venue for the exchange of information on various aspects of biological invasions in marine ecosystems, including ecological research, education, management and policies tackling marine bioinvasions.

Abstract

Determining the feasibility of controlling marine invasive algae through removal is critical to developing a strategy to manage their spread and impact. To inform control strategies, we investigated the efficacy and efficiency of removing an invasive seaweed, *Sargassum horneri,* from rocky reefs in southern California, USA. We tested the efficacy of removal as a means of reducing colonization and survivorship by clearing *S. horneri* from 60 m^2 circular plots. We also examined whether *S. horneri* is able to regenerate from remnant holdfasts with severed stipes to determine whether efforts to control *S. horneri* require the complete removal of entire individuals. The experimental removal of *S. horneri* in early winter, just prior to the onset of reproduction, reduced recruitment in the next generation by an average of 54% and reduced survivorship to adulthood by an average of 25%. However, adult densities one year after clearing averaged 83% higher in removal plots and 115% higher in control plots. We attribute these higher densities to anomalously warm water associated with the 2015–16 El Niño that reduced native canopy-forming algae and enhanced the recruitment and survival of *S. horneri*. We did not find any evidence to suggest that *S. horneri* has the capacity to regenerate, indicating that its control via removal does not require the tedious task of ensuring the removal of all living tissue. We developed efficiency metrics for manual removal with and without the aid of an underwater suction device and found the method with maximum efficiency (biomass removed worker^{-1} hr^{-1}) varied based on the number of divers and surface support workers. Our findings suggest that controlling *S. horneri* via removal will be most effective if done over areas much larger than 60 m^2 and during cool-water years that favor native algae. Such efforts should be targeted in places such as novel introduction sites or recently invaded areas of special biological or cultural significance where *S. horneri* has not yet become widely established.

Key words: introduced species, management, marine, macroalgae, rocky reef, *Sargassum filicinum*

Introduction

Invasive species are one of the greatest agents of human-induced change to ecosystems worldwide (Pejchar and Mooney 2009). Coastal marine systems are especially vulnerable to introductions of nonindigenous species via trans-oceanic shipping, aquaculture and the aquarium trade, which have greatly extended the distribution of many marine species outside of their native ranges (Carlton 1989). Marine invasions have steadily increased over the past two centuries (Ruiz et al. 2000) and are expected to continue to rise as global trade expands. Costs associated with the impact and management of invasive species are high, totalling over $1 billion annually in the USA

(Pimentel et al. 2000), while resources available for management are limited. Therefore, agencies tasked with controlling invasions must be efficient in their management strategies. Exploration of techniques aimed at controlling the spread and impact of marine invasive species and identification of species-specific traits that increase the efficacy of control are urgently needed.

A seaweed recently introduced to southern California, USA, presented an opportunity to test the efficacy of removal in controlling invasive algae on rocky reefs. *Sargassum horneri* (Turner) C. Agardh, 1820 (Fucales) is a large, annual brown alga native to shallow reefs of eastern Asia. It was first discovered in the eastern Pacific in Long Beach Harbor in 2003 and identified as *S. filicinum* Harvey, 1860 (Miller et al. 2007), now considered a synonym of *S. horneri* (Uwai et al. 2009). The species has spread aggressively across 700 km from Santa Barbara in southern California to Isla Natividad in Baja California, Mexico (Marks et al. 2015). It occurs primarily at offshore islands though it has also been found along the mainland and in coastal embayments. In southern California we have observed *S. horneri* growing in the intertidal down to 33 m depth, with its highest densities occurring between 5–15 m. In places where *S. horneri* is established, juveniles can attain high cover with upwards of 1,000 individuals m^{-2} during the summer and fall, and these grow to form thick canopies in the winter with dense stands of over 100 adults m^{-2} (author's unpublished data). While definitive evidence of ecological impacts on rocky reef systems from *S. horneri* invasion is not yet available (but see Cruz-Trejo et al. 2015), the detrimental effects on native assemblages caused by other invasive seaweeds (e.g., de Villèle and Verlaque 1995; Levin et al. 2002; Casas et al. 2004; Britton-Simmons 2004) suggest management of *S. horneri* is worth exploring (Anderson 2007; Schaffelke and Hewitt 2007; Forrest and Hopkins 2013).

Several life history characteristics of *S. horneri* make it potentially suitable for control by removal. First, it is a large and conspicuous alga consisting of a single main axis with multiple lateral branches that reaches up to several meters high (Yoshida 1983). The annual thallus is anchored by a small holdfast that gives rise to a stipe buoyed by many small gas bladders (Marks et al. 2015). The conspicuous adult thalli allow for efficient identification and removal by divers using SCUBA. Second, *S. horneri* propagates via sexual reproduction. Fertilization occurs in winter on the surface of reproductive structures born on the lateral branches of a mature thallus where embryos are developed and shed (author's unpublished data). Senescence of the thallus ensues after embryos are shed, completing the annual life cycle. *Sargassum* embryos tend to sink quickly (Gaylord et al. 2002) and the vast majority likely settle within a few meters of the parent thallus (Deysher and Norton 1982; Stiger and Payri 1999; Kendrick and Walker 1995). Clearing thalli in relatively small areas on the order of tens of square meters may therefore reduce colonization resulting from local dispersal. However, because colonization over longer distances is thought to occur via reproductively mature thalli that are dislodged and set adrift (Yatsuya 2008), any thalli removed must not be released. Asexual reproduction in *S. horneri* via fragmentation or regeneration from remnant tissue has not been studied, although it is known to occur in other fucoid species (McCook and Chapman 1992; Fletcher and Fletcher 1975). Information on the capacity of *S. horneri* to propagate asexually is needed to develop an effective management strategy for controlling its spread.

A new tool that has been developed to help control algal invasions is an underwater suction device. This type of device has been used on coral reefs in Oahu, Hawaii, to reduce densities of invasive algae (Conklin and Smith 2005), and a similar device was recently developed to aid in controlling seaweed invasions on rocky reefs in California. The device has been used to transport *S. horneri* removed from the ocean floor by divers to a platform at the sea surface, where the material can be collected for disposal on land (Meux 2013). However, the effectiveness of this approach in controlling *S. horneri* on temperate rocky reefs and how the efficiency of this method compares to non-mechanical techniques require further investigation.

To inform efforts to manage the spread and impact of *S. horneri*, we removed it from experimental areas and followed colonization and survivorship for one year to address three questions. First, how effective is local removal in controlling populations of *S. horneri*? Second, what is the capacity of the species to regenerate from remnant holdfasts? Third, how much effort is required to remove established populations with and without the aid of an underwater suction device?

Methods

This study was performed on the leeward side of Santa Catalina Island, California, USA on two nearby reefs (Howland Landing: 33.465ºN; 118.522ºW and Lion Head: 33.453ºN; 118.502ºW) at 6–8 m depth (Figure 1). We chose these locations because they are representative of the topography of reefs in the area, and have dense populations of *S. horneri*.

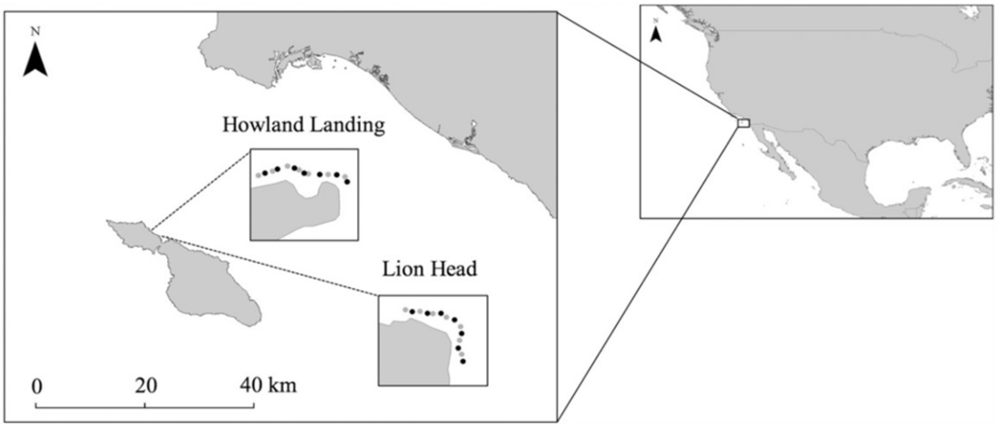

Figure 1. Map of Santa Catalina Island, located 27 km off the coast of southern California, USA. The insets show the distribution of 28 experimental plots spread across two sites: Howland Landing and Lion Head. Dark circles represent removal plots, and grey circles represent control plots.

Removal experiment

To evaluate the effectiveness of *S. horneri* extraction in reducing local populations, we performed a removal experiment and monitored colonization and survivorship of the next generation. We established twenty-eight 60 m^2 circular plots in areas where *S. horneri* was abundant and assigned plots alternately to either a removal or non-removal (i.e., control) treatment (Figure 1). Fourteen plots were located 15–20 m apart at each of the two study sites.

We extracted *S. horneri* from removal plots in the winter (February 2015) when individuals were at their largest size and lowest densities, but before the vast majority (i.e., 99%) of them became fertile so as to minimize the source of *S. horneri* propagules within the removal plots. Immediately prior to removal we counted the number of *S. horneri* adults (defined as > 5 cm tall) in sixteen 0.25 m^2 quadrats $plot^{-1}$ that were placed within each plot at 0, 1, 2 and 3 m from the edge along two perpendicular diameters. To prevent mature thalli from drifting away and starting distant populations, we captured all material removed and transported it to boats anchored at the surface. On deck, workers immediately transferred material into heavy-duty trash bags. We later emptied these bags at an upland location where we left the algae to decompose.

We removed all *S. horneri* from the substrate manually and employed one of two methods to transport it to the surface: mesh bags and lines, or an underwater suction device. The bag and line method involved divers placing *S. horneri* into weighed bags (Figure 2A). Once filled, buoyant bags were released from their weights and attached to lines hanging off the side of the boat (Figure 2B) and a worker at the surface hauled them onboard. The suction device consisted of a mechanical water pump (Subaru PTX201D Robin Pump) with 7.6 cm-diameter input and output hoses that is operated on the deck of the boat (Figure 2C). Divers fed material into the hose at depth and it was transported to the surface by the movement of a diaphragm (Figure 2D). Regardless of the method used, most individuals were completely removed from the substrate (Figure 2E). However, the holdfasts of some individuals remained after their stipes were severed.

Removal plots were resampled immediately after clearing to confirm all thalli had been removed and to quantify the density of remnant holdfasts. In September 2015, we measured colonization by counting the number of juveniles (defined as < 5 cm tall) in all plots. In February 2016, one year after experimental removals, we counted the number of adults in each plot to assess the effects of removal on population density. Because *S. horneri* grows on rock and the percent cover of rock was consistently high but slightly variable (mean ± SE = 97.9 ± 0.19%) we adjusted estimates of density within each quadrat by the percent cover of rock in that quadrat. Hence *S. horneri* is reported as number m^{-2} of rock rather than number m^{-2} of sea floor.

We tested the effects of removal on colonization (i.e., juvenile density in September 2015) and population density (i.e., adult density in February 2016) in separate two-way hierarchical ANOVAs with treatment (removal versus control) as a fixed factor and site (Howland Landing versus Lion Head) as a random factor and plots nested within sites. We considered plots independent replicates of treatment effects in cases when the random effect of site was not significant.

Fate of individuals with severed stipes

To determine whether severing a *S. horneri* stipe near its base while leaving the holdfast intact is sufficient to prevent it from regenerating, we followed the fate of individuals after cutting their stipes in March 2015. We attached identifying markers to the reef adjacent to 80 holdfasts and revisited the marked individuals monthly for four months to record whether they remained attached to the substrate and, if so, whether they regenerated new tissue. We also collected observations of the remnant holdfasts in the plots we cleared. Although we were not able to follow these holdfasts individually, we looked for perennating *S. horneri* holdfasts when resampling the plots.

Efficiency of removal

We evaluated the efficiency of removal with and without the aid of the suction device (Figure 2) by quantifying the effort required for each method for a given quantity of *S. horneri* biomass. We did this by recording the removal method being used (i.e., suction device or bags and lines), time spent collecting, number of workers (i.e., scuba divers and surface support person) and amount of biomass removed for each dive. To estimate the biomass removed, we collected the algae into bags as soon as it was brought to the surface and weighed it to the nearest 0.5 kg using a hanging scale. In addition, we measured the rate of transport to the surface using the suction device across a range of stipe lengths to determine if size affected performance. We fed 30 pieces of several stipe lengths that are often naturally observed (30 cm, 60 cm, 100 cm and 150 cm) into the hose and recorded the time it took to bring them up to the surface.

Results

Removal experiment

The density of adult *S. horneri* prior to experimental removal in February 2015 was similar in removal and control plots ($F_{1,1}$ = 0.98, p = 0.504) averaging 46.4 and 50.4 individuals m^{-2}, respectively (Figure 3A). Adult density differed significantly between the two sites ($F_{1,420}$ = 26.95, p < 0.001) with density ~55% higher at Howland Landing. Quadrat sampling and visual surveys of entire plots verified that experimental clearing resulted in the removal of virtually all visible thalli in removal plots, but some holdfasts with severed stipes remained. The density of remnant holdfasts immediately after clearing was 46.1% of the initial adult population (mean ± SE = 22.3 ± 2.9 m^{-2}).

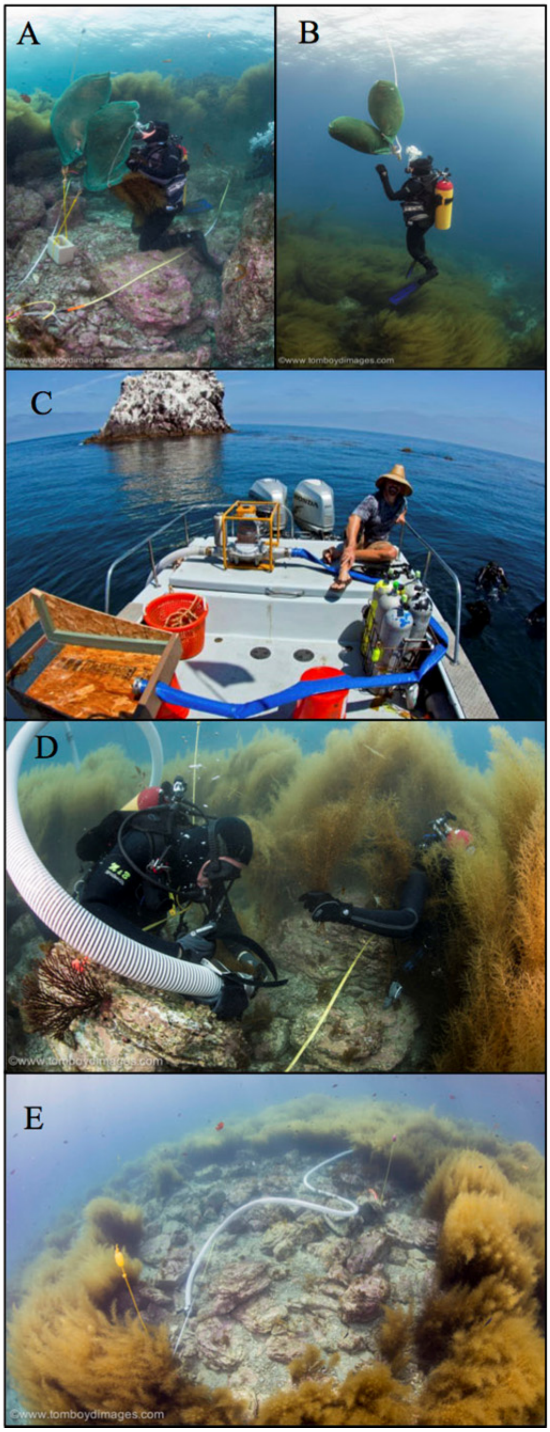

Figure 2. Two methods used to transport *Sargassum horneri* to the surface. Using the bag and line method, a diver fills bags anchored by a cinderblock (A), then clips bags to a line hanging from a boat anchored overhead (B). Using the suction device method, two divers work together to feed *S. horneri* into the hose (C), and a person at the surface collects the material from a sorting table after inspecting it for bycatch (D). After clearing using both methods, plots were left barren of *S. horneri* (E). Photo credits: Tom Boyd (A-B, D-E), Adam Obaza (C).

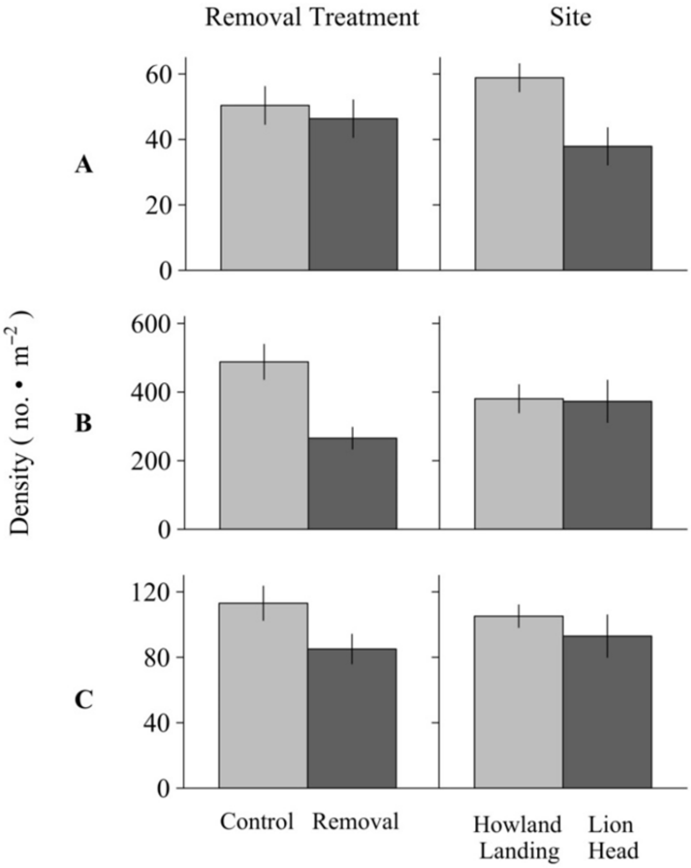

Figure 3. Results of removal experiment showing the average density ± SE of *Sargassum horneri* (A) adults prior to their removal, (B) juveniles ~220 days after removal, and (C) adults ~366 days after removal (N = 14 plots).

Similarly high densities of recently colonized juveniles were observed in all plots in September 2015, ~7 months after clearing (Figure 3B; $F_{1,420} = 0.08$, $p = 0.775$). Removal had a significant effect on subsequent colonization ($F_{1,26} = 12.95$, $p = 0.001$) as juvenile density was 54% lower in removal plots compared to control plots. The effect of removing *S. horneri* on colonization by juveniles was similar at both sites (treatment x site: $F_{1,1} = 0.236$, $p = 0.125$).

The reduced densities in removal versus control plots persisted but became less pronounced over time as juveniles grew into adults (Figure 3C). By February 2016, one year after clearing, adult densities averaged 25% lower in removal plots compared to control plots. However, overall adult densities were 83% higher in removal plots and 115% higher in control plots compared to February 2015 prior to removal (Figure 3A versus 3C).

Fate of individuals with severed stipes

Significant tag loss resulted in reduced and unequal sample sizes for estimating survivorship on the different sampling dates, which compromised our ability to quantitatively evaluate the regenerative capacity of individuals with severed stipes. Nonetheless, the data that we collected indicate that *S. horneri* has little or no capacity for regenerating from remnant holdfasts as none of the individuals with severed stipes that remained tagged generated new tissue. Fifty-six of the 80 tags remained after 31 days and remnants of holdfasts were found for only 20 of these 56 individuals. Remnants of 10 of 14, 4 of 9 and 0 of 8 holdfasts remained after 54, 85 and 113 days, respectively (Figure 4). Furthermore, when we sampled the removal experiment in September 2015, we found no remnant holdfasts, which suggests they had all senesced and disappeared within seven months.

Efficiency of removal

The efficiency of removing *S. horneri* varied by the method used to transport it to the surface and the number of workers. Three workers using the bag and line transport method yielded the slowest average removal rate of 29 kg $worker^{-1}$ hr^{-1}, while the suction device method with three workers (two divers and one surface support person) yielded an average of 38 kg worker^{-1} hr^{-1} (Figure 5). Limits on the amount of material that can be fed into the hose at any given time resulted in two divers being the optimum number to maximize the transport of algae to the surface. By contrast, the manual transportation method using bags and lines allowed for more divers to work efficiently in the same area. While the overall rate of removal using bags and lines increased with the number of workers, the maximum per capita efficiency was about 45 kg worker^{-1} hr^{-1} (Figure 5). The rate of transport using the suction device was highest at intermediate stipe lengths (~60 cm; Figure 6).

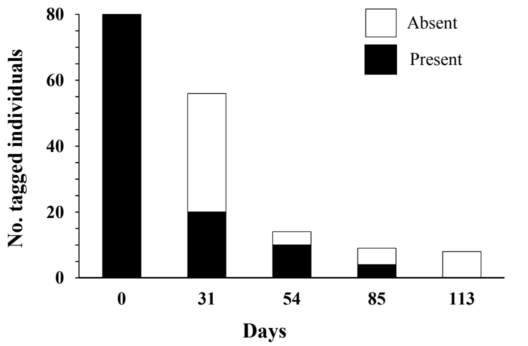

Figure 4. Survivorship of *Sargassum horneri* with severed stipes. Solid bars represent the number of thalli with remnant tissue remaining. Open bars represent the number of tags relocated where holdfasts had senesced. Combined, the bars represent the total number of tags found, and the number of individuals upon which survivorship was based for each sampling period.

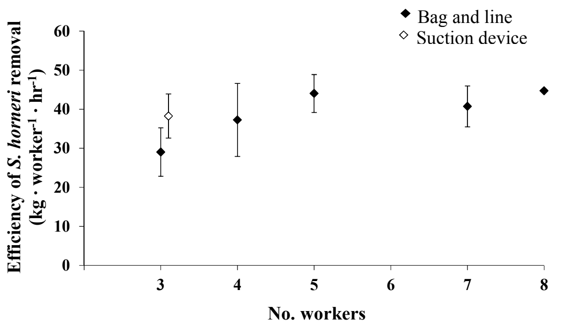

Figure 5. *Sargassum horneri* average removal rate (kg wet biomass worker^{-1} hr^{-1}) ± SE reported for each removal method. Replication varies by the number of dives with each given number of workers using each method. N = 15 dives with 3 workers using the suction device, and N = 6, 4, 6, 6 and 1 dives with 3, 4, 5, 6, and 8 workers using the bag and line removal method, respectively.

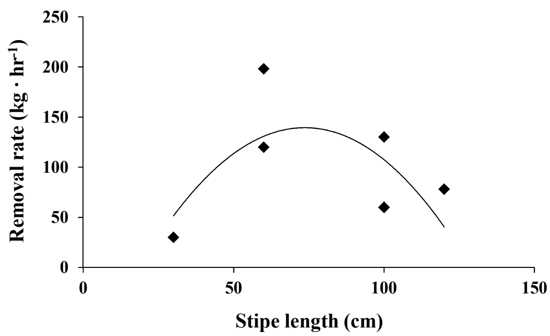

Figure 6. The rate (kg wet biomass hr^{-1}) at which stipes of *Sargassum horneri* were transported by workers using the suction device as a function of stipe length.

Discussion

Our results show that the experimental removal of *S. horneri* reduced the local population in the next generation by ~25% relative to control plots. However, despite this reduction, removing *S. horneri* did not lead to a decline in population density relative to the previous year as adult densities in both the removal and control plots were substantially greater in 2016 than in 2015 prior to removal. These results highlight some of the challenges associated with efforts to reduce established populations of *S. horneri* via removal. Moreover, they suggest that measurable success using removal techniques as a means of controlling *S. horneri* will likely require that removals be done over much larger areas to ensure an adequate reduction in propagule supply, which will be costly. The effect of removing *S. horneri* on its abundance in subsequent generations (as measured by the difference in *S. horneri* density between control and removal plots in the year following removal) was most apparent during the fall when the majority of individuals were juveniles, and became less pronounced in the winter when most were adults. The order of magnitude higher densities that we observed for juveniles compared to adults is consistent with self-thinning induced by intra-specific competition, which is common in large brown algae (Schiel and Choat 1980; Schiel 1985; Dean et al. 1989; Reed 1990). The dampened effect of removal between the juvenile and adult phases suggests removal accelerated the self-thinning process.

The increased density of *S. horneri* that we observed in our removal and control plots may have been due to the unusually warm water resulting from the 2015–16 El Niño. The native canopy-forming kelps *Macrocystis pyrifera* and *Eisenia arboria* commonly found on shallow reefs of Santa Catalina Island thrive in cool, nutrient-rich water. These species largely disappeared from the leeward side of the island during our study while *S. horneri* flourished, as did other species with warm water affinities (e.g., *Zonaria farlowii*, *Dictyota* spp. and *Dictyopteris undulata*). Evidence from the nonindigenous congener *Sargassum muticum,* which became abundant at Santa Catalina Island for several years following the El Niño of 1976 (Coyer 1979), suggests that *Sargassum* spp. with warm-water affinities decline once cooler waters return and large, perennial native kelps become re-established (Ambrose and Nelson 1982) Whether *S. horneri* declines over time remains to be seen, but if the warming observed in 2015–16 is a preview of future conditions, then tropicalization of an algal assemblage that favors *S. horneri* may be the norm.

The efficacy of removing invasive algae could be strengthened by selecting conditions under which native species can exert biotic control on the remaining population, or even by enhancing these controls. Researchers in Hawaii attributed their success in controlling invasive *Eucheuma* spp. and *Kappaphycus* spp. on patch reefs to introducing urchins after performing removals (Conklin and Smith 2005). Once divers reduced the algae below a critical threshold, the herbivores were able to prevent it from growing back. While this is an effective strategy on coral reefs where indiscriminant grazing is acceptable, introducing generalist herbivores is not a viable strategy to control invasive algae on temperate rocky reefs, which are often dominated by a diversity of macroalgae.

An alternative strategy to enhance biological resistance to the regrowth of invasive algae on rocky reefs is to perform removals under conditions favoring the colonization of native species of macroalgae and sessile invertebrates that compete for space and/or light. Resource competition is recognized as an important mechanism structuring communities (MacArthur 1970; Levine and D'Antonio 1999; Tilman 2004), and competition for space and light plays a key role in organizing the benthic community on rocky reefs (Miller and Etter 2008; Arkema et al. 2009). The invasion of a community is thought to be inversely related to species richness due to the enhanced ability of resident species to preempt resources (Elton 1958), and manipulative field experiments have shown that decreasing native diversity increases limited resources and the abundance and survivorship of non-native species in subtidal benthic communities. For example, Stachowicz et al. (2002) found that experimentally increasing sessile invertebrate species richness decreased both the availability of space, the limiting resource in this system, and the abundance of nonindigenous ascidians by buffering against temporal fluctuations in the cover of individual native species. Furthermore, multiple resources might be limiting the success of a non-native species throughout its life cycle, and higher functional diversity may allow a community to preempt multiple resources more effectively. A native algal community with crustose and turfing algae preempting space and understory and canopy-forming algae preempting light sequentially suppressed the recruitment and survivorship of the nonindigenous seaweed *Sargassum muticum* (Britton-Simmons 2006). The preemption of limited resources by native species of algae and invertebrates in areas where *S. horneri* has been removed could likewise limit *S. horneri's* ability to re-establish.

Another important factor to consider when controlling invasive algae through removal is the mechanisms by which it recolonizes cleared areas. Many species of invasive algae have the ability to regenerate from miniscule amounts of tissue (e.g., Fletcher and Fletcher 1975; McCook and Chapman 1992) and this characteristic presents a challenge when considering control via removal (Smith 2015). We found no evidence that *S. horneri* has the capacity to regenerate from remnant holdfasts. This suggests that severing stipes, which is far less time consuming than carefully scraping all tissue from the reef, would be an effective and efficient means of reducing *S. horneri* abundance.

Whether an underwater suction device, such as the one tested in this study, would be the preferred method for invasive algae control depends on staff and budget limitations. The bag and lines method is optimal when many workers (i.e., > two divers and one surface support worker) are available. It also requires minimal training and material costs, and so may be preferred with constrictive budgets. A suction device minimizes surface support effort, particularly associated with lifting heavy bags, and offers increased efficiency with a limited number of workers (< 3 divers). Drawbacks of using a suction device include increased start-up costs, logistical challenges associated with equipment transportation and maintenance, and limitations on working depths. In addition, significant time can be spent troubleshooting, such as identifying appropriately sized pieces of algae to reduce the frequency of clogs. However, removal efficiency is likely to improve as operators become more familiar with the device and alter equipment to better suit the target species. Workers in Hawaii designed several models using different kinds of pumps until they identified the optimal configuration for their target species (Conklin personal communication). Therefore, long-term efficiency gains may make a suction device preferable if an extended control effort is expected.

Eradicating problematic species from their novel habitats is most likely to be successful if attempted before they become widely established (Myers et al.

2000; Bax et al. 2003; Hulme 2006). *Caulerpa taxifolia*, a green alga native to the Indo-Pacific region, was introduced in two protected embayments in southern California in 2000 and a rapid response effort successfully eradicated this species (Anderson 2005). The appearance of *S. horneri* off the open coast of North America is the first record of this species outside of its native range in Asia (Marks et al. 2015). While the aggressive spread of *S. horneri* throughout southern California and Baja California, Mexico makes total eradication in this region highly unlikely, *S. horneri* has the potential to spread to other temperate reefs around the globe. Knowledge about the life history and effective methods for controlling *S. horneri* abundance will prepare resource managers in other regions to eradicate new populations before they become widely established. Our study is one of the first on targeted control of an invasive species on the open coast of California. Development of a removal protocol along with awareness generated by this work will better prepare resource managers and the general public for future invasions of *S. horneri* in other regions.

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References

Agardh CA (1820) Species algarum rite cognitae, cum synonymis, differentiis specificis et descriptionibus succinctis. *Ex Officina Berlingiana, Lund.* 1.1: 1–168

Arkema KK, Reed DR, Schroeter SC (2009) Direct and indirect effects of giant kelp determine benthic community structure and dynamics. *Ecology* 90: 3126–3137, https://doi.org/10.1890/08-1213.1

Ambrose RF, Nelson BV (1982) Inhibition of giant kelp recruitment by an introduced brown alga. *Botanica Marina* 25: 265–267, https://doi.org/10.1515/botm.1982.25.6.265

Anderson LWJ (2005) California's reaction to *Caulerpa taxifolia*: a model for invasive species rapid response. *Biological Invasions* 7: 1003–1016, https://doi.org/10.1007/s10530-004-3123-z

Anderson LWJ (2007) Control of invasive seaweeds. *Botanica Marina* 50: 418–437, https://doi.org/10.1515/BOT.2007.045

Bax N, Williamson A, Aguero M, Gonzalez E, Geeves W (2003) Marine invasive alien species: a threat to global diversity. *Marine Policy* 27: 313–323, https://doi.org/10.1016/s0308-597x(03)00041-1

Britton-Simmons KH (2004) Direct and indirect effects of the introduced alga *Sargassum muticum* on benthic, subtidal communities of Washington State, USA. *Marine Ecology Progress Series* 277: 61–78, https://doi.org/10.3354/meps277061

Britton-Simmons KH (2006) Functional group diversity, resource preemption and the genesis of invasion resistance in a community of marine algae. *Oikos* 113: 395–401, https://doi.org/10.1111/j.2006.0030-1299.14203.x

Carlton J (1989) Man's role in changing the face of the ocean: biological invasions and implications for conservation of near-shore environments. *Conservation Biology* 3: 265–273, https://doi.org/10.1111/j.1523-1739.1989.tb00086.x

Casas G, Scrosati R, Piriz ML (2004) The invasive kelp *Undaria pinnatifida* (Phaeophyceae, Laminariales) reduces native seaweed diversity in Nuevo Gulf (Patagonia, Argentina). *Biological Invasions* 6: 411–416, https://doi.org/10.1023/B:BINV.0000041555.29305.41

Coyer JA (1979) The invertebrate assemblage associated with *Macrocystis pyrifera* and its utilization as a food resource by kelp forest fishes. Ph.D. dissertation, University of Southern California, 364 pp, http://aquaticcommons.org/id/eprint/2664

Conklin EJ, Smith JE (2005) Abundance and spread of the invasive red algae, *Kappaphycus* spp., in Kane'ohe Bay, Hawai'i and an experimental assessment of management options. *Biological Invasions* 7: 1029–1039, https://doi.org/10.1007/s10530-004-3125-x

Cruz-Trejo GI, Ibarra-Obando SE, Aguilar-Rosas LE, Poumian-Tapia M, Solana-Arellano E (2015) Presence of *Sargassum horneri* at Todos Santos Bay, Baja California, Mexico: its effects on the local macroalgae community. *American Journal of Plant Sciences* 6: 2693–2707, https://doi.org/10.4236/ajps.2015.617271

Dean TA, Thies K, Lagos SL (1989) Survival of juvenile giant kelp: the effects of demographic factors, competitors, and grazers. *Ecology* 70: 483–495, https://doi.org/10.2307/1937552

de Villèle X, Verlaque M (1995) Changes and degradation in a *Posidonia oceanica* bed invaded by the introduced tropical alga *Caulerpa taxifolia* in the north western Mediterranean. *Botanica Marina* 38: 79–88, https://doi.org/10.1515/botm.1995.38.1-6.79

Deysher L, Norton TA (1982) Dispersal and colonization in *Sargassum muticum* (Yendo) Fensholt. *Journal of Experimental Marine Biology and Ecology* 56: 179–195, https://doi.org/10.1016/0022-0981(81)90188-X

Elton CS (1958) The ecology of invasions by plants and animals. Methuen, London, England, 181 pp, https://doi.org/10.1007/978-1-4899-7214-9

Fletcher RL, Fletcher SM (1975) Studies on the recently introduced brown alga *Sargassum muticum* (Yendo) Fensholt II. Regenerative ability. *Botanica Marina* 18: 157–162, https://doi.org/10.1515/botm.1975.18.3.157

Forrest BM, Hopkins GA (2013) Population control to mitigate the spread of marine pests: insights from management of the Asian kelp *Undaria pinnatifida* and colonial ascidian *Didemnum vexillum*. *Management of Biological Invasions* 4: 317–326, https://doi.org/10.3391/mbi.2013.4.4.06

Gaylord B, Reed DC, Raimondi PT, Washburn L, McLean S (2002) A physically based model of macroalgal spore dispersal in the wave and current-dominated nearshore. *Ecology* 83: 1239–1251, https://doi.org/10.1890/0012-9658(2002)083[1239:APBMOM]2.0.CO;2

Harvey WH (1860) Characters of new algae, chiefly from Japan and adjacent regions, collected by Charles Wright in the North Pacific Exploring Expedition under Captain James Rodgers. *Proceedings of the American Academy of Arts and Sciences* 4: 327–335

Hulme PE (2006) Beyond control: wider implications for the management of biological invasions. *Journal of Applied Ecology* 43: 835–847, https://doi.org/10.1111/j.1365-2664.2006.01227.x

Kendrick GA, Walker DI (1995) Dispersal of propagules of *Sargassum* spp. (Sargassaceae: Phaeophyta): Observations of local patterns of dispersal and consequences for recruitment and population structure. *Journal of Experimental Marine Biology and Ecology* 192: 273–288, https://doi.org/10.1016/0022-0981(95)00076-4

Levine JM, D'Antonio CM (1999) Elton revisited: a review of evidence linking diversity and invisibility. *Oikos* 87: 15–26, https://doi.org/10.2307/3546992

Levin PS, Coyer JA, Petrik R, Good TP (2002) Community-wide effects of nonindigenous species on temperate rocky reefs. *Ecology* 83: 3182–3193, https://doi.org/10.1890/0012-9658(2002)083[3182:CWEONS]2.0.CO;2

MacArthur R (1970) Species packing and competitive equilibrium for many species. *Theoretical Population Biology* 1: 1–11, https://doi.org/10.1016/0040-5809(70)90039-0

Marks LM, Salinas-Ruiz P, Reed DC, Holbrook SJ, Culver CS, Engle JM, Kushner DJ, Caselle JE, Freiwald J, Williams JP, Smith JR, Aguilar-Rosas LE, Kaplanis NJ (2015) Range expansion of a non-native, invasive macroalga *Sargassum horneri* (Turner) C. Agardh, 1820 in the eastern Pacific. *Bio-Invasions Records* 4: 243–248, https://doi.org/10.3391/bir.2015.4.4.02

McCook LJ, Chapman ARO (1992) Vegetative regeneration of *Fucus* rockweed canopy as a mechanism of secondary succession on an exposed rocky shore. *Botanica Marina* 35: 35–36, https://doi.org/10.1515/botm.1992.35.1.35

Miller KA, Engle JM, Uwai S, Kawai H (2007) First report of the Asian seaweed *Sargassum filicinum* Harvey (Fucales) in California, USA. *Biological Invasions* 9: 609–613, https://doi.org/10.1007/s10530-006-9060-2

Miller RJ, Etter RJ (2008) Shading facilitates sessile invertebrate dominance in the rocky subtidal gulf of Maine. *Ecology* 89: 452–462, https://doi.org/10.1890/06-1099.1

Meux B (2013) Construction and demonstration of a mechanical suction device for non-native algae. Los Angeles Waterkeeper Technical Report, 27 pp

Myers JH, Simberloff D, Kuris AM, Carey JR (2000) Eradication revisited: dealing with exotic species. *Trends in Ecology and Evolution* 15: 316–320, https://doi.org/10.1016/S0169-5347(00)01914-5

Pejchar L, Mooney HA (2009) Invasive species, ecosystem services and human well-being. *Trends in Ecology and Evolution* 24: 497–504, https://doi.org/10.1016/j.tree.2009.03.016

Pimentel DL, Lach L, Zuniga R, Morrison D (2000) Environmental and economic costs of nonindigenous species in the United States. *Bioscience* 50: 53–65, https://doi.org/10.1641/0006-3568(2000)050[0053:EAECON]2.3.CO;2

Reed DC (1990) An experimental evaluation of density dependence in a subtidal algal population. *Ecology* 71: 2286–2296, https://doi.org/10.2307/1938639

Ruiz GM, Fofonoff PW, Carlton JT, Wonham MJ, Heins AH (2000) Invasion of coastal marine communities in North America: apparent patterns, processes, and biases. *Annual Review of Ecology and Systematics* 31: 481–531, https://doi.org/10.1146/annurev.ecolsys.31.1.481

Schaffelke B, Hewitt C (2007) Impacts of introduced species. *Botanica Marina* 50: 397–417, https://doi.org/10.1515/BOT.2007.044

Schiel DR (1985) Growth, survival and reproduction of two species of marine algae at different densities in natural stands. *Journal of Ecology* 73: 199–217, https://doi.org/10.2307/2259778

Schiel DR, Choat JH (1980) Effects of density on monospecific stands of marine algae. *Nature* 285: 324–326, https://doi.org/10.1038/285324a0

Smith J (2015) The putative impacts of the non-native seaweed *Sargassum muticum* on native communities in tidepools of Southern California and investigation into the feasibility of local eradication. *Marine Ecology* 37: 645–667, https://doi.org/10.1111/maec.12335

Stachowicz JJ, Fried H, Osman RW, Whitlatch RB (2002) Biodiversity, invasion resistance, and marine ecosystem function: reconciling pattern and process. *Ecology* 83: 2575–2590, https://doi.org/10.2307/3071816

Stiger V, Payri CE (1999) Spatial and temporal patterns of settlement of the brown macroalgae *Turbinaria ornata* and *Sargassum mangarevense* in a coral reef on Tahiti. *Marine Ecology Progress Series* 191: 91–100, https://doi.org/10.3354/meps191091

Tilman D (2004) Niche tradeoffs, neutrality, and community structure: a stochastic theory of resource competition, invasion, and community assembly. *Proceedings of the National Academy of Sciences of the United States of America* 101: 10854–10861, https://doi.org/10.1073/pnas.0403458101

Uwai S, Kogame K, Yoshida G, Kawai H, Ajisaka T (2009) Geographical genetic structure and phylogeography of the *Sargassum horneri/filicinum* complex in Japan, based on the mitochondrial cox3 haplotype. *Marine Biology* 156: 901–911, https://doi.org/10.1007/s00227-009-1136-y

Yatsuya K (2008) Floating period of Sargassacean thalli estimated by the change in density. *Journal of Applied Phycology* 20: 797–800, https://doi.org/10.1007/s10811-007-9293-1

Yoshida T (1983) Japanese species of *Sargassum* subgenus *Bactrophycus* (Phaeophyta, Fucales). *Journal of the Faculty of Science, Hokkaido University. Series 5, Botany* 13: 99–246, http://hdl.handle.net/2115/26402

Supplemental material

The following supplementary material is available for this article:

Table S1. Recruitment and survivorship of *Sargassum horneri* following removal

Table S2. Survivorship of *Sargassum horneri* with severed stipes

Table S3. Per capita removal rate of *Sargassum horneri*

Table S4. Transport rate of *Sargassum horneri* using suction device

This material is available online for download from the Long Term Ecological Research Network Data Portal, http://dx.doi.org/10.6073/pasta/a812d149f4d6e9cd5662d4c44eaedd22

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Niche Complementarity and Resistance to Grazing Promote the Invasion Success of *Sargassum horneri* in North America

Lindsay M. Marks [1,*], Daniel C. Reed [2] and Sally J. Holbrook [1]

[1] Department of Ecology, Evolution and Marine Biology, University of California Santa Barbara, Santa Barbara, CA 93106-6150, USA; holbrook@ucsb.edu

[2] Marine Science Institute, University of California Santa Barbara, Santa Barbara, CA 93106-6150, USA; danreed@ucsb.edu

* Correspondence: Lindsay.Orsini@Wildlife.ca.gov

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Abstract: Invasive species are a growing threat to conservation in marine ecosystems, yet we lack a predictive understanding of ecological factors that influence the invasiveness of exotic marine species. We used surveys and manipulative experiments to investigate how an exotic seaweed, *Sargassum horneri*, interacts with native macroalgae and herbivores off the coast of California. We asked whether the invasion (i.e., the process by which an exotic species exhibits rapid population growth and spread in the novel environment) of *S. horneri* is influenced by three mechanisms known to affect the invasion of exotic plants on land: competition, niche complementarity and herbivory. We found that the removal of *S. horneri* over 3.5 years from experimental plots had little effect on the biomass or taxonomic richness of the native algal community. Differences between removal treatments were apparent only in spring at the end of the experiment when *S. horneri* biomass was substantially higher than in previous sampling periods. Surveys across a depth range of 0–30 m revealed inverse patterns in the biomass of *S. horneri* and native subcanopy-forming macroalgae, with *S. horneri* peaking at intermediate depths (5–20 m) while the aggregated biomass of native species was greatest at shallow (<5 m) and deeper (>20 m) depths. The biomass of *S. horneri* and native algae also displayed different seasonal trends, and removal of *S. horneri* from experimental plots indicated the seasonality of native algae was largely unaffected by fluctuations in *S. horneri*. Results from grazing assays and surveys showed that native herbivores favor native kelp over *Sargassum* as a food source, suggesting that reduced palatability may help promote the invasion of *S. horneri*. The complementary life histories of *S. horneri* and native algae suggest that competition between them is generally weak, and that niche complementarity and resistance to grazing are more important in promoting the invasion success of *S. horneri*.

Keywords: introduced species; biological invasion; macroalgae; canopy shading; competition; herbivory; *Sargassum filicinum*

1. Introduction

Marine ecosystems are increasingly threatened by invasive species as global trade expands and human-mediated introductions via commercial shipping occur at escalating rates [1–5]. Developing a predictive understanding of factors influencing the success of marine invasive species has clear implications for managing their spread and impacts. Yet relative to terrestrial systems, little is known about the ecological processes that influence marine invasions [6,7]. In terrestrial ecosystems, once an introduced species becomes established, biotic interactions with native species can play a major role in limiting population growth, spread and ecological impacts [8–11]. These interactions can either promote or inhibit "invasion", here defined as the process by which an exotic species exhibits rapid population growth and spread in the novel environment [12].

In terrestrial and freshwater plants, biotic interactions such as competition with natives and herbivory can affect invasion success [9,13]. Competition for limited resources among native and invasive species is expected to be most intense when they have similar life histories and resource requirements [14–16]; invasion is promoted when exotic plants employ resource acquisition strategies superior to native competitors, reducing their abundance or diversity [17]. Invasion success can also be promoted when exotic species have functional traits or resource requirements that differ from the native biota, which allows them to take advantage of underutilized resources in space and time [16,18–21]. Such niche complementarity can facilitate invasions by allowing exotics to avoid interacting with natives that have superior competitive abilities. Like native plants, native consumers can promote or hinder invasion depending on their dietary preference. For example, herbivores that prefer exotic plants to natives can inhibit invasion, while those that prefer native plants can facilitate invasion by reducing the strength of competition between exotic and native plants [10,22,23]. Studies aimed at determining the mechanisms affecting the invasiveness of exotic marine macrophytes are needed to derive meaningful generalizations about the role of biotic interactions in influencing the invasibility of a wide range of ecosystems.

The Asian brown alga *Sargassum horneri* (Turner) C. Agardh, 1820 (Fucales) was first detected in California in 2003 [24] and has since spread throughout southern California and Baja California, Mexico [25]. Several life history characteristics of *S. horneri* are typical of "weedy" invaders with r-selected traits including broad habitat requirements and high fecundity with >60% of its biomass dedicated to reproductive tissue at its peak fertility [26,27]. It has highly localized propagule dispersal, as well as the ability to disperse long distances via the dislodgement and drifting of buoyant fertile adults [27]. The biomass of *S. horneri* is strongly seasonal: juveniles prevalent in the summer exhibit rapid growth to several meters in height during the winter, and reproduction and biomass peak in the spring [27]. *S. horneri* has the potential to compete with native algae by reducing the amount of light reaching algae growing beneath its canopy. Throughout the invaded range, *S. horneri* has become a dominant macroalga in some areas, but remains rare in others [7,25]. However, it is unclear whether this dominance results from competitive displacement of native species or opportunistic occupation of an underutilized niche.

During its reproductive phase, *S. horneri* can form dense canopies that shade the bottom, and canopy shading by invasive algae has been shown to cause the decline or exclusion of native seaweeds [28–30]. However, it has been hypothesized that the invasion of *S. horneri* is suppressed in areas dominated by native algae [7], suggesting that niche complementarity rather than competitive superiority accounts for its rapid spread in North America. Detailed information on patterns of distribution of *S. horneri* and native algae across space (e.g., depths) and through time (e.g., seasons) can provide valuable insight into the relative importance of competition versus niche complementarity in accounting for the invasion success of *S. horneri*.

The effects of herbivores in structuring temperate marine communities are well documented [31–33], but less is known about their potential role in influencing invasions. Exotic seaweeds with traits that deter herbivory (i.e., structural or chemical defenses) can gain an advantage over native competitors in areas with high grazing pressure. Such may be the case for *S. horneri* as it is in the order Fucales, which is known for having high levels of phenolic compounds that deter grazing [34–36]. Thus, preferential consumption of less defended native algae such as laminarian kelps [36,37] could facilitate the spread of *S. horneri* by weakening competition with other more palatable native algae.

The purpose of this study was to determine the degree to which competition, niche complementarity and herbivory account for patterns of abundance of *S. horneri* in an area where it has become established. To do this, we documented patterns of co-occurrence between *S. horneri* and native algae spatially across a depth gradient and temporally over multiple years in experimental plots with *S. horneri* removed or left intact to evaluate niche complementarity and competition as mechanisms contributing to the invasiveness of *S. horneri*. If invasion by *S. horneri* results from its ability to outcompete native algae, then we expected the biomass and taxonomic richness of native algae to increase in areas where we experimentally removed *S. horneri*. Alternatively, if the invasion success of *S. horneri* relies on its ability to occupy underutilized resources, then we expected to see little change in the native algal assemblage in response to *S. horneri* removal. We also performed a field experiment involving the major herbivores to examine their grazing preferences for *S. horneri* versus other algae. Using a combination of feeding assays and distributional surveys, we tested the hypothesis that herbivores facilitate *S. horneri* by preferentially consuming native algae.

2. Materials and Methods

2.1. Study System

Field experiments and surveys were conducted on rocky reefs on the leeward side of Santa Catalina Island, located 35 km offshore of Los Angeles, CA, USA. Study reefs consisted of bedrock, boulders and cobble distributed along a moderate slope that transitioned to sand at depths of about 30 m. The reefs were dominated by native macroalgae and the invasive *Sargassum horneri*. Native macroalgae included the canopy-forming giant kelp *Macrocystis pyrifera*, subcanopy-forming species of kelp (e.g., *Eisenia arborea* and *Agarum fimbriatum*) and fucoid algae (e.g., *Sargassum palmeri*, *Stephanocystis neglecta* and *Halidrys diocia*), and understory-forming foliose and calcified algae. Sessile invertebrates occupied only about 3% of the reef surface. *S. horneri* has become one of the most common macrophytes on shallow reefs at Santa Catalina Island since its introduction in 2006.

The primary grazers at Santa Catalina Island include sea urchins and herbivorous snails. *Centrostephanus coronatus*, the most abundant species of urchin, takes refuge in crevices and forages within <1 m from its shelter during the night before returning to the same location before sunrise [38]. This behavior leads to the formation of urchin "halos" where they commonly graze down algae within small home ranges.

2.2. Competition

To test the effects of *Sargassum horneri* on the abundance and taxonomic richness of native algae, we compared the native algal assemblages in experimental plots from which *S. horneri* was continually removed (hereafter referred to as S−) with those in unmanipulated control plots with *S. horneri* left intact (S+) over 3.5 years. We also measured the reduction in the amount of light permeating through its canopy as a potential mechanism of competition. This experiment was conducted at Isthmus Reef (33.4476° N, 118.4898° W) at 6 m depth, within the range where *S. horneri* is most abundant. Twenty-four 1 m^2 plots separated by a distance of at least 2 m were established on areas of reef comprised of >90% rock and with a high density (i.e., at least 30 individuals) of *S. horneri. S. horneri* was removed from 12 randomly assigned plots (S−) beginning in spring 2014 and every 6 to 12 weeks thereafter until summer 2017. S− plots had a 30 cm wide buffer zone around the perimeter where *S. horneri* was removed to minimize potential edge effects such as shading by individuals outside of the plot. Removal entailed divers using knives to pry all *S. horneri* holdfasts off the substrate, minimizing disturbance to the other biota within the plot as much as possible. Since competitive interactions may vary with time and among seasons, we sampled the algal communities in all S+ and S− plots just prior to the initial removal of *S. horneri* in spring 2014 and quarterly thereafter (i.e., summer, autumn, winter and spring) over three consecutive growing seasons (2014–2015, 2015–2016 and 2016–2017).

Algae were identified to the lowest taxonomic level possible, which in most cases was species (Table S1), and measurements of all understory and subcanopy-forming algae were taken in order to estimate the damp biomass of algae in each plot. The abundance of low-lying understory algae was measured as percent cover using a uniform point contact (UPC) method that involved recording the presence and identity of all algae intersecting 49 points distributed in a grid within each 1 m^2 plot. Percent cover was determined as the fraction of points a taxon intersected × 100. Although multiple organisms may intersect a single point if they overlay one another, a taxon was only recorded once at a given point even if it intersected that point multiple times. Using this technique, the percent cover of all taxa combined in a plot can exceed 100%, but the percent cover of any individual species or morphological group cannot. This sampling resolution was sufficient to detect species covering at least 2% of the area in a quadrat. If a species was present in the plot but not recorded at one of the 49 points, then it was assigned a percent cover value of 0.5%. Since percent cover does not necessarily scale with biomass for larger subcanopy-forming algae, we recorded the density and the average size of these taxa. Damp biomass was estimated from density and size data of subcanopy algae and percent cover data of understory algae using taxon-specific relationships obtained from the literature [27,39–41] or developed specifically for this project (Table S2).

All but two species of algae recorded in the study plots were native to the region; the non-native *Sargassum muticum* and *Codium fragile* occurred in low abundance. Both of these species and *S. horneri* were excluded from analyses to test specifically for the effects of *S. horneri* on the native algal assemblages [42]. The surface canopy-forming giant kelp, *Macrocystis pyrifera*, was present at the beginning of the experiment, but it declined quickly during a warming trend and disappeared by December 2014 for the duration of the study. Consequently, its presence did not factor into our analyses.

The effects of *S. horneri* removal on the taxonomic richness and aggregate biomass of native algae were evaluated using linear mixed effects models [43]. Taxonomic richness was calculated as the number of unique native algal taxa within each plot, and aggregate biomass was calculated as the summed damp biomass of all native algae within each plot. Since we hypothesized that treatment effects may differ among seasons and develop over time, we included season, treatment (S+ or S−) and days since the start of the experiment (elapsed time) as main effects in the model. To account for variation associated with resampling individual plots, we included plot and the summed damp biomass of native algae within each plot at the start of the experiment prior to the first removal of *S. horneri* as random effects. Full models with the main effects in question (i.e., season, removal treatment, elapsed time and the interactions of time–removal treatment and season–removal treatment) were compared against null or full models without the effects in question using likelihood ratio tests with chi-square test statistics to select the best fit based on the Akaike Information Criterion (AIC). Model assumptions of normality and homoscedasticity were validated through visual inspection of the residuals, and biomass data were square-root transformed to meet model assumptions. To identify which time periods contributed to the time-by-removal treatment interaction, we used Tukey's Honest Significant Difference (HSD) post hoc analysis to compare the means of S+ and S− treatments for each sampling period.

Differences in the composition of the algal community between S+ and S− plots were tested using non-metric multi-dimensional scaling (nMDS) and analysis of similarities (ANOSIM). We compared the mean biomass of each taxon in S+ and S− plots in spring and summer 2017, during and after the sampling period when *S. horneri* removal had a significant effect. We used an unrestricted permutation of raw data (999 permutations) on Bray–Curtis similarity matrices with square-root transformation applied. A similarity percentage (SIMPER) analysis was used to determine the taxa that contributed most to dissimilarity between S+ and S− plots.

To determine the amount of shading caused by the *S. horneri* canopy we calculated the percent transmission of photosynthetically active radiation (PAR, 400–700 nm) during the spring sampling periods in S− and S+ plots. Light was measured using a handheld spherical quantum sensor (LI-COR Model LI-192) oriented vertically in the center of each plot 30 cm above the bottom. Ten readings of Photosynthetic Photon Flux Density (PPFD in µmol m^{-2} s^{-1}) were taken in each plot and averaged. Percent transmission was calculated from the average of 10 PPFD readings taken at the surface before and after the dive as:

$$\%\text{ transmission PAR } = \left[1 - \frac{\text{PAR}_{scf} - \text{PAR}_{plot}}{\text{PAR}_{scf}}\right] \times 100$$

We assessed how percent transmission of PAR was affected by *S. horneri* canopy biomass in S+ plots during spring using linear regression. We also tested the hypothesis that the removal of *S. horneri* increases PAR reaching the bottom compared to unmanipulated plots during spring following the initial removal of *S. horneri* using a repeated-measures ANOVA with removal treatment as a fixed factor, and plot and year as random factors. We used one-tailed *t*-tests to determine how the years differed from each other with respect to light transmission because we had an a priori expectation that light would be lower in S+ plots than S− plots. Percent transmission light data were arcsin-transformed prior to analyses to meet the assumptions of ANOVA.

2.3. Complementarity

We examined seasonal patterns of biomass of *Sargassum horneri* and native algae in the experimental plots described above to test their degree of temporal complementarity. Comparisons of native algae and *S. horneri* in S+ plots were used to determine whether the seasonality in biomass differed between the two, while comparisons of native algae in S+ and S− plots were used to determine whether seasonal fluctuations in biomass of native algae occurred independent of *S. horneri* abundance.

We examined the degree of spatial complementarity between *S. horneri* and native algae by comparing their biomass across the depth range within which most species of brown algae at Santa Catalina Island occur (0–30 m). Scuba divers counted the number of recruit (defined as <5 cm tall) and adult (defined as >5 cm tall) *S. horneri* and native species of subcanopy-forming macroalgae within 1 m^2 quadrats placed every 5 m along transects at four sites that ran perpendicular to shore from the intertidal to 30 m depth or where the reef transitioned to sand, whichever came first. Density data were converted to units of damp biomass using the method described above (see 2.2 Competition). Since these algae grow only on hard bottom substrate, we visually estimated the percent cover of rock within each quadrat and standardized density estimates to m^{-2} hard bottom. We performed these surveys in April of 2016, the time of year when the biomass of *S. horneri* reaches its peak [27]. Although smaller native understory species may also compete with *S. horneri*, limits on bottom time prevented us from sampling them.

Measured depths were adjusted relative to the Mean Lower Low Water (MLLW) and quadrats were binned into depth intervals of 5 m. Between one and three quadrats were sampled within each depth interval at each site, depending on the grade of the reef. The aggregate biomass of native algae within a quadrat was calculated as the sum of the biomass of the juvenile and adult stages of all native species measured. A two-way ANOVA was used to test whether the biomass of *S. horneri* and the aggregate biomass of native algae varied by depth interval and taxa.

2.4. Herbivory

We performed grazing assays and surveys of benthic algae within and adjacent to urchin halos to assess whether the palatability of *S. horneri* differed from that of other algae. In September 2016, replicate arrays consisting of *Sargassum horneri*, its native and introduced congeners *S. palmeri* and *S. muticum* and the native kelps *Macrocystis pyrifera* and *Eisenia arborea* were deployed at Isthmus Reef for periods of 48 h. Arrays were either exposed to grazing by urchins and snails or placed inside cages nearby that were designed to exclude these grazers. Cages were constructed from 1 cm-gauge plastic mesh and were cylindrical in shape (1 m in height and 0.5 m in diameter) with mesh covering the top. Cages were open at the bottom and a 1 m-wide weighted skirt secured them to the reef and prevented grazers >1 cm from entering. All urchins and snails were removed from the cages at the beginning of each assay.

During each of the four deployments, 15 arrays containing one sample of each of the five target species of algae were placed in urchin halos while another 15 were placed inside cages. Urchin halos were defined as sections of the reef adjacent to a small ledge where >10 urchins were found and grazing activity was apparent from a lack of algae growing within a 30 cm radius. Some herbivorous snails were also present in the halos, including *Tegula eiseni*, *Tegula aureotincta*, *Megastrea undosa* and *Norrisia norrisii*. Cages were left in the same location for the duration of the experiment, but we selected unique halos for each deployment so that herbivores would be naïve to the arrays. In the day preceding each deployment, we collected and weighed similarly sized blades or thalli of the five target species. Damp weights were quantified prior to deployment and immediately after collection by spin-drying samples for 10 s before weighing them. Three repeat measurements of each sample were taken by re-hydrating the sample and repeating the drying and weighing process. The average of three replicate measurements for each sample was used to optimize our ability to detect small changes in tissue loss.

Herbivore preference was assessed by comparing algal weights measured before and after each deployment in the exposed versus caged arrays. We calculated the percent of biomass lost as:

$$\%\ \Delta = \left[\frac{G_{final} - G_{initial}}{G_{initial}}\right] \times 100$$

where $G_{initial}$ and G_{final} represent the mean of the three replicate weights measured for each sample before and after deployment respectively. For each deployment, exposed and caged arrays were randomly paired and the biomass of each species of algae lost due to grazing was calculated as the difference in the change in biomass between paired arrays. One-way ANOVA was used to evaluate whether the biomass lost due to grazing differed by species, and post hoc contrasts were tested for significance with a Tukey HSD test to determine which species were preferentially consumed. Model assumptions of normality and homoscedasticity were validated through visual inspection of the residuals.

To provide a more time-integrated assessment of the feeding preferences of grazers, we tested whether the relative abundance of *S. horneri* differed from that of native algae in heavily grazed areas during the final deployment. We did this by measuring the percent cover of all subcanopy and understory algae in 1 m^2 quadrats placed adjacent to the 15 urchin halos and at 15 nearby reference locations with high algal cover. Percent cover was assessed using the uniform point contact sampling method described above (see 2.2 Competition). We standardized estimates of cover for individual algal taxa to the total cover of subcanopy and understory algae within each quadrat to compare the relative algal composition adjacent to and away from halos. We ignored encrusting algae and unoccupied space in order to focus on the differences between the foliose algal species that are likely to be consumed by the grazers. Algae were identified to the lowest taxonomic level possible, and were analyzed in the following groups: *S. horneri*, *S. palmeri* and other native algae (Table S3). We used a two-way ANOVA to test whether the cover of these taxonomic groups differed adjacent to and away from urchin halos, and Tukey HSD post hoc contrasts were used to determine how the taxonomic groups differed from one another. Standardized percent cover data were arcsin-transformed prior to analyses to meet the assumptions of ANOVA.

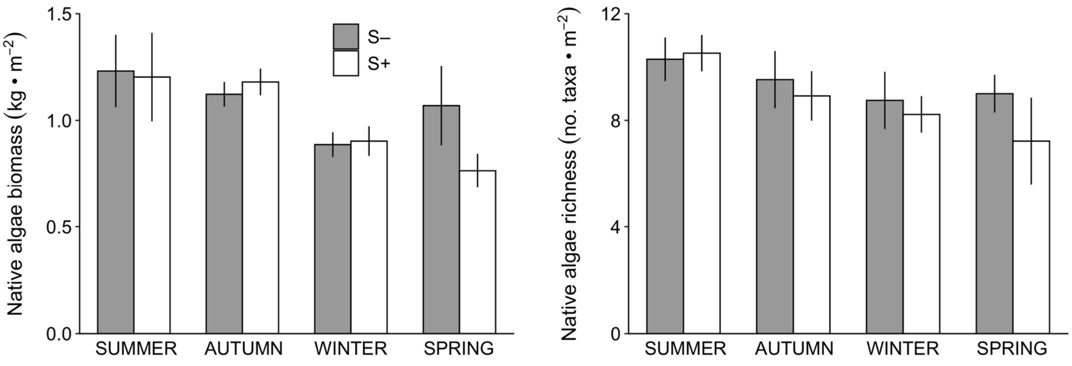
2.5. Software Used for Statistical Analysis

All univariate statistical models and tests were completed using RStudio (version 1.1.414) for R Statistical Computing Package [44]. Linear mixed models were fit using the lme4 package [45], and post hoc comparisons were performed using the multcomp library [46]. All multivariate analyses were conducted using PRIMER v7.0 [47] and PERMANOVA+ for PRIMER [48].

3. Results

3.1. Competition

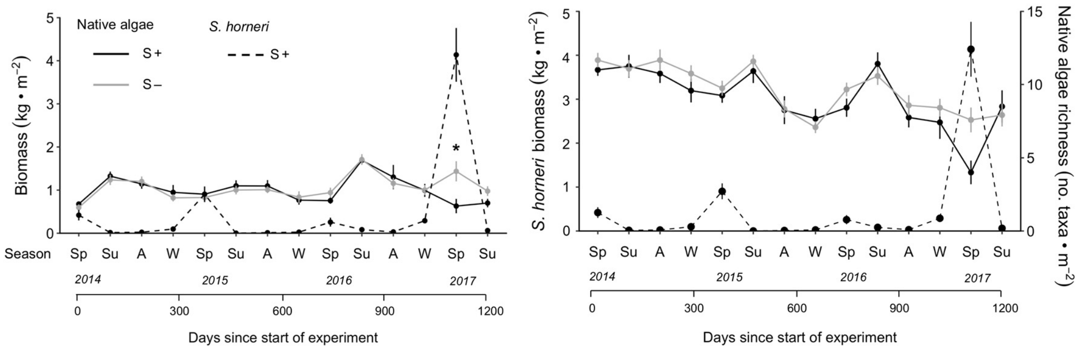
The aggregated biomass and taxonomic richness of native algae varied significantly by season (Table 1). Biomass peaked during summer and autumn, declined by winter and remained low into spring (Figure 1a), while richness also peaked in summer and declined slightly through spring (Figure 1b). The effects of experimentally removing *Sargassum horneri* on the biomass and species richness of native algae were dependent on season (see season × removal interactions in Table 1).



(**a**) (**b**)

Figure 1. Mean (± SE) biomass (**a**) and taxonomic richness (**b**) of all native algae measured in *Sargassum horneri*-removal (S−; grey bars) and non-removal (S+; white bars) plots. N = 4 years for summer, and 3 years for autumn, winter and spring.

Although there was a significant interaction between season and removal for both biomass and species richness, post hoc tests revealed no particular season as driving the difference ($p > 0.05$ for all comparisons). Closer examination of the data revealed that the effects of *S. horneri* removal varied dramatically with days since the start of the experiment (Figure 2) as post hoc testing showed a significant difference in algal biomass between treatments in spring 2017 only, approximately 1100 days since the start of the experiment (Tukey's HSD, $p = 0.002$ indicated by * in Figure 2a; all other periods $p > 0.05$). This difference was driven by a bloom in native algae in S− plots that coincided with a dramatic increase in the biomass of *S. horneri* in S+ plots (Figure 2a). The biomass of native algae in S− and S+ plots began to converge again by summer 2017 when *S. horneri* biomass declined. The taxonomic richness of native algae decreased over the course of the study (Figure 2b), independent of the removal of *S. horneri* (Table 1b).



(**a**) (**b**)

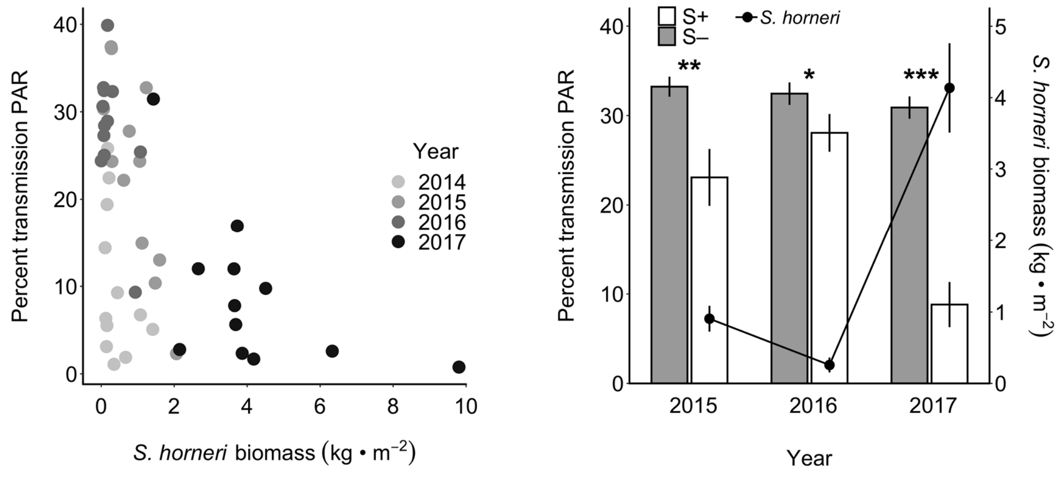
Figure 2. Mean (± SE) biomass (**a**) and taxonomic richness (**b**) of native algae in *Sargassum horneri* -removal (S−; grey solid line) and non-removal (S+; black solid line) plots, overlaid by biomass of *S. horneri* in non-removal plots (S+; dashed line). Asterisk indicates sampling period where multiple comparisons tests (Tukey's HSD, $p < 0.05$) indicated a significant difference between treatments. N = 12 plots per sampling period. First data points in each series are from the pre-removal census.

The percent of photosynthetically active radiation (PAR) reaching the bottom in spring was inversely related to the biomass of *S. horneri* in S+ plots when examined across all four years (Figure 3a; $R^2 = 0.33$, $F_{1,46} = 24.03$, $p < 0.001$). This reduction in light can be attributed to the development of the *S. horneri* canopy, as evidenced by the significant effect of *S. horneri* removal on PAR (Figure 3b; ANOVA, $F_{1,22} = 25.2$, $p < 0.0001$). Post hoc tests revealed that *S. horneri* removal significantly increased PAR in each year (2015: $t = 3.00$, df = 22, $p = 0.003$; 2016: $t = 1.78$, df = 22, $p < 0.04$; 2017: $t = 7.84$, df = 22, $p < 0.001$), especially in 2017 when the biomass of *S. horneri* in S+ plots was greatest.

Table 1. Results from likelihood ratio tests and model selection for determining the influence of experimental removal of *Sargassum horneri* on the (**a**) biomass and (**b**) taxonomic richness of native algae. Independent variables included were: Days since the start of the experiment (Days), *S. horneri* removal treatment (Removal), and season of the sampling period (Season). Individual variables were tested against the null model and interactions were tested against additive models with the same parameters. Models were ranked according to Akaike Information Criterion (AIC) selection with lower AIC values indicating a better fit of the data. Significance was based on chi-square test statistics. Statistically significant *p*-values are in bold text.

Variables	Model	df	AIC	χ^2	Chi df	p (<χ^2)
a. Biomass of native algae [1]						
Individual parameters	Null	4	2140.4			
	Days	5	2139.9	2.52	1	0.112
	Removal	5	2141.9	0.51	1	0.473
	Season	7	2106.3	40.22	3	< **0.001**
Interactions	Days + Removal	6	2141.4			
	Days × Removal	7	2132.2	11.15	1	< **0.001**
	Season + Removal	8	2107.7			
	Season × Removal	11	2104.7	9.02	3	**0.029**
b. Richness of native algae						
Individual parameters	Null	4	1489.7			
	Days	5	1403.8	87.83	1	< **0.001**
	Removal	5	1491.6	0.04	1	0.842
	Season	7	1447.1	48.54	3	< **0.001**
Interactions	Days + Removal	6	1405.8			
	Days × Removal	7	1407.1	0.72	1	0.397
	Season + Removal	8	1449.1			
	Season × Removal	11	1446.6	8.54	3	**0.036**

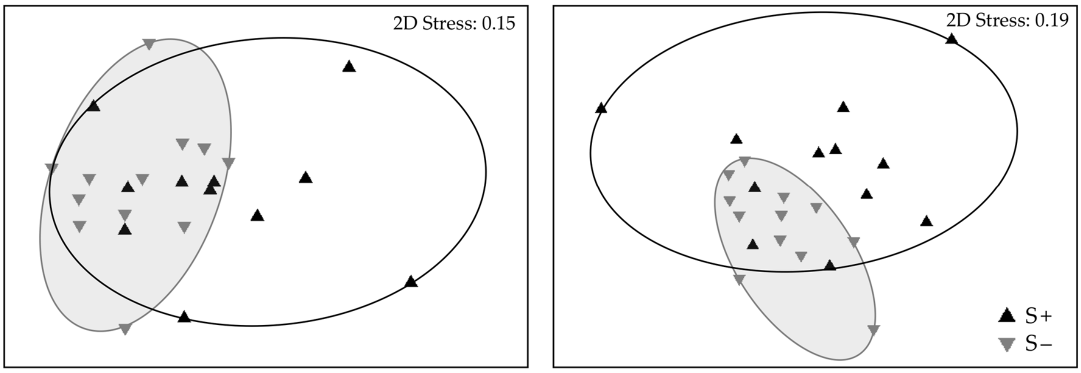
[1] data square-root transformed.



(**a**) (**b**)

Figure 3. Percent transmission (i.e., percent of surface light reaching the bottom) of photosynthetically active radiation (PAR, 400–700 nm) related to *Sargassum horneri* biomass during spring. (**a**) Percent transmission of PAR related to *S. horneri* biomass in non-removal (S+) plots only, with each sampling year indicated by a different shade. (**b**) Effect of *S. horneri* removal on PAR. The left y-axis shows percent transmission of PAR (mean ± SE) in *S. horneri*-removal (S–; grey bars) and non-removal (S+; white bars) plots, and the right y-axis shows damp biomass of *S. horneri* (± SE) in non-removal (S+) plots when light measurements were taken. Asterisks indicate sample dates where *t*-tests indicated significant differences between treatments (*, **, ***: $p < 0.05$, 0.01, and 0.001, respectively).

Since *S. horneri* manipulation had no significant effect on the total biomass of native algae until spring 2017, we restricted our analysis of community structure in S+ and S− plots to data collected during spring and summer 2017. *S. horneri* removal significantly influenced the native algal assemblages in the spring (Figure 4a; PERMANOVA: Pseudo-$F_{1,21}$ = 2.90, p = 0.016) and summer (Figure 4b; Pseudo-$F_{1,22}$ = 2.12, p = 0.041). SIMPER analysis (Table 2) revealed that nearly fifty percent of the dissimilarity between S− and S+ treatments was explained by just two species in spring (*Sargassum palmeri* and *Zonaria farlowii*) and three species in summer (*Z. farlowii*, *S. palmeri* and *Colpomenia sinuosa*).



(**a**) (**b**)

Figure 4. Non-metric multidimensional scaling (nMDS) plots showing benthic algal assemblage structure in plots where *Sargassum horneri* was removed (S−; grey) and in non-removal plots (S+; black) sampled in 2017. Data are presented by season as (**a**) spring and (**b**) summer. *N* = 24 plots. Analysis used damp biomass with a square root transform and Bray–Curtis similarity index. Two-dimensional (2D) stress values indicate the degree of mismatch between the predicted values from the regression of the similarity matrix and the distances between samples.

Table 2. Composition of the native algae present in spring and summer 2017 in unmanipulated (S+) plots and those where *Sargassum horneri* was removed (S−). Data are damp biomass (mean ± SE g·m^{-2}) and the percent contribution of individual taxa to the top 70% of the dissimilarity between S+ and S− treatments in SIMPER analysis.

Taxonomic Group	Taxon	Spring			Summer		
		S+	S−	%	S+	S−	%
Subcanopy algae	*Stephanocystis neglecta*	25.9 ± 15.3	27.2 ± 11.3	7.6	27.5 ± 10.3	19.0 ± 8.1	5.9
	Sargassum palmeri	415.1 ± 154.1	911.3 ± 232.5	29.0	172.3 ± 45.8	262.6 ± 67.6	14.3
Understory algae	Articulated coralline spp.	0 ± 0	1.6 ± 1.6	.	0.4 ± 0.4	1.6 ± 1.6	.
	Asparagopsis taxiformis	0 ± 0	0 ± 0	.	0.3 ± 0.3	1.1 ± 1.1	.
	Brown blade spp.	0 ± 0	6.0 ± 4.3	.	0 ± 0	0 ± 0	.
	Cladophora graminea	0 ± 0	0 ± 0	.	0.1 ± 0.1	0 ± 0	.
	Colpomenia sinuosa	0 ± 0	10.6 ± 8.4	.	148.3 ± 72.3	12.7 ± 5.4	12.3
	Chondria californica	0 ± 0	0.3 ± 0.3		1.1 ± 0.5	0.5 ± 0.4	
	Corallina chilensis	20.2 ± 10.6	30.5 ± 13.0	7.2	13.6 ± 7.4	12.3 ± 7.0	.
	Dictyopteris undulata	3.9 ± 2.2	23.5 ± 6.1	6.6	14.8 ± 6.7	45.9 ± 12.4	7.2
	Dictyota spp.	1.1 ± 0.7	20.4 ± 7.7	.	24.0 ± 11.2	24.0 ± 11.6	.
	Filamentous brown spp.	0 ± 0	0 ± 0	.	0.1 ± 0.1	0 ± 0	.
	Filamentous green spp.	0 ± 0	0.2 ± 0.2	.	0.2 ± 0.2	0.5 ± 0.3	.
	Filamentous red spp.	1.1 ± 1.1	1.2 ± 1.0	.	0 ± 0	2.4 ± 1.9	.
	Green foliose spp.	0 ± 0	0.5 ± 0.5	.	0 ± 0	0 ± 0	.
	Halicystis ovalis	0 ± 0	0 ± 0	.	0.2 ± 0.2	0.7 ± 0.4	.
	Haliptylon gracile	20.6 ± 11.5	20.4 ± 7.9	.	37.8 ± 21.3	28.7 ± 13.4	6.6
	Hydroclathrus clathratus	0 ± 0	0 ± 0	.	8.5 ± 4.2	5.3 ± 4.3	.
	Laurencia pacifica	0.6 ± 0.6	3.6 ± 1.1	.	7.7 ± 3.0	11.3 ± 5.2	.
	Lithothrix aspergillum	19.8 ± 10.0	21.0 ± 11.5	6.5	33.7 ± 20.9	25.1 ± 15.0	6.3
	Plocamium cartilagineum	2.7 ± 2.3	2.2 ± 1.5	.	17.3 ± 10.5	2.4 ± 1.4	.
	Pterocladia capillacea	4.6 ± 4.6	5.3 ± 4.3	.	8.5 ± 4.2	6.4 ± 4.3	.
	Rhodymenia californica	0 ± 0	1.9 ± 1.3	.	1 ± 0.5	0.6 ± 0.4	.
	Scytosiphon lomentaria	0 ± 0	0 ± 0	.	1 ± 0.7	0 ± 0	.
	Zonaria farlowii	171.9 ± 34.9	347.6 ± 72.2	16.2	182.7 ± 47.1	513.2 ± 84.7	17.7
Cumulative % contribution to dissimilarity		-	-	73.1	-	-	70.3

3.2. Complementarity

Sargassum horneri displayed a different seasonal pattern in biomass compared to the aggregated biomass of native algae. There was strong seasonality in the biomass of *S. horneri* in S+ plots, remaining low during summer and autumn, and increasing slightly in winter and dramatically in the spring (Figure 5). By contrast, the aggregated biomass of native algae fluctuated much less throughout the year with highest mean values recorded in summer and biomass declining through winter. In S+ plots, the biomass of native algae continued to decrease into spring, while in S− plots, an increase in the biomass of native algae occurred, which was driven primarily by the native congener *S. palmeri* in spring 2017.

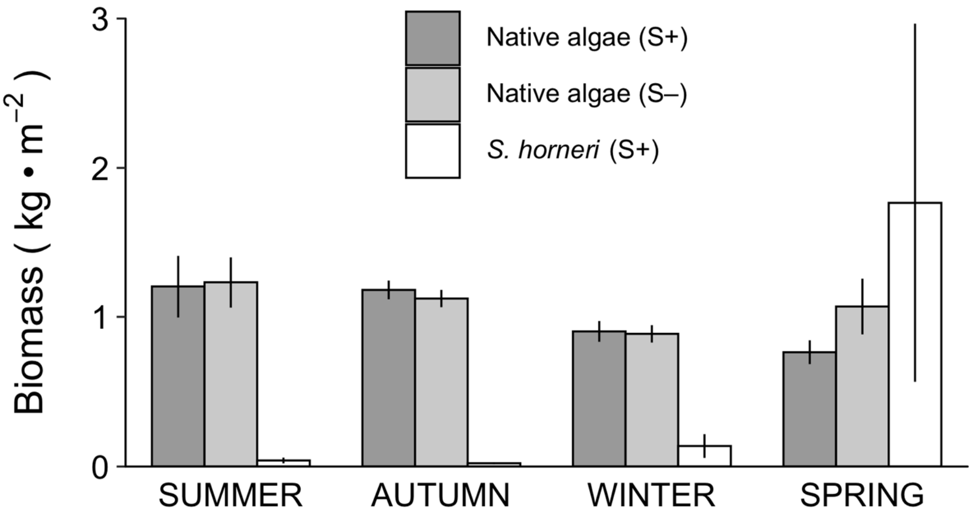


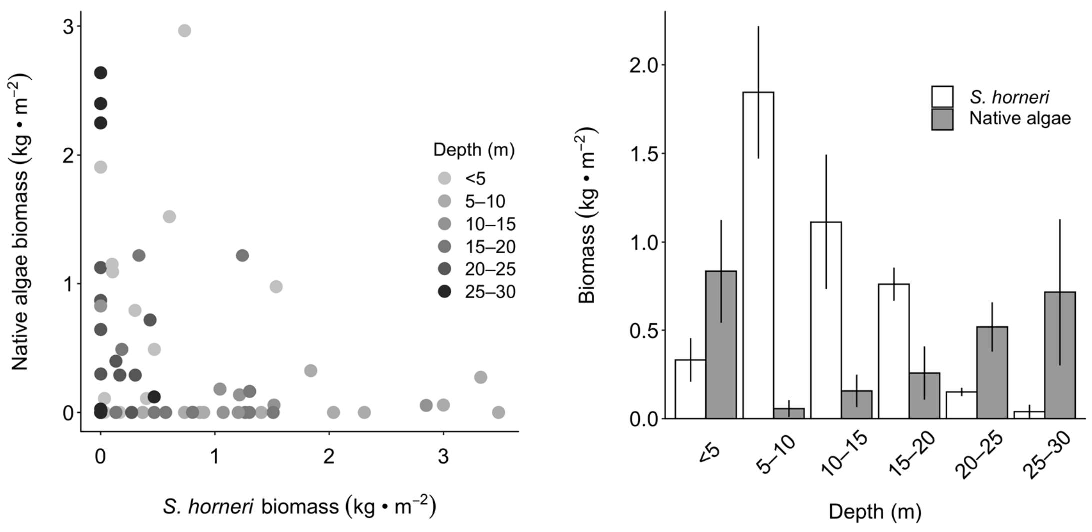
Figure 5. Seasonal mean (± SE) damp biomass of native algae (all species combined) and *Sargassum horneri* in *S. horneri*-removal (S−) and non-removal (S+) plots. *N* = 4 years for summer, and 3 years for autumn, winter and spring.

Results of the depth surveys were consistent with the hypothesis that spatial complementarity with native algae facilitates the invasiveness of *S. horneri.* Two-way ANOVA revealed that the effect of depth on biomass differed for *S. horneri* and native algae ($F_{5,1} = 11.78$, $p < 0.0001$ for depth × taxa interaction), and the two were inversely related (Figure 6a). *S. horneri* was present from the intertidal to the deepest depths sampled, but was most abundant between depths of 5–20 m while the biomass of native algae showed peaks at <5 and >20 m (Figure 6b). The occurrence of specific taxa of native algae varied with depth (Table S4). Biomass of fucoid species (such as *Stephanocystis neglecta*, *Halidrys dioica* and *Sargassum palmeri*) as well as the native kelp *Eisenia arborea* peaked at shallow depths, while *E. arborea* also occurred at deeper depths in addition to another native kelp, *Agarum fimbriatum*.

3.3. Herbivory

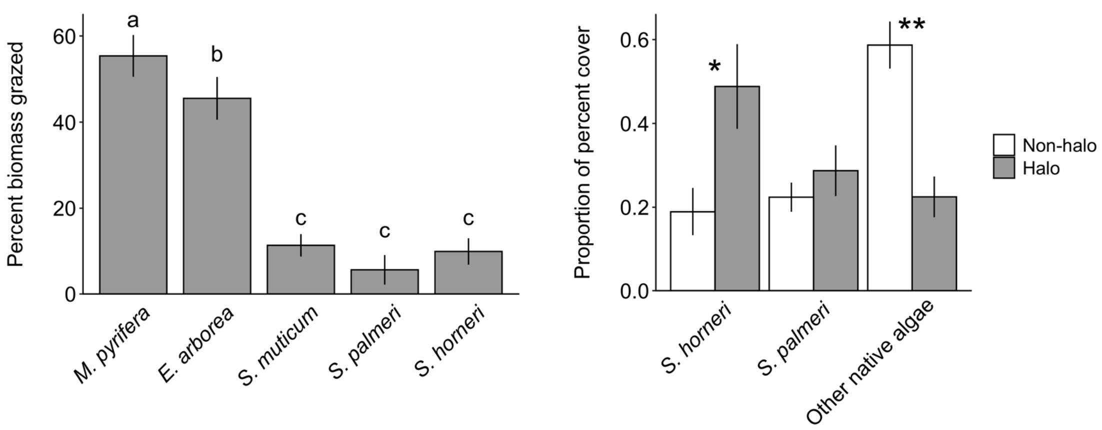
The effects of grazing on the biomass of algae remaining after 48 h assays differed significantly among the five species of algae tested (Figure 7a; ANOVA, $F_4 = 35.146$, $p < 0.001$). Approximately five times more biomass of *Macrocystis pyrifera* and four times more biomass of *Eisenia arborea* was lost due to grazing compared to the three species of *Sargassum*.

Surveys revealed that the taxonomic composition of algae varied between areas adjacent to and away from urchin halos (Figure 7b; Table S3). There was a significant interaction between taxonomic group and proximity on the relative percent cover (ANOVA, $F_{2,1} = 12.97$, $p < 0.0001$). Post hoc tests revealed that the cover of *S. horneri* was approximately two times greater near the halos ($p = 0.01$). By contrast, the proximity to halos had no effect on the cover of *S. palmeri* ($p = 0.98$), while that of other native algae taxa near halos was about one third of the level away from halos ($p = 0.001$).



(**a**) (**b**)

Figure 6. Spatial co-occurrence of *Sargassum horneri* and native algae. Data are damp biomass of *S. horneri* and aggregated damp biomass of all native algae measured within 1 m^2 quadrats sampled along transects running perpendicular to shore. (**a**) Points represent individual quadrats, and are shaded by depth bin. N = 64 quadrats sampled across 4 sites. (**b**) Bars represent mean (± SE) biomass of *S. horneri* (white) and the native algae (grey) by 5 m depth bins. The mean and SE of individual species is provided in Table S4. N = 4 sites per depth bin except 25–30 m where N = 3 sites.



(**a**) (**b**)

Figure 7. Evidence for consumer avoidance of *Sargassum horneri*. (**a**) The difference in percent change in biomass (mean ± SE) in randomly paired samples of algae deployed in urchin halos and away from halos inside mesh cages over 48-h periods. Lower-case letters differentiate statistically significant differences between species (Tukey's HSD, $p < 0.05$). N = 57 paired arrays from four deployments. (**b**) Composition of algae adjacent to urchin halos (grey bars) and in nearby reference areas (white bars). Data are the mean proportion of the total percent cover of algae measured in 1 m^2 quadrats. N = 15 quadrats sampled per treatment. Asterisks indicate a significant difference between treatments (*, **: $p < 0.05, 0.01$, respectively).

4. Discussion

The ability of invasive plants to outcompete native flora for limited resources has been well documented [13,49,50] and is the primary mechanism that has been attributed to the successful invasion of *Sargassum muticum* in the coastal waters off Washington state, USA [30]. Its congener, *S. horneri*, has a similar potential to displace native algae as a result of shading caused by the high canopy biomass it achieves during the spring [27]. However, we found little evidence that competitive superiority explains the high invasiveness of *S. horneri* in California as its sustained removal had a minimal effect on the biomass and composition of native algae over a 3.5-year period. Taxonomic richness of the native flora declined over the course of this study but was unresponsive to *S. horneri* removal. The total biomass of native algae was also unaffected by *S. horneri* manipulation until 2017, when it increased sharply in plots where *S. horneri* had been removed. The increase was driven primarily by a perennial congener, *S. palmeri*. This bloom of *S. palmeri* coincided with a large increase in the ambient biomass of *S. horneri* in spring 2017, which dramatically reduced the amount of light reaching the bottom in non-removal plots. Studies of aquatic plants and animals, marsh grasses and marine macroalgae have shown that impacts scale with the abundance of an invader (e.g., [51–54]). In this study, *S. horneri* had no detectable effects until it reached extremely high abundance, at which point only modest impacts to the native algal community occurred, driven primarily by a single closely related species.

The strength of competition between introduced and native species can vary spatially and temporally, depending on fluctuations in biomass driven by species' life histories or environmental factors [55]. The seasonal phenology of the macroalgal community suggested that *S. horneri*'s peak biomass was generally complementary to that of most of the native macroalgae, whose biomass tended to be highest in summer. This pattern was consistent regardless of the presence of *S. horneri* (i.e., in removal and non-removal plots) except during spring 2017 when *S. horneri* was extremely abundant, suggesting it was not a consequence of *S. horneri*, but rather a natural cycle. This conclusion is substantiated by similar estimates of seasonal biomass of native algae at Santa Catalina Island and elsewhere in southern California prior to invasion by *S. horneri* [39,56]. Since the giant kelp, *M. pyrifera*, was absent from our survey and experimental sites throughout nearly the entire course of this study, it did not factor into our analyses. However, like the other native algae we observed, the biomass of *M. pyrifera* in southern California often peaks in the summer and autumn and drops during winter and spring due to wave-induced disturbance to the canopy [57]. Hence, the success of *S. horneri* may be attributed in part to the decreased abundance of native algae during its period of peak growth and reproduction.

The depth distribution of *S. horneri* relative to that of native subcanopy algae could reflect the strength of their competitive interactions or physiological preferences for different parts of the environment. We found that *S. horneri* displayed spatial complementarity with other subcanopy algae as it was most abundant at intermediate depths (5–20 m), while native algae were most abundant at shallower (<5 m) and deeper (>20 m) depths. That the depth distributions of native subcanopy algae observed in our surveys were similar to those reported by others at Santa Catalina Island prior to the arrival of *S. horneri* [58–61] suggests that their lower abundance at intermediate depths was not due to competition with *S. horneri*.

The reasons for the peak in *S. horneri* abundance at intermediate depths in our study are unknown. However, the distribution of *S. horneri* in other regions indicates great versatility in light requirements, and opportunistic growth in situations where competition is minimal. For example, in its native range in Japan, *S. horneri* grows from the intertidal to 20 m [62] but is most common on shallow reefs from the low intertidal to 4 m [63]. In Baja California, Mexico, near the southern extent of its invaded range, *S. horneri* has been reported to occur from the intertidal [64,65] to at least 8 m depth [66]. Perhaps robust subcanopy-forming macroalgal communities at Santa Catalina Island deter *S. horneri* at very deep (>20 m) and very shallow (<5 m) depths, while increased space and light available at intermediate depths allow *S. horneri* to thrive with minimal competition. Such appears to be the case for the annual Asian kelp, *Undaria pinnatifida*, whose invasion success in the United Kingdom has been attributed in part to its broad depth range as well as its niche dissimilarities with native algae as the abundances of *U. pinnatifida* and native algae were inversely correlated along a depth gradient [67].

Our findings revealed that *S. horneri* has the greatest biomass at depths where, and times when, the abundance of native macroalgae is lowest. The consistent phenology of *S. horneri* in its native and invaded range [27] and of most native algae in the presence or absence of *S. horneri* suggest that niche complementarity between them occurs throughout the year. Recent work by Sullaway and Edwards [68] at nearby sites at Santa Catalina Island supports this idea, showing that *S. horneri* increased rather than decreased levels of community production and respiration in this system. They concluded that *S. horneri* takes advantage of environmental conditions that disturb native algae and thrives as a consequence of disturbance, rather than causing an ecosystem shift due to its ability to outcompete the native flora [69]. Consistent with this idea is the observation by Caselle et al. [7] that *S. horneri* abundance at nearby Anacapa Island was significantly lower in older, well-established marine protected areas (MPAs) where the abundance of native algae was high relative to newly established MPAs. These authors argued that the differences in *S. horneri* abundance between new and old MPAs reflect stronger competition between native algae and *S. horneri* in the older MPAs where native algae flourish. Thus, niche complementarity may allow *S. horneri* to achieve high abundance only in places where competition from native algae is not strong.

Herbivores can influence the invasion success of freshwater and marine macrophytes directly through consumption of the invader, or they can mediate interspecific competition through preferential consumption of native species [23,36,37,70]. These preferences may arise from morphological differences or chemical defenses. For example, algae in the order Fucales (which includes the genus *Sargassum)* typically have high levels of phenolic compounds that are known to deter grazing [37]. Our results are consistent with this hypothesis, demonstrating that grazers consumed the native kelps *M. pyrifera* and *E. arborea* while avoiding *S. horneri* and its congeners *S. palmeri* and *S. muticum*. Our results also support the hypothesis posed by Caselle et al. [7] that urchins avoid *S. horneri* and preferentially consume native algae in areas where they co-occur, thereby reducing the potential for competition between them.

The composition of the benthic algal community reflected the grazer preferences we observed. *Centrostephanus centrotus*, the most abundant species of sea urchin in our study, is known to display strong feeding preferences, decreasing the abundance of favored species dramatically before switching to less-preferred species [38]. We found that native foliose algae were reduced and *S. horneri* was more dominant adjacent to urchin halos compared to nearby reference areas. Interestingly, we found no biomass response to grazing by its perennial congener *S. palmeri,* which is native to southern California. Thus while grazers avoided both species of *Sargassum* in favor of native foliose algae, only *S. horneri* responded to a lack of herbivory with increased abundance. It may be that *S. horneri* is able to colonize space created on the reef more readily than *S. palmeri* due to its annual life history and high fecundity. Traits related to rapid growth and high fecundity, as well as deterrence to herbivory, are often associated with invasive plants [71]. However, defenses often come at a fitness cost [72] and shorter lived, r-selected plants are not typically heavily defended [73]. Yet *S. horneri* is a species with r-selected traits that allow it to rapidly colonize available space, and it is also a member of an order of algae that typically displays high levels of chemical defense. These traits undoubtedly contribute to the ability of *S. horneri* to proliferate in places where interactions with native species are weak.

5. Conclusions

We found that the high propensity of *S. horneri* to invade southern California reefs results largely from its ability to occupy resources underutilized by native species in space and time and to resist grazing relative to native algae. Its annual life history, high fecundity and capacity for widespread dispersal further enhance its ability to colonize novel habitats. The complementary phenology of *S. horneri* and native algae suggest competition between them is generally weak, which is consistent with the results of our 3.5-year manipulative experiment. Our findings indicate the greatest potential for competitive interactions between *S. horneri* and native algae is at intermediate depths during spring when *S. horneri* peaks in biomass. Future work testing the effects of *S. horneri* on native algae should focus on this depth range and season. Collectively, our results highlight the importance of considering exotic marine species in the context of the invasibility of native assemblages when assessing their invasiveness and developing management strategies for controlling their spread.

Supplementary Materials: The following are available online at http://www.mdpi.com/1424-2818/12/2/54/s1, Table S1: List of native subcanopy and understory algal taxa recorded in the *Sargassum horneri* removal experiment, Table S2: Coefficients (a = intercept, b = slope), r^2, and p values or SE for formulas to convert size-specific density, or percent cover to damp biomass (g), Table S3: Proportional percent cover of algae adjacent to and away from sea urchin halos, Table S4: Depth distribution of *Sargassum horneri* and native subcanopy algae. The data presented in this manuscript are available online for download from the Long Term Ecological Research Network Data Portal, doi:10.6073/pasta/2c2237bb3cee86e7c6d9488e8ce2795d [74].

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References

1. Cohen, A.N.; Carlton, J.T. Accelerating invasion rate in a highly invaded estuary. *Science* **1998**, *279*, 555–558. [CrossRef]
2. Stachowicz, J.J.; Terwin, J.R.; Whitlatch, R.B.; Osman, R.W. Linking climate change and biological invasions: Ocean warming facilitates nonindigenous species invasions. *Proc. Natl. Acad. Sci. USA* **2002**, *99*, 15497–15500. [CrossRef]
3. Molnar, J.L.; Gamboa, R.L.; Revenga, C.; Spalding, M.D. Assessing the global threat of invasive species to marine biodiversity. *Front. Ecol. Environ.* **2008**, *6*, 485–492. [CrossRef]
4. Sorte, C.J.; Williams, S.L.; Zerebecki, R.A. Ocean warming increases threat of invasive species in a marine fouling community. *Ecology* **2010**, *91*, 2198–2204. [CrossRef]
5. Seebens, H.; Gastner, M.T.; Blasius, B. The risk of marine bioinvasion caused by global shipping. *Ecol. Lett.* **2013**, *16*, 782–790. [CrossRef] [PubMed]
6. Papacostas, K.J.; Rielly-Carroll, E.W.; Georgian, S.E.; Long, D.J.; Princiotta, S.D.; Quattrini, A.M.; Reuter, K.E.; Freestone, A.L. Biological mechanisms of marine invasions. *Mar. Ecol. Prog. Ser.* **2017**, *565*, 251–268. [CrossRef]
7. Caselle, J.C.; Davis, K.; Marks, L.M. Marine management affects the invasion success of a non-native species in a temperate reef system in California, USA. *Ecol. Lett.* **2018**, *21*, 43–53. [CrossRef] [PubMed]
8. Elton, C.S. *The Ecology of Invasions by Animals and Plants*; Methuen: London, UK, 1958; 181p.
9. Levine, J.M.; Adler, P.B.; Yelenik, S.G. A meta-analysis of biotic resistance to exotic plant invasions. *Ecol. Lett.* **2004**, *7*, 975–989. [CrossRef]
10. Maron, J.L.; Vilà, M. When do herbivores affect plant invasion? Evidence for the natural enemies and biotic resistance hypotheses. *Oikos* **2001**, *95*, 361–373. [CrossRef]
11. Parker, J.D.; Hay, M.E. Biotic resistance to plant invasions? Native herbivores prefer non-native plants. *Ecol. Lett.* **2005**, *8*, 959–967. [CrossRef]
12. Valéry, L.; Fritz, H.; Lefeuvre, J.C.; Simberloff, D. In search of a real definition of the biological invasion phenomenon itself. *Biol. Invasions* **2008**, *10*, 1345–1351. [CrossRef]
13. Fleming, J.P.; Dibble, E.D. Ecological mechanisms of invasion success in aquatic macrophytes. *Hydrobiologia* **2015**, *746*, 23–37. [CrossRef]
14. MacArthur, R.; Levins, R. The limiting similarity, convergence, and divergence of coexisting species. *Am. Nat.* **1967**, *101*, 377–385. [CrossRef]
15. Spencer, D.F.; Rejmanek, M. Propagule type influences competition between two submersed aquatic macrophytes. *Oecologia* **1989**, *81*, 132–137. [CrossRef] [PubMed]

16. Petruzzella, A.; Manschot, J.; van Leeuwen, C.H.A.; Grutters, B.M.C.; Bakker, E.S. Mechanisms of invasion resistance of aquatic plant communities. *Front. Plant Sci.* **2018**, *9*, 1–11. [CrossRef]
17. Madsen, J.D. Predicting invasion success of Eurasian watermilfoil. *J. Aquat. Plant Manag.* **1998**, *36*, 28–32. [CrossRef]
18. Crawley, M.J.; Harvey, P.H.; Purvis, A. Comparative ecology of the native and alien floras of the British Isles. *Philos. Trans. R. Soc. Lond. B. Biol. Sci.* **1996**, *351*, 1251–1259. [CrossRef]
19. Lloret, F.; Medail, F.; Brundu, G.; Camarda, I.; Moragues, E.; Rita, J.; Lambdon, P.; Hulme, P. Species attributes and invasion success by alien plants on Mediterranean islands. *J. Ecol.* **2005**, *93*, 512–520. [CrossRef]
20. Mack, R.N. Phylogenetic constraint, absent life forms, and preadapted alien plants: A prescription for biological invasions. *Int. J. Plant Sci.* **2003**, *164*, 185–196. [CrossRef]
21. Muthukrishnan, R.; Hansel-Welch, N.; Larkin, D.J.; Nilsson, C. Environmental filtering and competitive exclusion drive biodiversity-invasibility relationships in shallow lake plant communities. *J. Ecol.* **2018**, *106*, 2058–2070. [CrossRef]
22. Grosholz, E. Avoidance by grazers facilitates spread of an invasive hybrid plant. *Ecol. Lett.* **2010**, *13*, 145–153. [CrossRef] [PubMed]
23. Pulzatto, M.M.; Lolis, L.A.; Louback-Franco, N.; Mormul, R.P. Herbivory on freshwater macrophytes from the perspective of biological invasions: A systematic review. *Aquat. Ecol.* **2018**, *52*, 297–309. [CrossRef]
24. Miller, K.A.; Engle, J.M.; Uwai, S.; Kawai, H. First report of the Asian seaweed *Sargassum filicinum* Harvey (Fucales) in California, USA. *Biol. Invasions* **2007**, *9*, 609–613. [CrossRef]
25. Marks, L.M.; Salinas-Ruiz, P.; Reed, D.C.; Holbrook, S.J.; Culver, C.S.; Engle, J.M.; Kushner, D.J.; Caselle, J.E.; Freiwald, J.; Williams, J.P.; et al. Range expansion of a non-native, invasive macroalga *Sargassum horneri* (Turner) C. Agardh, 1820 in the eastern Pacific. *BioInvasions Rec.* **2015**, *4*, 243–248. [CrossRef]
26. Baker, H.G. Characteristics and modes of origin of weeds. In *The Genetics of Colonizing Species*; Baker, H.G., Stebbins, G.L., Eds.; Academic Press: New York, NY, USA, 1965; Volume X, pp. 147–168.
27. Marks, L.M.; Reed, D.C.; Holbrook, S.J. Life history traits of the invasive seaweed *Sargassum horneri* at Santa Catalina Island, California. *Aquat. Invasions* **2018**, *13*, 339–350. [CrossRef]
28. DeWreede, R.E. *Sargassum muticum* (Fucales, Phaeophyta): Regrowth and interaction with *Rhodomelalarix* (Ceramiales, Rhodophyta). *Phycologia* **1983**, *22*, 153–160. [CrossRef]
29. Casas, G.; Scrosati, R.; Piriz, L. The invasive kelp *Undaria pinnatifida* (Phaeophyceae, Laminariales) reduces native seaweed diversity in Nuevo Gulf (Patagonia, Argentina). *Biol. Invasions* **2004**, *6*, 411–416. [CrossRef]
30. Britton-Simmons, K.H. Direct and indirect effects of the introduced alga *Sargassum muticum* on benthic, subtidal communities of Washington State, USA. *Mar. Ecol. Prog. Ser.* **2004**, *27*, 61–78. [CrossRef]
31. Mann, K.H. Destruction of kelp beds by sea urchins: A cyclical phenomenon or irreversible degradation? *Helgolander Wissenshaftlichen Meeresuntersuchungen* **1977**, *30*, 455–732. [CrossRef]
32. Shears, N.T.; Babcock, R.C. Marine reserves demonstrate top-down control of community structure on temperate reefs. *Oecologia* **2002**, *132*, 131–142. [CrossRef]
33. Lafferty, K.D. Fishing for lobsters indirectly increases epidemics in sea urchins. *Ecol. Appl.* **2004**, *14*, 1566–1573. [CrossRef]
34. Geiselman, J.A.; McConnell, O.J. Polyphenols in brown algae *Fucus vesiculosus* and *Ascophyllum nodusum*: Chemical defenses against the marine herbivorous snail, *Littorina littorea*. *J. Chem. Ecol.* **1981**, *8*, 1115–1133. [CrossRef] [PubMed]
35. Alstyne, K.L. Herbivore grazing increases polyphenolic defenses in the intertidal brown algae *Fucus distichus*. *Ecology* **1988**, *69*, 655–663. [CrossRef]
36. Estes, J.A.; Steinberg, P.D. Predation, herbivory, and kelp evolution. *Paleobiology* **1988**, *4*, 19–36. [CrossRef]
37. Van Alstyne, K.L.; McCarthy, J.J., III; Hustead, C.L.; Duggins, D.O. Geographic variation in polyphenolic levels of Northeastern Pacific kelps and rockweeds. *Mar. Biol.* **1999**, *133*, 371–379. [CrossRef]
38. Vance, R.R.; Schmitt, R.J. The effect of the predator-avoidance behavior of the sea urchin, *Centrostephanus coronatus*, on the breadth of its diet. *Oecologia* **1979**, *44*, 21–25. [CrossRef]
39. Harrer, S.L.; Reed, D.C.; Miller, R.J.; Holbrook, S.J. Patterns and controls of the dynamics of net primary production by understory macroalgal assemblages in giant kelp forests. *J. Phycol.* **2013**, *49*, 248–257. [CrossRef]
40. Nelson, J.; Reed, D.; Harrer, S.; Miller, R. SBC LTER: Reef: Coefficients for estimating biomass from body size or percent cover for kelp forest species. *Environ. Data Initiat.* **2020**, in press.

41. *Santa Barbara Coastal Long Term Ecological Research*; SBC LTER (University of California Santa Barbara): Santa Barbara, CA, USA, 2019; Unpublished data.
42. Thomsen, M.S.; Wernberg, T.; South, P.M.; Schiel, D.R. To include or not to include (the invader in community analyses)? that is the question. *Biol. Invasions* **2016**, *18*, 1515–1521. [CrossRef]
43. Gelman, A.; Hill, J. *Data Analysis Using Regression and Multilevel/Hierarchical Models*, 2nd ed.; Cambridge University Press: London, UK, 2006; p. 648.
44. RStudio Team (2019). RStudio: Integrated Development for R. RStudio, Inc.: Boston, MA, USA. Available online: http://www.rstudio.com/ (accessed on 14 December 2019).
45. Bates, D.; Maechler, M.; Bolker, B.; Walker, S. Fitting Linear Mixed-Effects Models Using lme4. *J. Stat. Softw.* **2015**, *67*, 1–48. [CrossRef]
46. Hothorn, T.; Bretz, F.; Westfall, P. Simultaneous inference in general parametric models. *Biom. J.* **2008**, *50*, 346–363. [CrossRef] [PubMed]
47. Clarke, K.R.; Gorley, R.N. *PRIMER v7: User Manual/Tutorial*, 1st ed.; PRIMER-E: Plymouth, UK, 2015; p. 300.
48. Anderson, M.J.; Gorley, R.N.; Clarke, K.R. *PERMANOVA+ for PRIMER: Guide to Software and Statistical Methods*; PRIMER-E: Plymouth, UK, 2018; p. 214.
49. Levine, J.M.; Vilà, M.; D'Antonio, C.M.; Dukes, J.S.; Grigulis, K.; Lavorel, S. Mechanisms underlying the impacts of exotic plant invasions. *Proc. R. Soc. Lond. B* **2003**, *270*, 775–781. [CrossRef] [PubMed]
50. Vilà, M.; Weiner, J. Are invasive plant species better competitors than native plant species? – evidence from pair-wise experiments. *Oikos* **2004**, *105*, 229–238. [CrossRef]
51. Thomsen, M.S.; Wernberg, T.; Tuya, F.; Silliman, B.R. Evidence for impacts of nonindigenous macroalgae: A meta-analysis of experimental field studies. *J. Phycol.* **2009**, *45*, 812–819. [CrossRef] [PubMed]
52. Theuekauf, S.J.; Pukett, B.J.; Theuekauf, K.W.; Theuerkauf, E.J.; Eggleston, D.B. Density-dependent role of an invasive marsh grass, *Phragmites australis*, on ecosystem service provision. *PLoS ONE* **2017**, *12*, e0173007. [CrossRef]
53. White, L.F.; Shurin, J.B. Density dependent effects of an exotic marine macroalga on native community diversity. *J. Exp. Mar. Biol. Ecol.* **2011**, *405*, 111–119. [CrossRef]
54. Olson, E.R.; Doherty, J.M. Macrophyte diversity-abundance relationship with respect to invasive and native dominants. *Aquat. Bot.* **2014**, *119*, 111–119. [CrossRef]
55. Shea, K.; Chesson, P. Community ecology theory as a framework for biological invasions. *Trends Ecol. Evol.* **2002**, *17*, 170–176. [CrossRef]
56. Benes, K.M.; Carpenter, R.C. Kelp canopy facilitates understory algal assemblage via competitive release during early stages of secondary succession. *Ecology* **2015**, *96*, 241–251. [CrossRef]
57. Reed, D.C.; Rassweiler, A.; Arkema, K. Density derived estimates of standing crop and net primary production in the giant kelp *Macrocystis pyrifera*. *Mar. Biol.* **2009**, *156*, 2077–2083. [CrossRef]
58. Kastendiek, J. Competitor-mediated coexistence: Interactions among three species of benthic macroalgae. *J. Exp. Mar. Biol. Ecol.* **1982**, *62*, 201–210. [CrossRef]
59. Anderson, T.W. Role of macroalgal structure in the distribution and abundance of a temperate reef fish. *Mar. Ecol. Prog. Ser.* **1994**, *113*, 279–290. [CrossRef]
60. Lafferty, K.D.; Behrens, M.D.; Davis, G.E.; Haaker, P.L.; Kushner, D.J.; Richards, D.V.; Taniguchi, I.K.; Tegner, M.J. Habitat of endangered white abalone, *Haliotis sorenseni*. *Biol. Conservation* **2004**, *116*, 191–194. [CrossRef]
61. Morrow, K.; Carpenter, R. Shallow kelp canopies mediate macroalgal composition: effects on the distribution and abundance of *Corynactis californica* (Corallimorpharia). *Mar. Ecol. Prog. Ser.* **2008**, *361*, 119–127. [CrossRef]
62. Yoshida, T. Japanese species of *Sargassum* subgenus *Bactrophycus* (Phaeophyta, Fucales). *J. Fac. Sci. Hokkaido Univ. Ser. V (Botany)* **1983**, *13*, 99–246.
63. Tkaba, M.; Mizokami, A. Seasonal fluctuation of *Sargassum* communities and vertical distribution of Sargassaceae at Kuroshima Island in the western Akinada. *Bull. Hiroshima. Fish. Exp. Stn.* **1982**, *12*, 33–44.
64. Aguilar-Rosas, L.E.; Aguilar-Rosas, R.; Kawai, H.; Uwai, S.; Valenzuela-Espinoza, E. New record of *Sargassum filicinum* Harvey (Fucales, Phaeophyceae) in the Pacific coast of Mexico. *Algae* **2007**, *22*, 17–21. [CrossRef]
65. Cruz-Trejo, G.I.; Ibarra-Obando, S.E.; Aguilar-Rosas, L.E.; Poumian-Tapia, M.; Solana-Arellano, E. Presence of *Sargassum horneri* at Todos Santos Bay, Baja California, Mexico: its effects on the local macroalgae community. *Am. J. Plant Sci.* **2015**, *6*, 2693–2707. [CrossRef]

66. Riosmena-Rodríguez, R.; Boo, G.H.; López-Vivas, J.M.; Hernández-Velasco, A.; Sáenz-Arroyo, A.; Boo, S.M. The invasive seaweed *Sargassum filicinum* (Fucales, Phaeophyceae) is on the move along the Mexican Pacific coastline. *Bot. Mar.* **2012**, *55*, 547–551. [CrossRef]
67. Epstein, G.; Hawkins, S.; Smale, D. Identifying niche and fitness dissimilarities in invaded marine macroalgal canopies within the context of contemporary coexistence theory. *Sci. Rep.* **2019**, *9*, 8816. [CrossRef]
68. Sullaway, G.; Edwards, M. Impacts of the non-native alga, *Sargassum horneri*, on benthic community production in a California Kelp Forest. *Mar. Ecol. Prog. Ser.* **2020**, in press. [CrossRef]
69. MacDougall, A.S.; Turkington, R. Are invasive species the drivers or passengers of change in degraded ecosystems? *Ecology* **2005**, *86*, 42–55. [CrossRef]
70. Bulleri, F.; Tamburello, L.; Beneditti-Cecchi, L. Loss of consumers alters the effects of resident assemblages on the local spread of an introduced macroalga. *Oikos* **2009**, *118*, 269–279. [CrossRef]
71. Pyšek, P.; Richardson, D.M. Traits associated with invasiveness in alien plants: where do we stand. In *Biol. Invasions*; Nentwig, W., Ed.; Springer-Verlag: Berlin, Germany, 2007; pp. 97–125. [CrossRef]
72. Koricheva, J. Meta-analysis of sources of variation in fitness costs of plant antiherbivore defenses. *Ecology* **2002**, *83*, 176–190. [CrossRef]
73. Strauss, S.; Rudgers, J.A.; Lau, J.A.; Irwin, R.E. Direct and ecological costs of resistance to herbivory. *Trends Ecol. Evol.* **2002**, *17*, 278–285. [CrossRef]
74. Marks, L.; Reed, D.; Holbrook, S. SBC LTER: REEF: Data to support "Niche complementarity and resistance to grazing promote the invasion success of *Sargassum horneri* in North America". *Environ. Data Initiat* **2020**. [CrossRef]

Region Nine Kelp Consortium
Annual Meeting
August 18, 2020

Size of Kelp Beds in 2019
Orange & San Diego Counties

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OUTLINE OF PRESENTATION

1. Background Information
2. Survey Methods
3. Region Nine Survey Results
    - Status in 2018
    - Regional Overview for 2019
    - Descriptions of Individual Beds
4. Factors Affecting Kelp Beds
5. Conclusions
6. Preview of 2020

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BACKGROUND INFORMATION

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Region Nine Kelp Surveys

- Annual surveys each year >50 years (1967 to 2019)
- Methods developed by Dr. Wheeler North, Caltech (Pasadena)
- Region Nine Kelp Survey Consortium formed in 1982 (San Diego RWQCB and several ocean dischargers)
- Program funded by NPDES permit requirements for major dischargers

Central Region Kelp Surveys

- Sporadic surveys >50 years (five from 1967 to 1998, annually 1999 to 2019, except 2001)
- Central Region Kelp Survey Consortium formed in 2003 (Los Angeles RWQCB and several ocean dischargers)
- Used Region Nine model - program funded by NPDES permit requirements for major dischargers

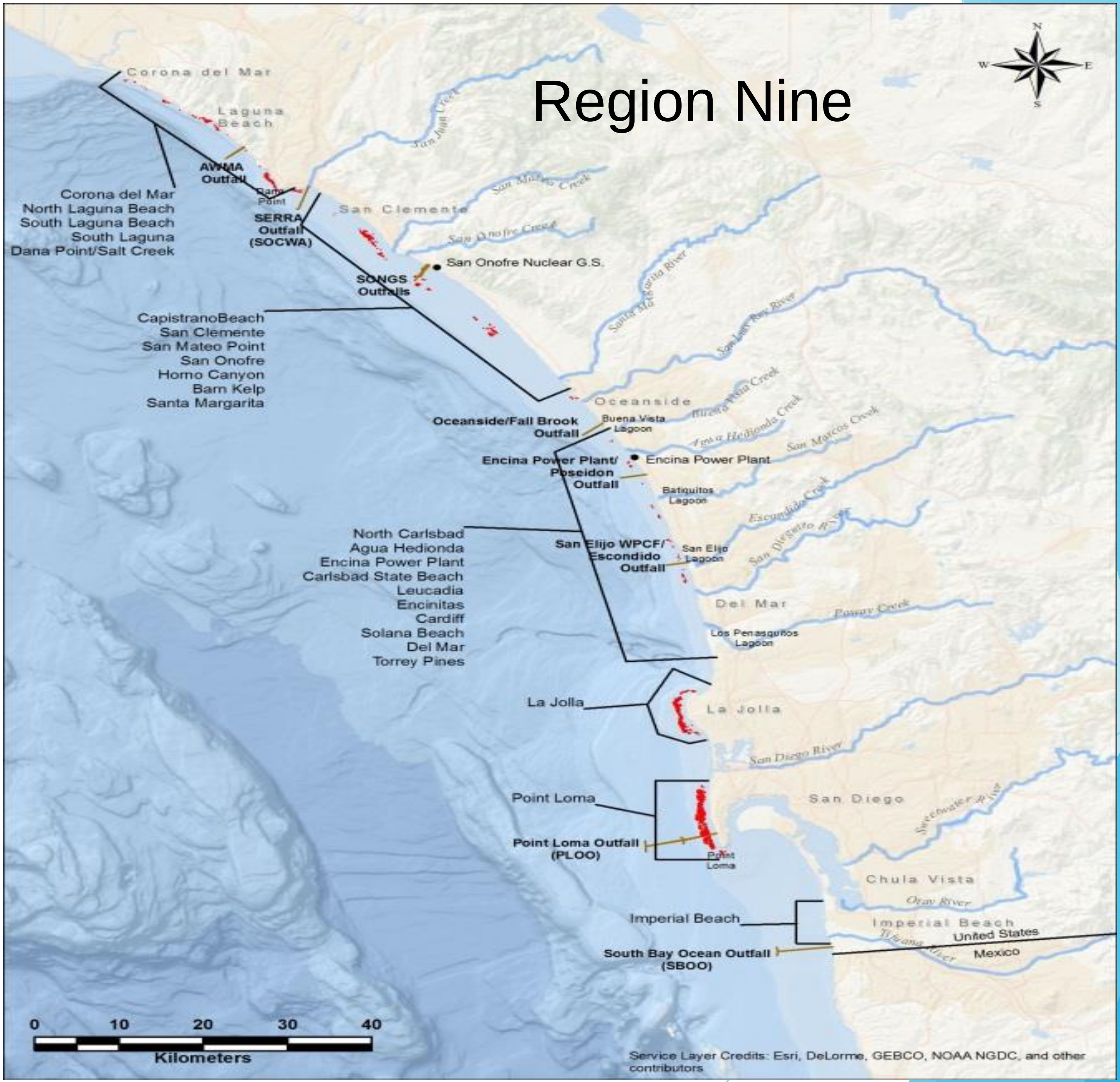
SoCal Kelp Consortia Web Site

- https://www.mbcaquatic.com/service/socal-kelp-consortium

- Annual reports: 2010 to 2018
- List of consortium members for Region Nine and Central Region
- Meeting information
- Status of kelp in 2018

SURVEY METHODS

Region Nine



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Kelp Overflights

- Ecoscan (Santa Cruz)
- Cessna 182
- 30-mm lens
- Color IR film

@200 photos per survey

- 10-14,000 feet
- Wind <10 knots
- Swell <1.5 m
- Tides <1 foot range
- Sun angle >30°

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2019 Kelp Overflights

Survey	Date
1st Quarter	March 31, 2019
2nd Quarter	July 19, 2019
3rd Quarter	September 19, 2019
4th Quarter	December 19, 2019

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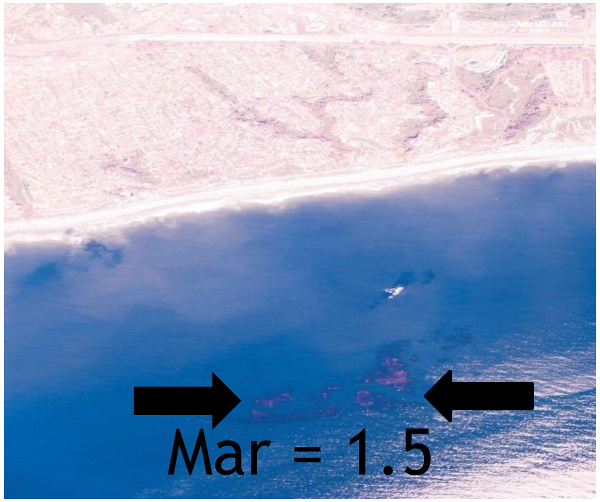
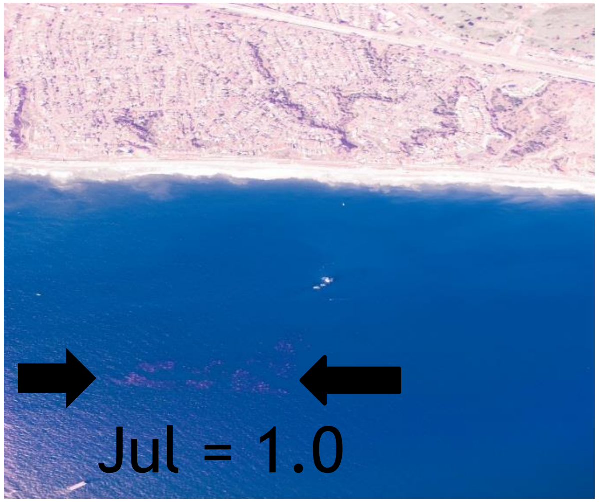
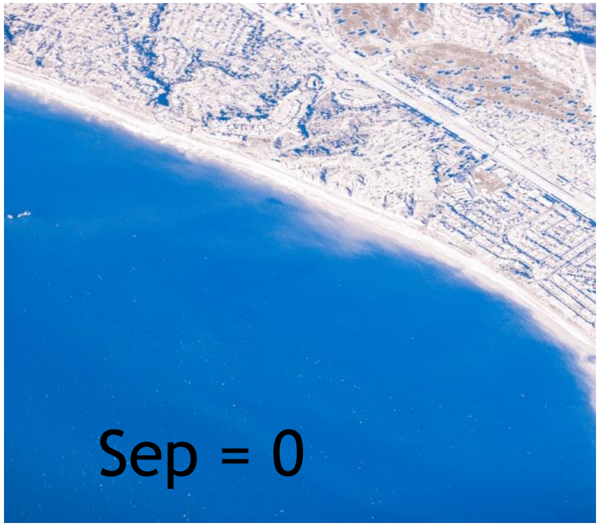
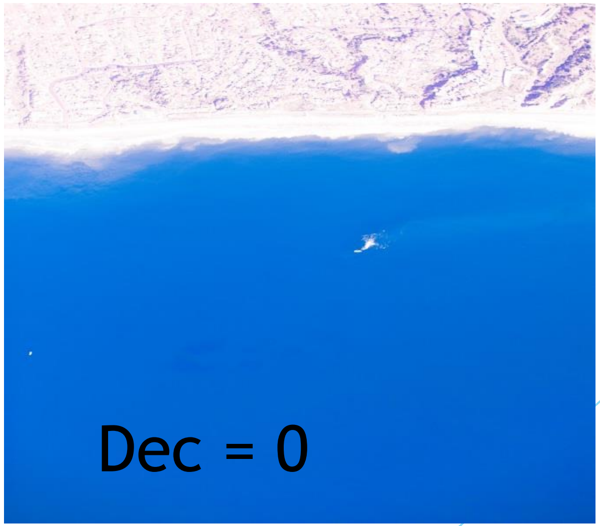
Maximum Canopy Area
San Clemente









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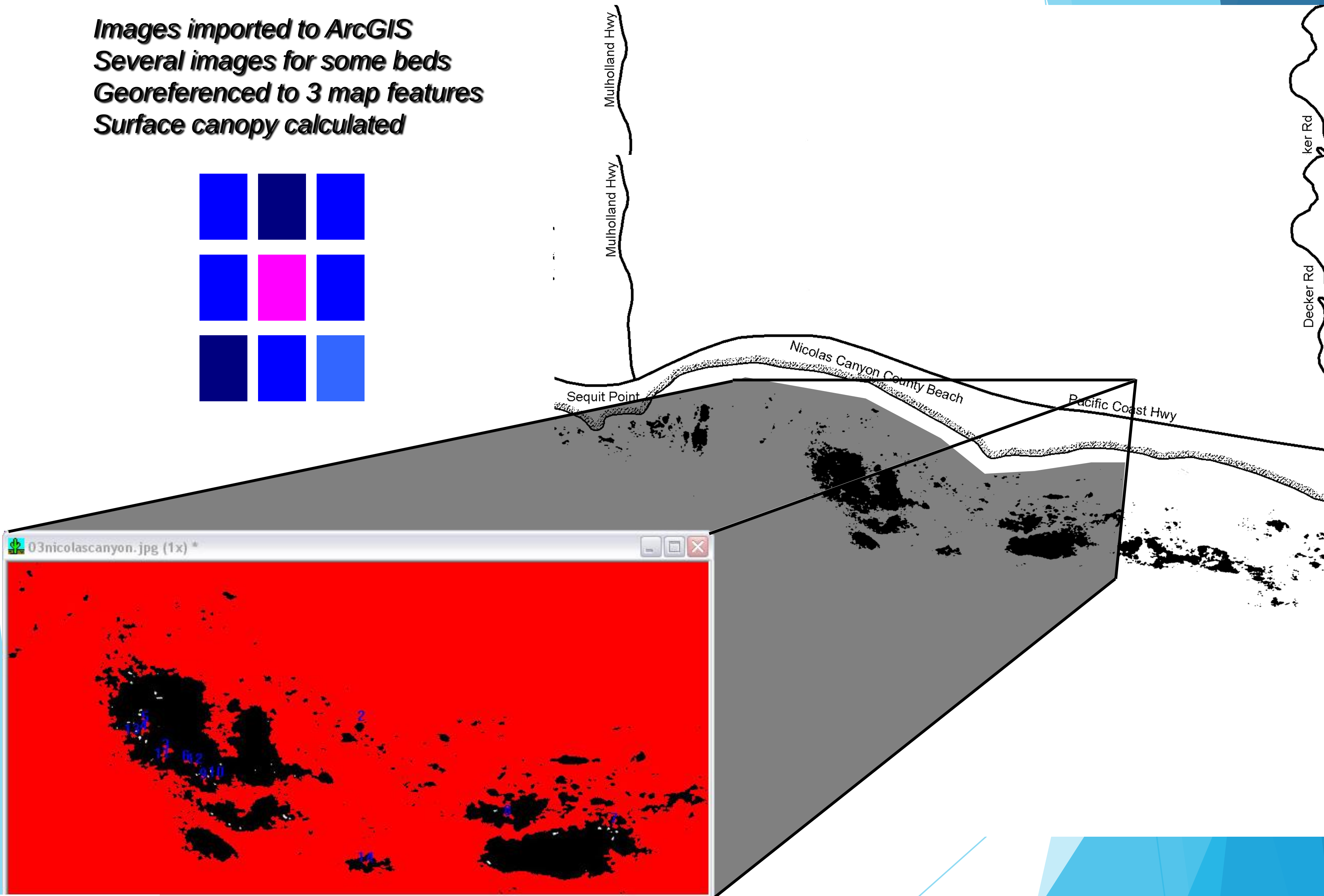
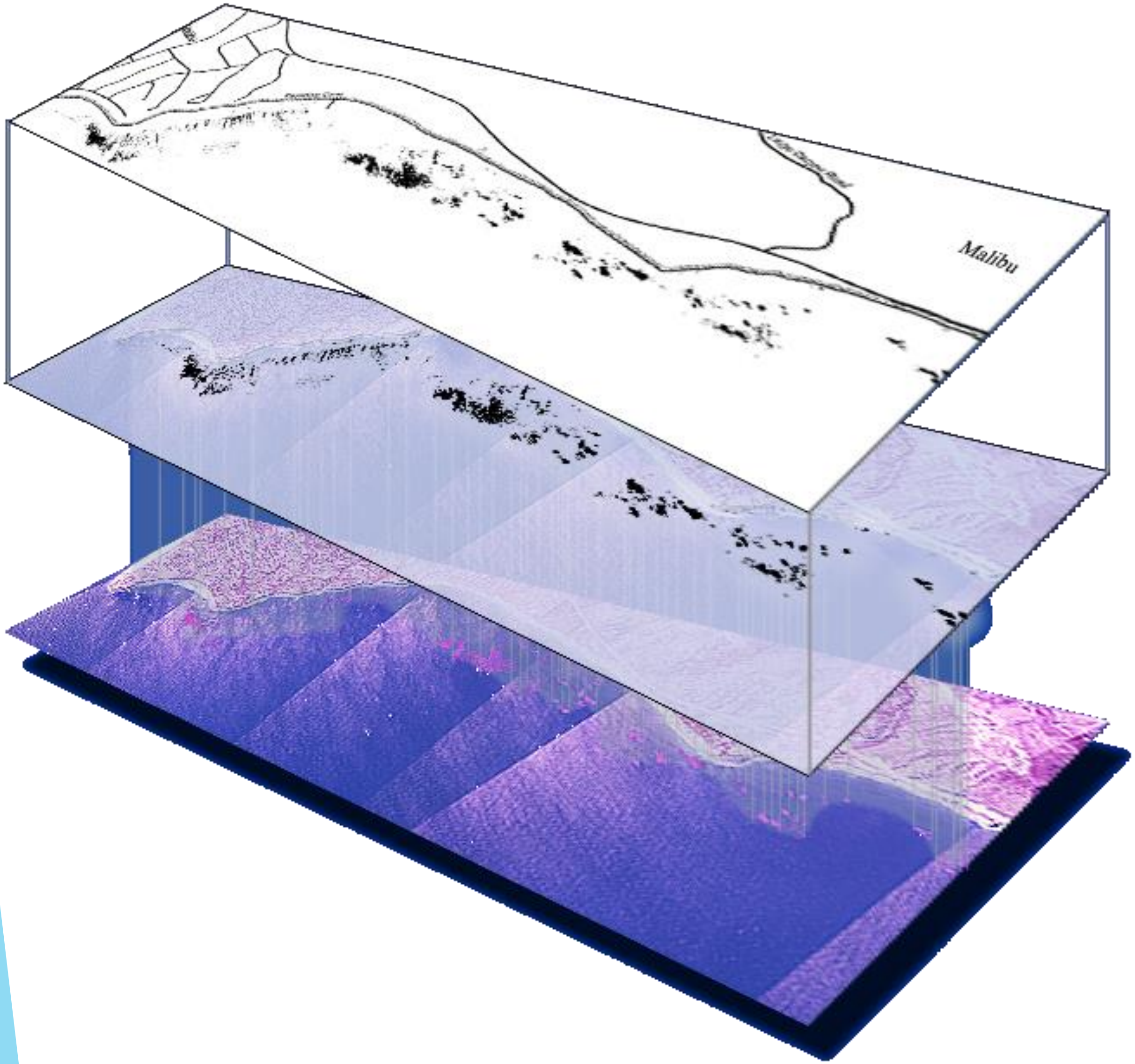
Images imported to ArcGIS
Several images for some beds
Georeferenced to 3 map features
Surface canopy calculated



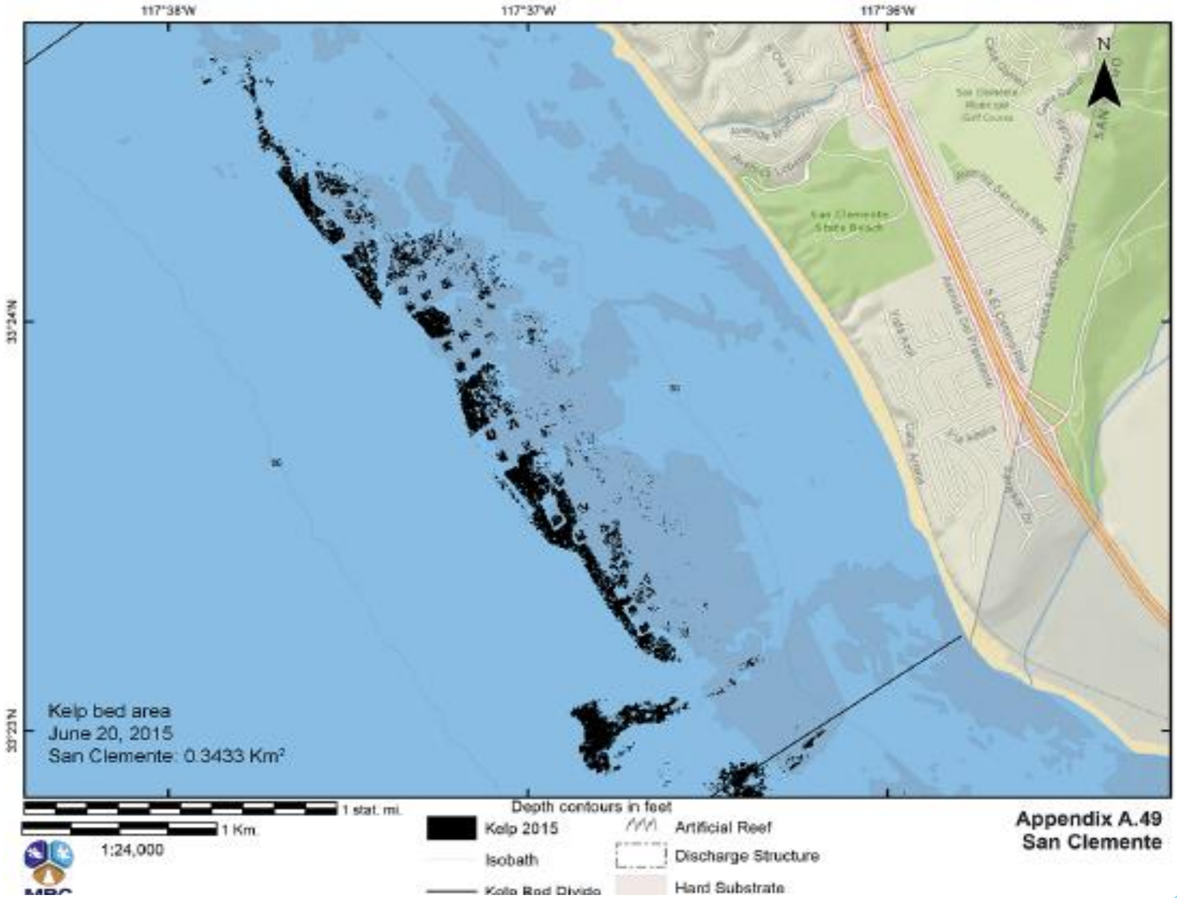


Photomosaics

Kelp extracted

Layered to basemaps

Standardized Basemaps of the Coastline



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Region 9 Vessel Survey

- January 4, 15 & 30, 2020

- Surface observations
  - Approximate extent of surface canopy
  - Tissue color, age of fronds, encrustrations
  - Subsurface kelp
- In-water diver surveys
- Dana Point/Salt Creek, Encina Power Plant, Leucadia north kelp beds
  - Marine life (e.g., urchins, fish)
  - Age and color of fronds
  - Presence and extent of subsurface giant kelp and other algae

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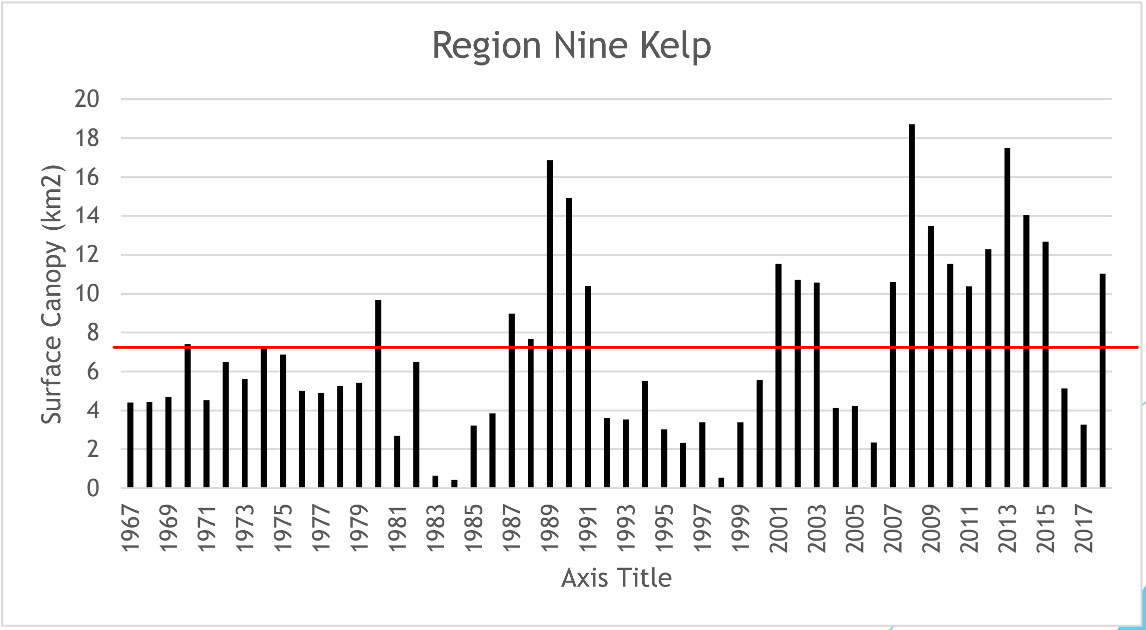
REGION NINE SURVEY RESULTS

Region Nine 2018 Overview

- Total canopy coverage increased substantially
  - 15 beds increased in size
  - 4 beds decreased in size
  - 1 bed disappeared (Carlsbad State Beach)



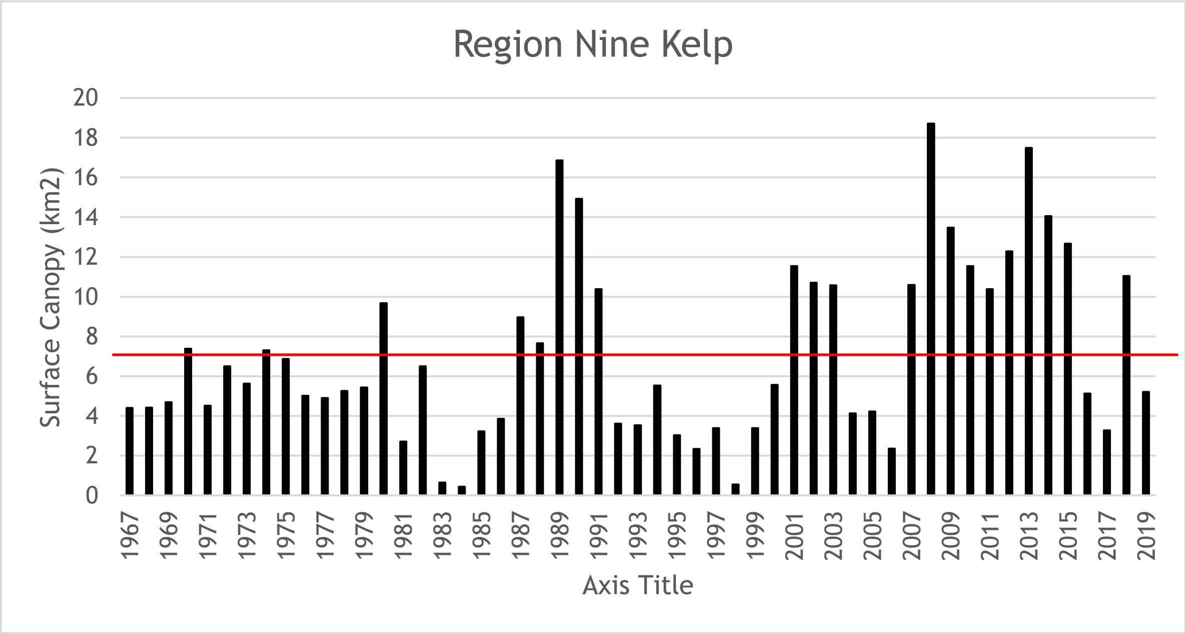
Region Nine 2019 Overview

- Total canopy coverage decreased substantially
  - 18 beds decreased in size
  - 10 beds disappeared

11.0 km^2

-53%

5.2 km^2



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	2019 Quarterly Overflights			
Kelp Beds	March 31	July 19	September 19	December 19
North Laguna Beach	0.5	0.5	–	0.5
South Laguna Beach	0.5	0.5	–	0.5
South Laguna	–	–	–	–
Salt Creek-Dana Point	–	–	–	–
Dana Marina *	–	–	–	–
Capistrano Beach	–	–	–	–
San Clemente	1.5	1.0	–	–
San Mateo Point	0.5	–	–	–
San Onofre	0.5	0.5	–	–
Pendleton Reefs *	–	–	–	–
Horno Canyon	–	–	–	–
Barn Kelp	–	–	–	–
Santa Margarita	–	–	–	–
Oceanside Harbor *	–	–	–	–
North Carlsbad	–	–	–	–
Agua Hedionda	–	–	–	–
Encina Power Plant	–	–	–	–
Carlsbad State Beach	–	–	–	–
North Leucadia	–	0.5	–	–
Central Leucadia	–	–	–	–
South Leucadia	–	–	–	–
Encinitas	–	–	–	–
Cardiff	–	–	–	–
Solana Beach	–	–	–	–
Del Mar	–	–	–	–
Torrey Pines Park	–	–	–	–
La Jolla Upper	0.5	1.5	1.0	1.0
La Jolla Lower	2.5	3.0	1.0	2.5
Point Loma Upper	3.0	4.0	1.5	3.5
Point Loma Lower	3.0	4.0	1.5	2.5
Imperial Beach	–	–	–	–

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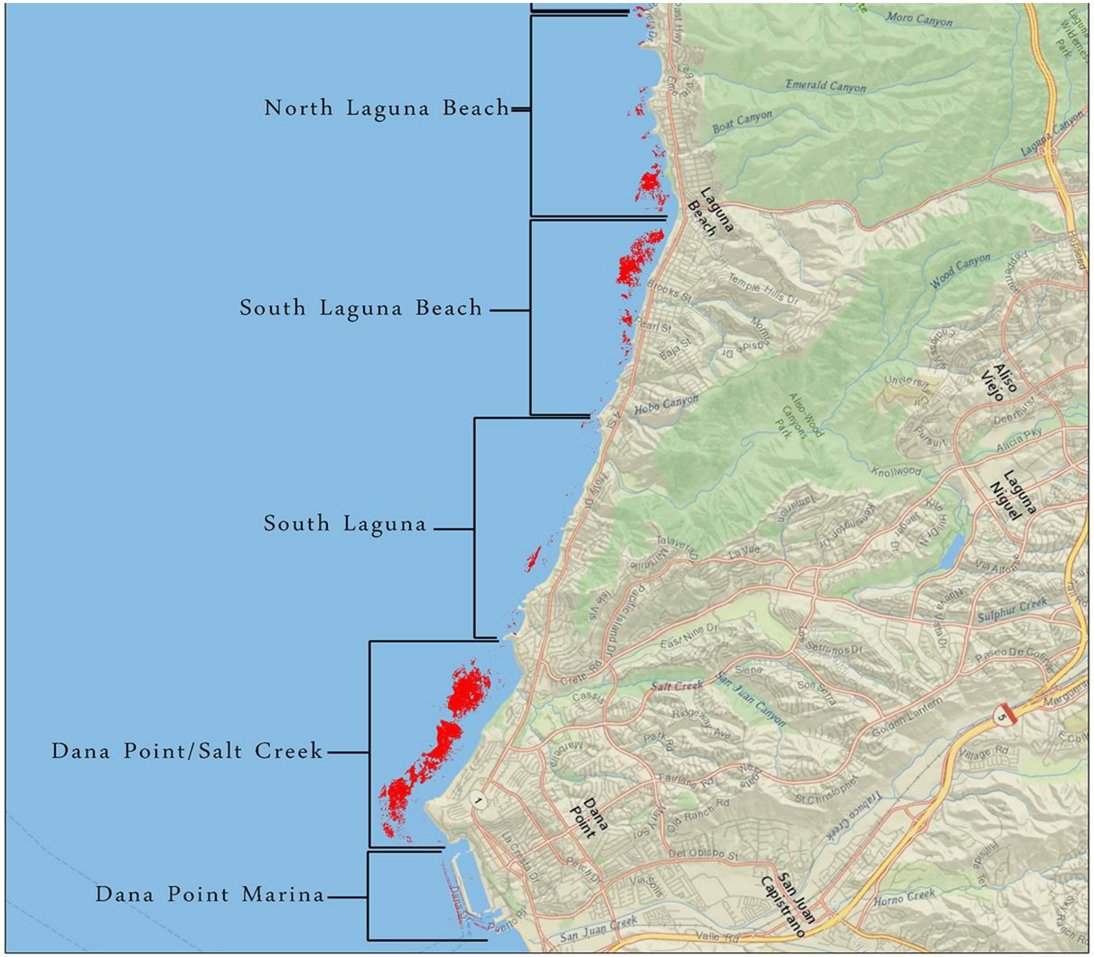
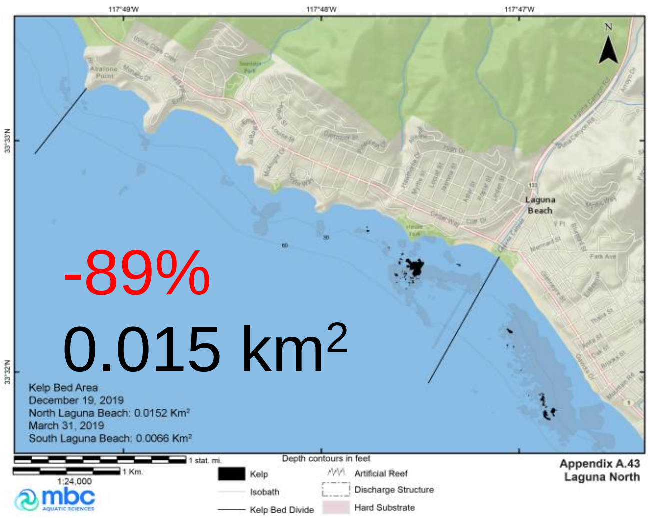
Orange County



Appendix D.9

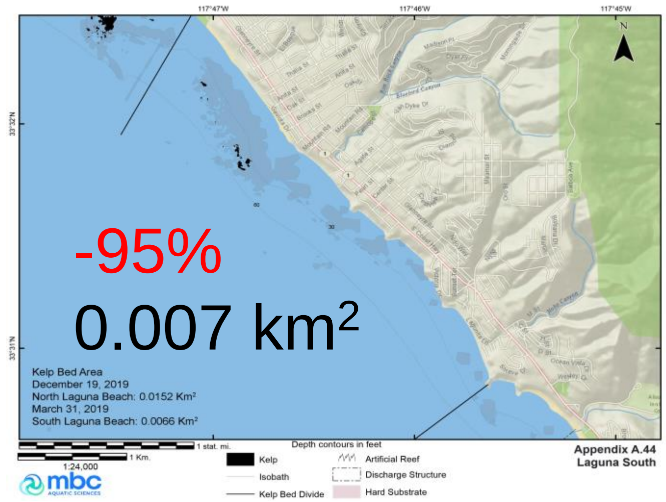
North Laguna Beach



-89%

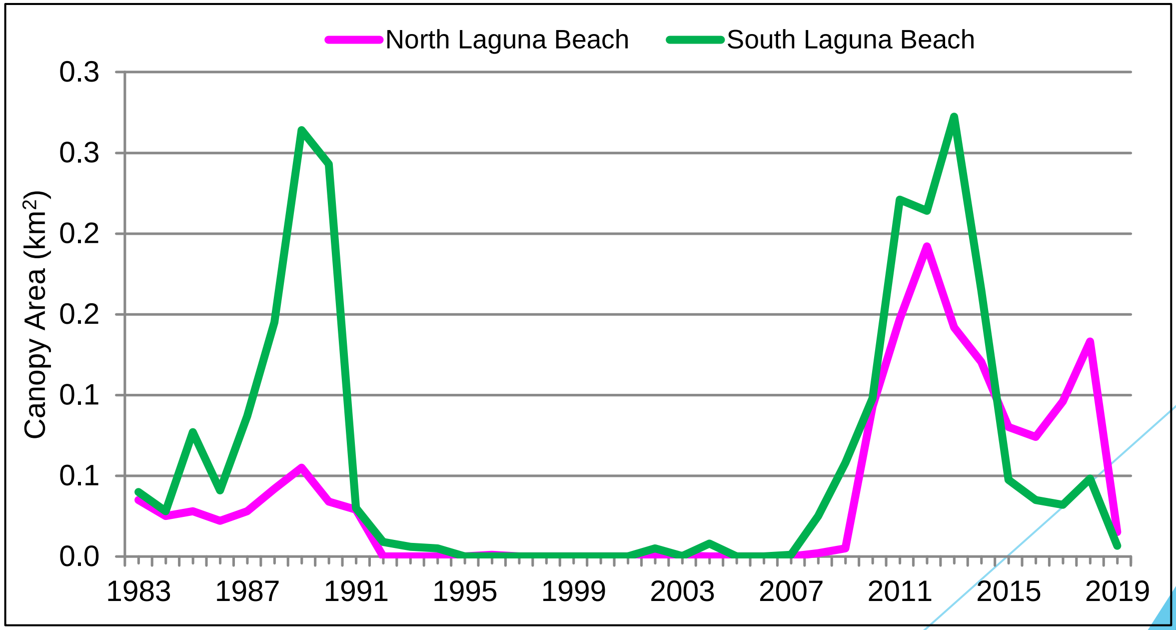
0.015 km²

South Laguna Beach

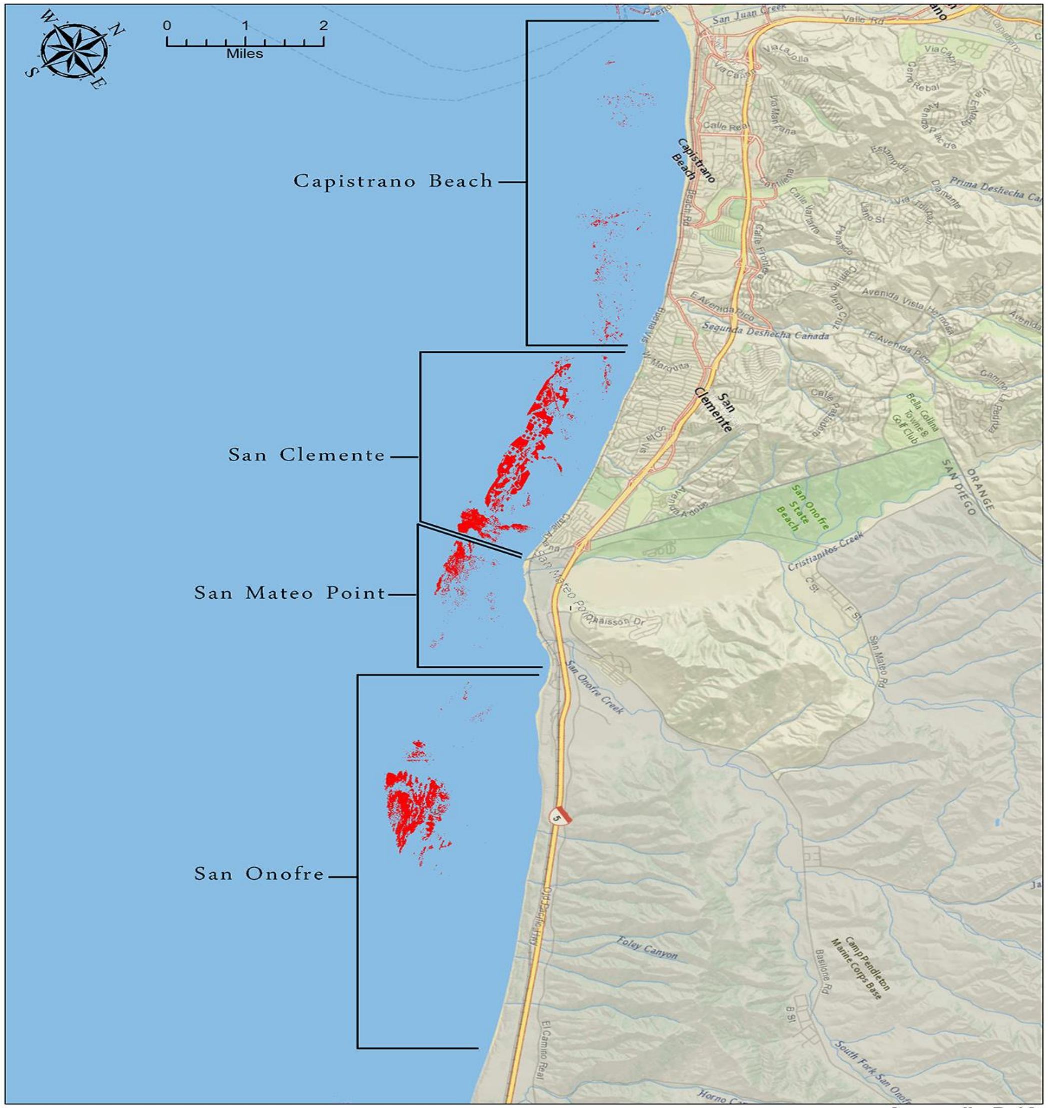


-95%

0.007 km²

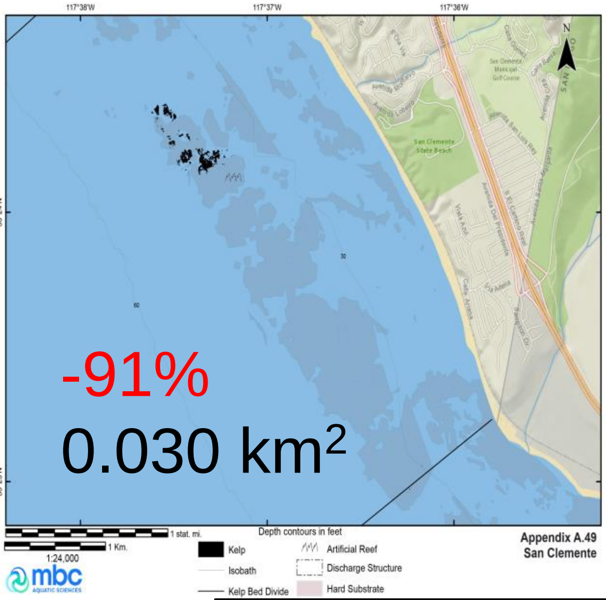


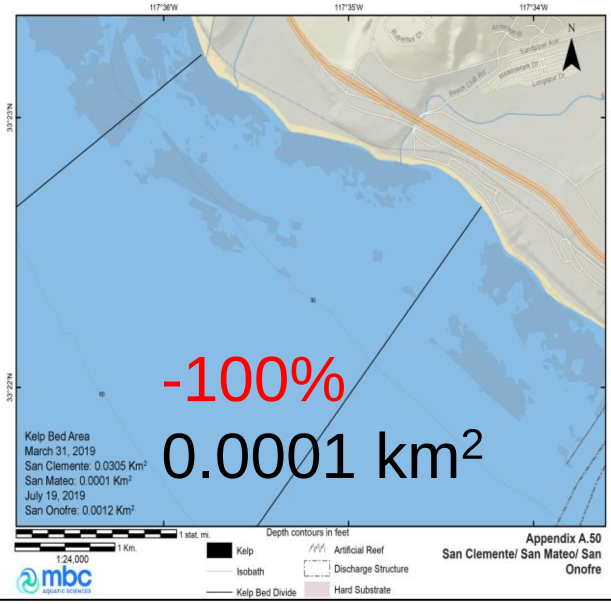
Capistrano Beach to San Onofre

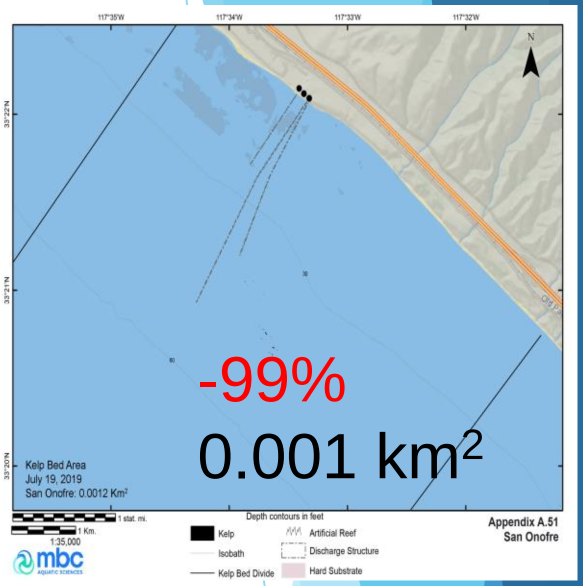


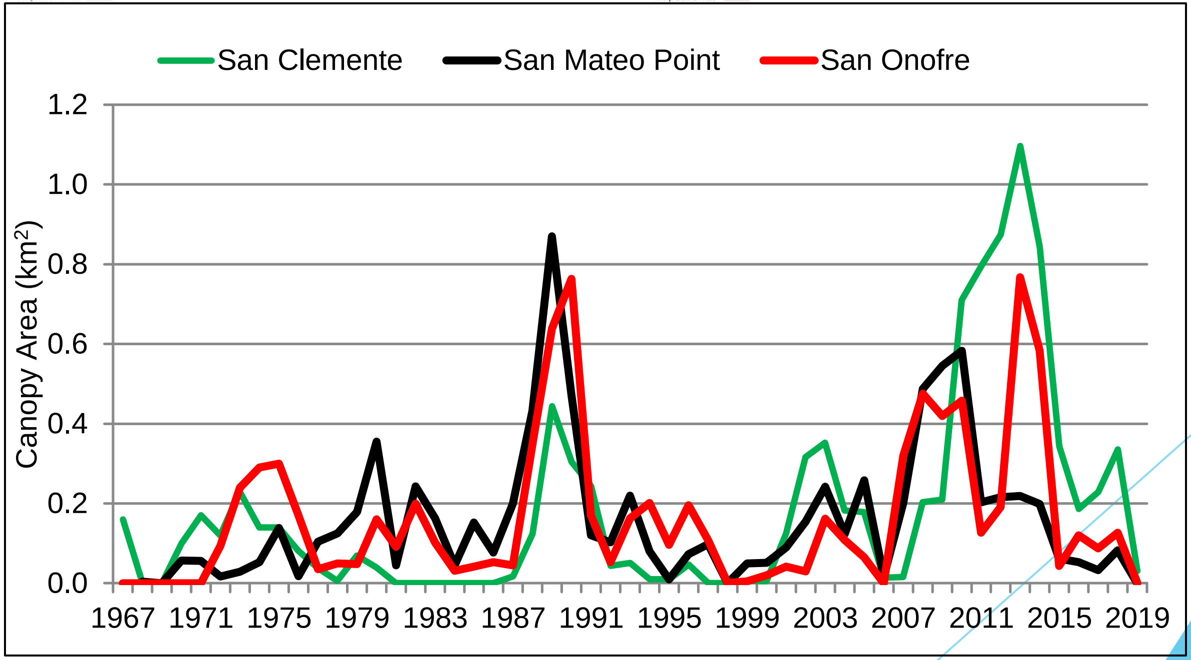
Appendix D.10

San Clemente San Mateo Pt San Onofre









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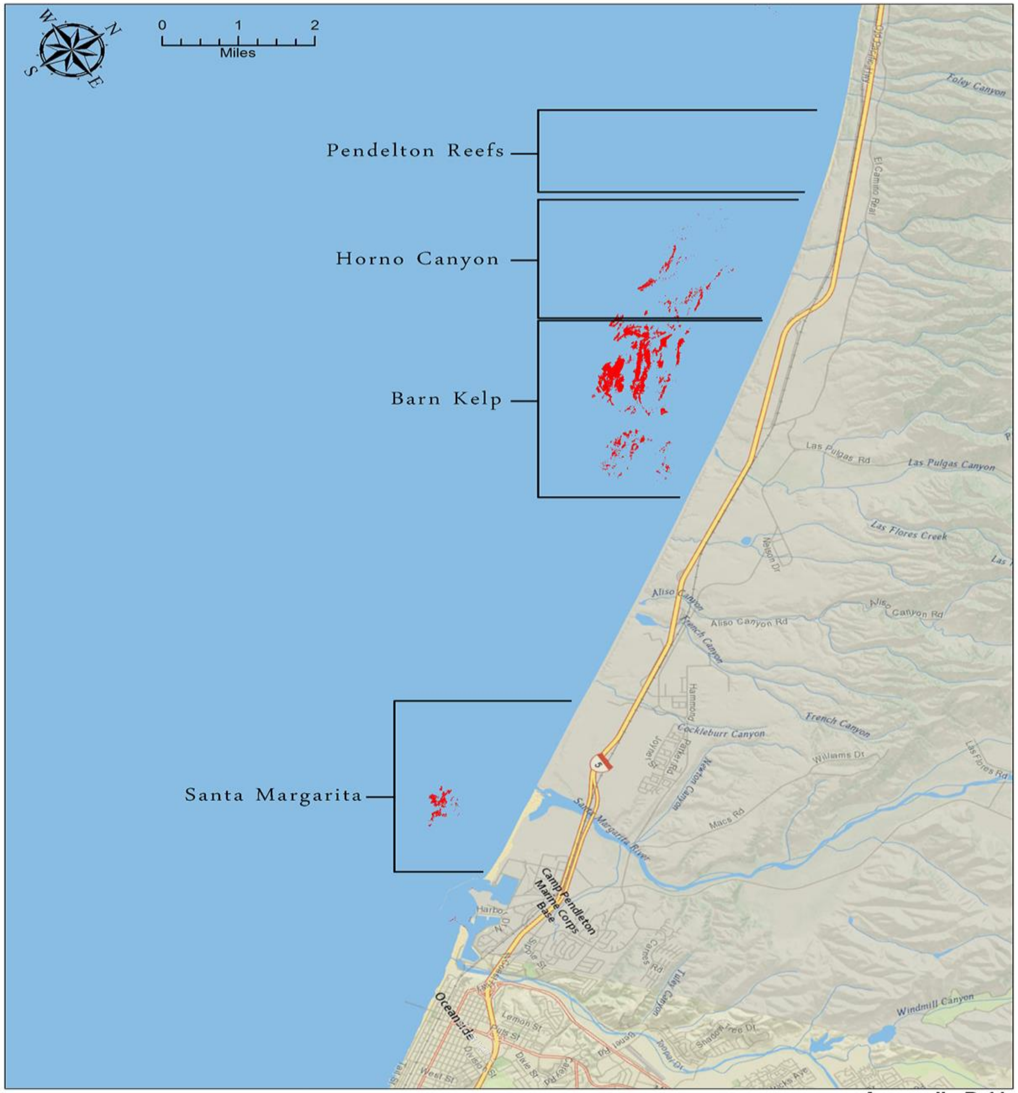
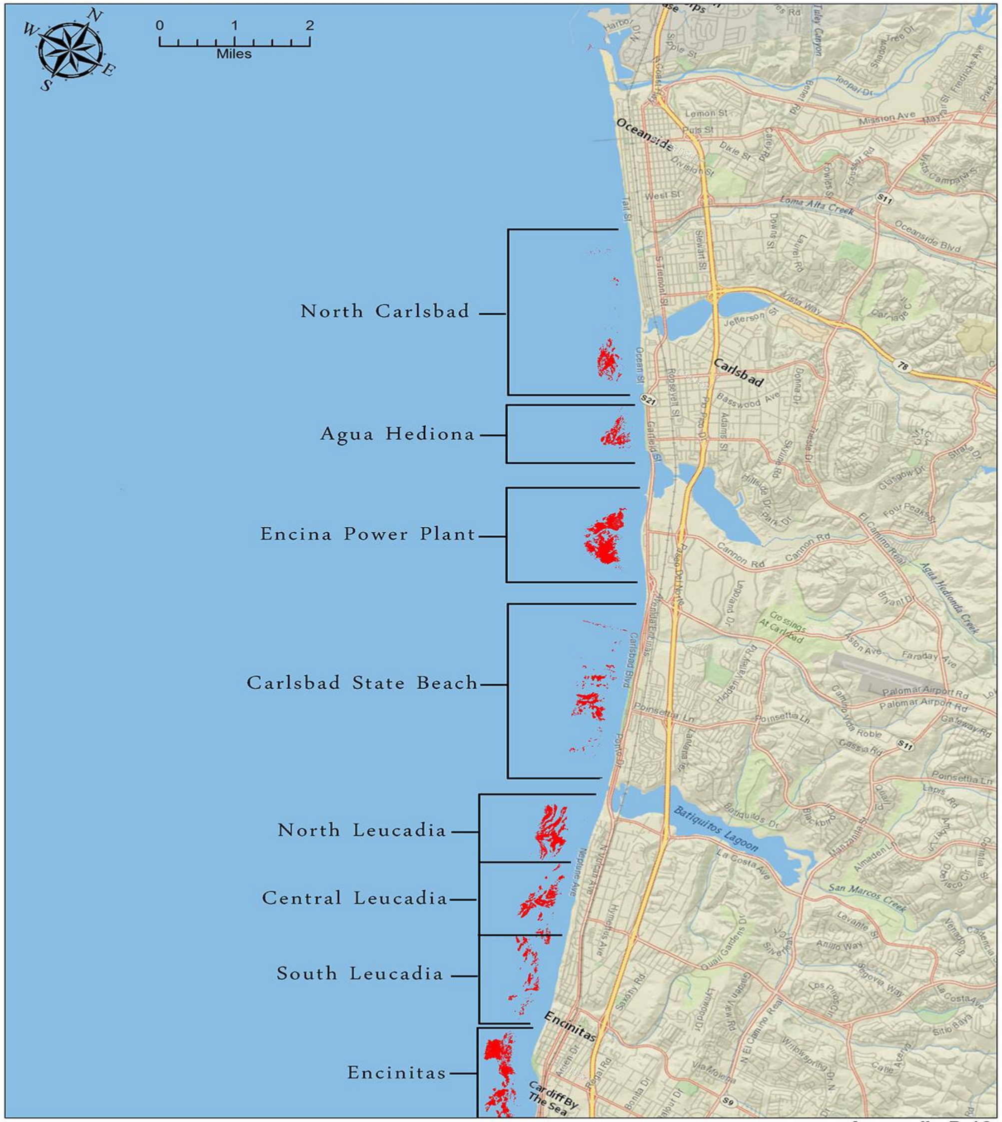
Horno Canyon to Santa Margarita



Appendix D.11

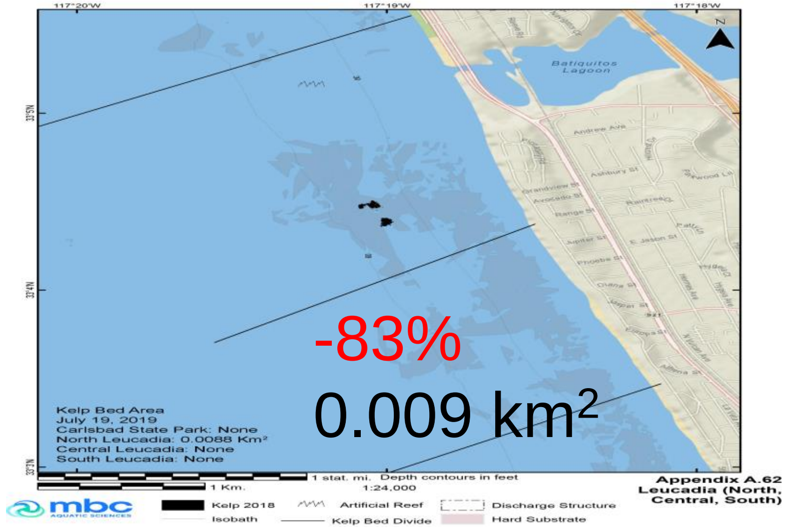
MBC AQUATIC SCIENCES

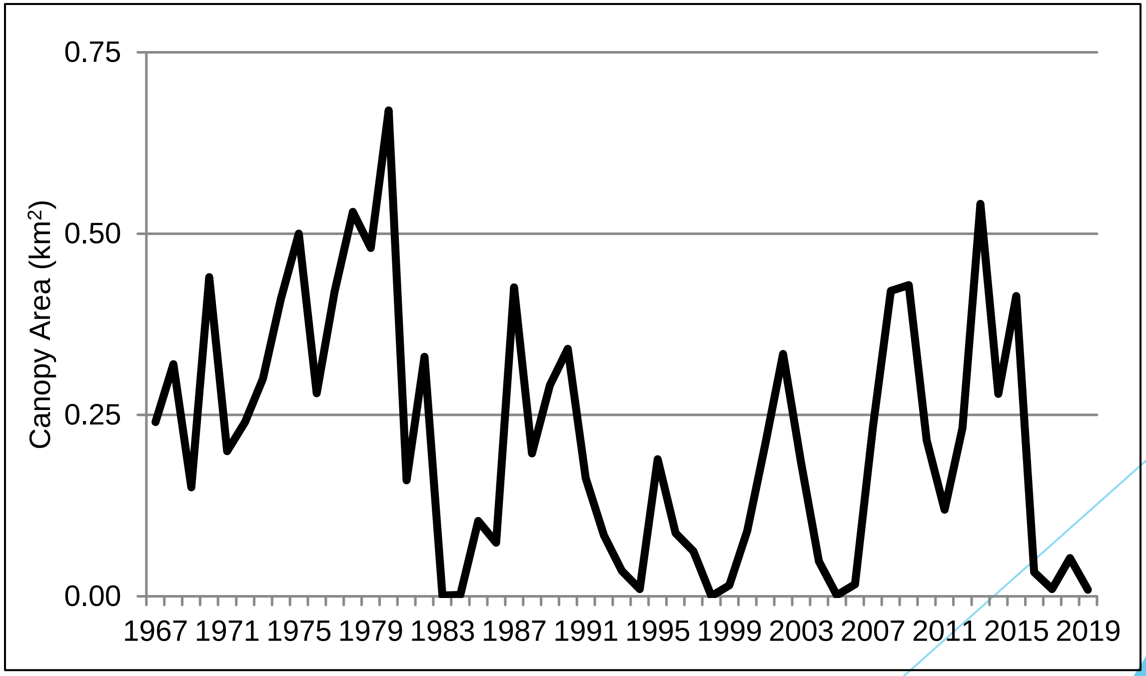
North Carlsbad to Encinitas



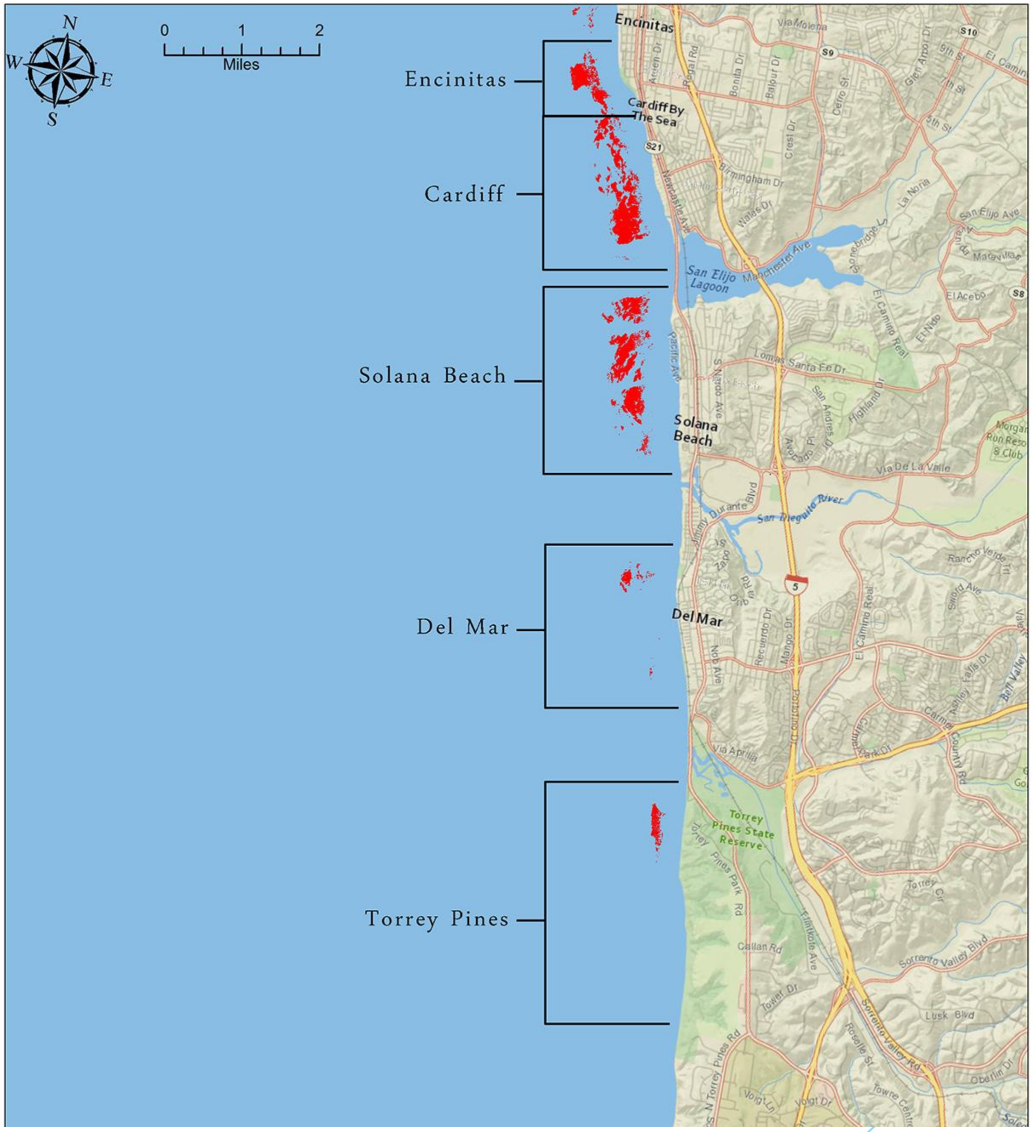
Appendix D.12

Leucadia - North

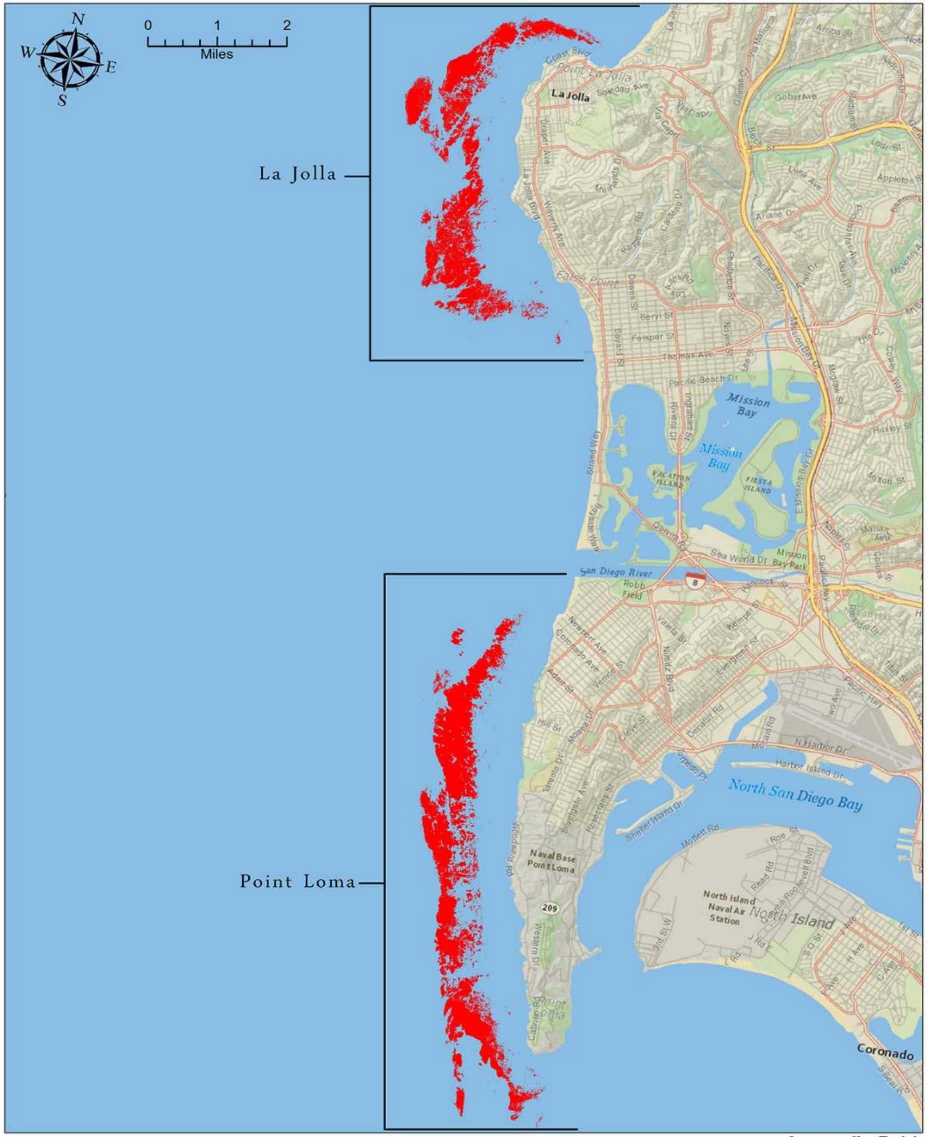




Cardiff to Torrey Pines



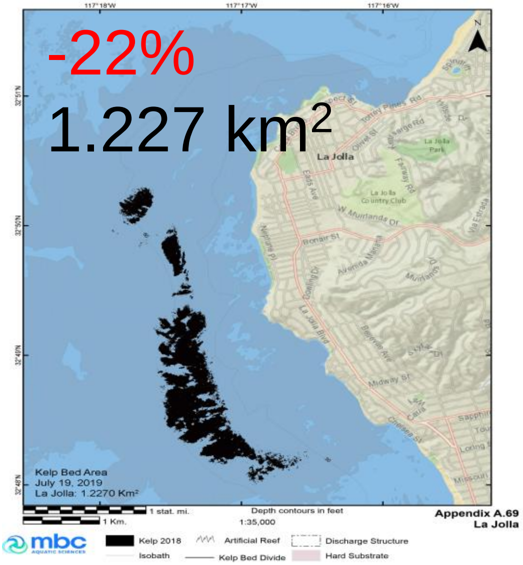
La Jolla and Point Loma

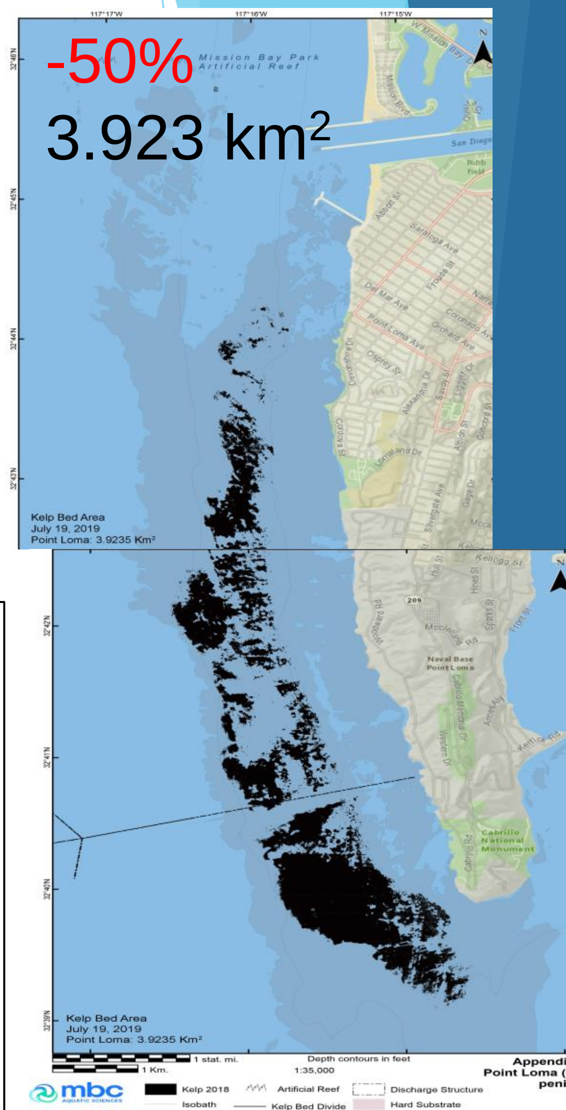


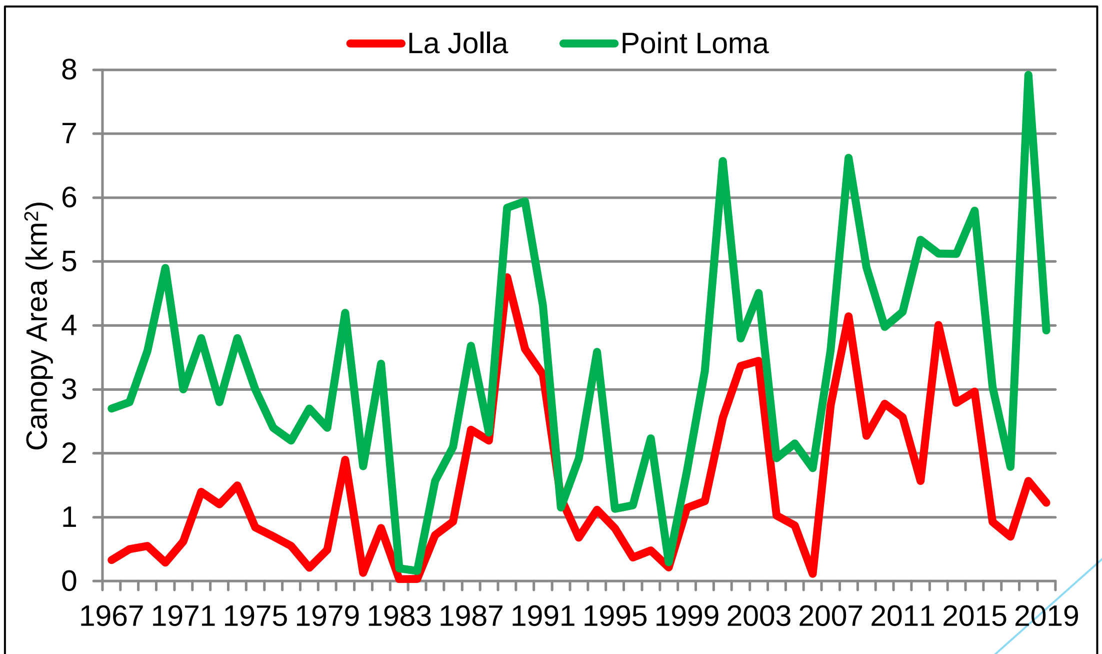
Appendix D.14

La Jolla

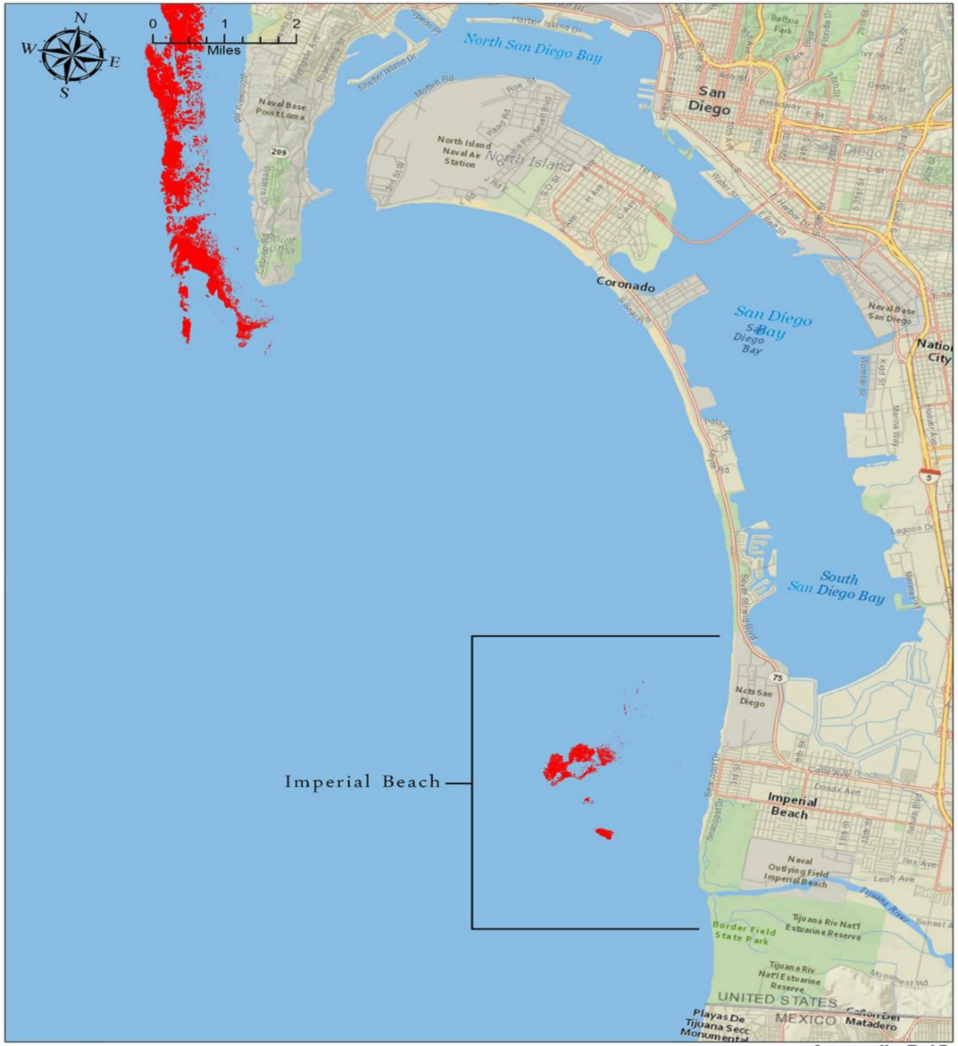
Point Loma







Imperial Beach



Appendix D.15

KELP BED		SURFACE CANOPY AREA IN 2019
North Laguna Beach	Smallest since:	2009
South Laguna Beach		2007
South Laguna		2006
Dana Point/Salt Creek		2006
Capistrano Beach		2005
San Clemente		2007
San Mateo Point		1998
San Onofre		2006
Horno Canyon		2011
Barn Kelp		2006
Encina Power Plant		2006
Encinitas		2005
Cardiff		2005
Solana Beach		1983

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FACTORS AFFECTING KELP BEDS

Parnell, Dayton, Riser & Bulach. 2019. Evaluation of anthropogenic impacts on the San Diego coastal kelp forest ecosystem (2014 to 2019): final report.

- SoCal kelp forests subjected to severe temperature and nutrient stress from late 2013 through spring 2017
- BLOB present during 2014-2015 = anomalously warm surface waters across much of Northeast Pacific Ocean
- Strong El Niño occurred during fall 2015 and winter of 2016 - just as the BLOB dissipated
- El Niño/BLOB combo caused longest and warmest period ever observed in 103-year SST time series at Scripps Pier
- Spring upwelling in 2017 and 2018 brought cool, nutrient-laden waters onto SoCal inner continental shelf creating favorable conditions for giant kelp regrowth

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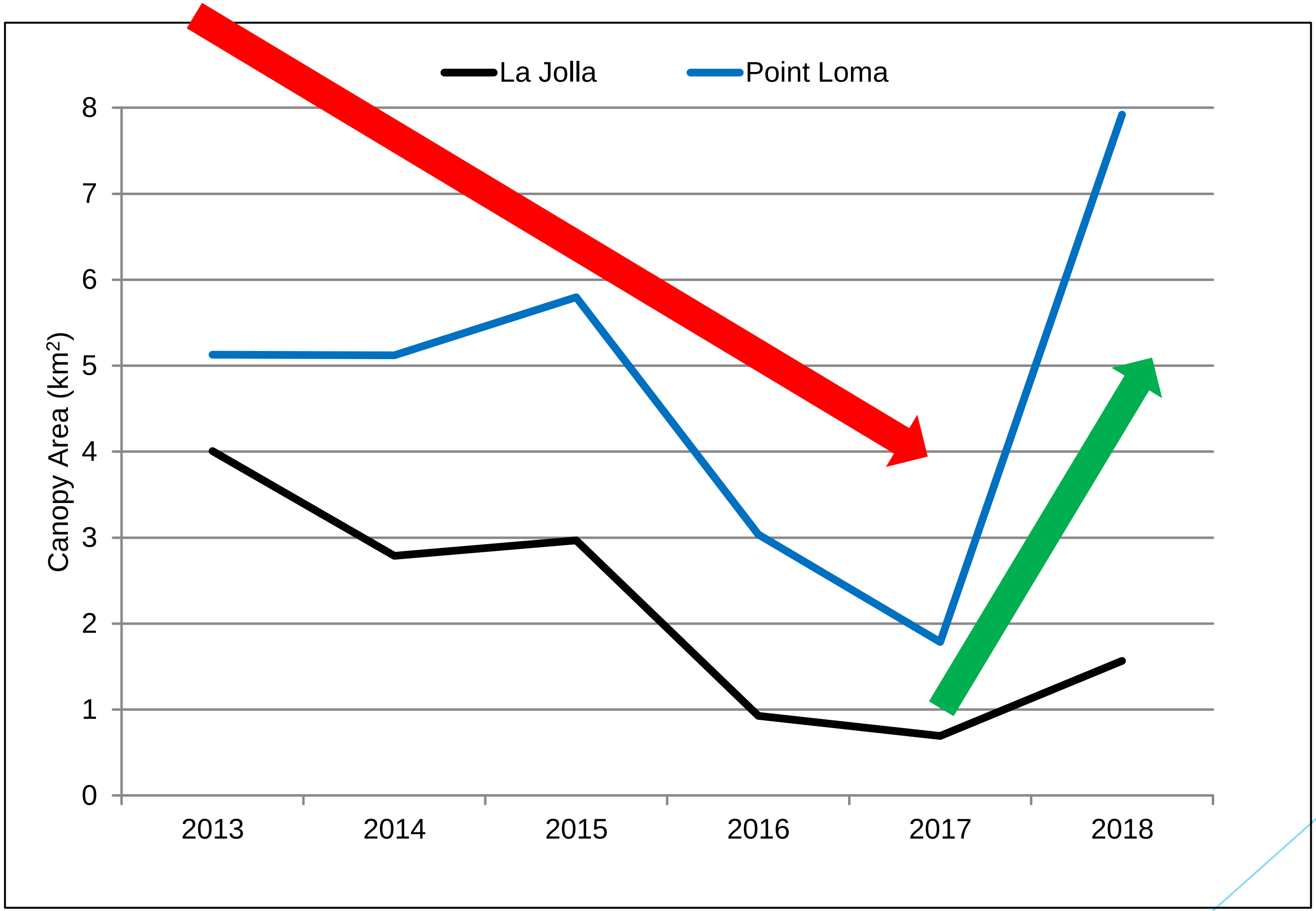
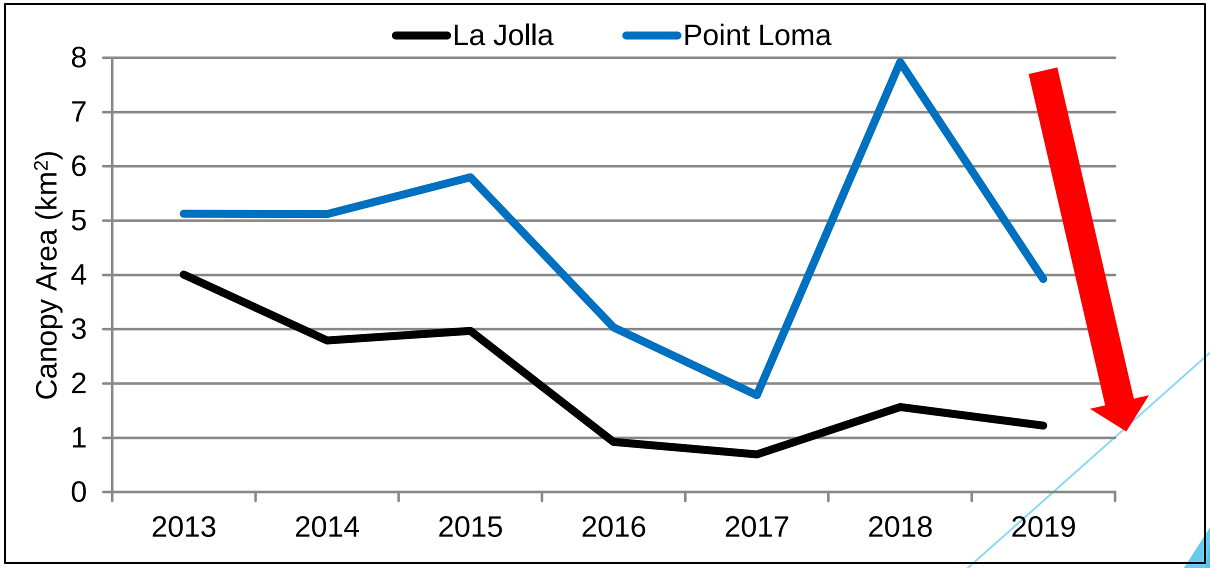
LA JOLLA & POINT LOMA KELP BEDS 2013-2018



What Happened In 2019?

- In 2018, Region Nine Kelp beds had reached their maximum size in March or June (overflight data)
- Anomalously warm surface layer present during summer 2018 (Parnell et al, 2019)
- No surface canopy present throughout most of Region Nine in September or December 2018 (overflight data)
- Very little surface canopy present throughout most of Region Nine in March or June 2019, and almost none in September or December (except La Jolla and Point Loma)



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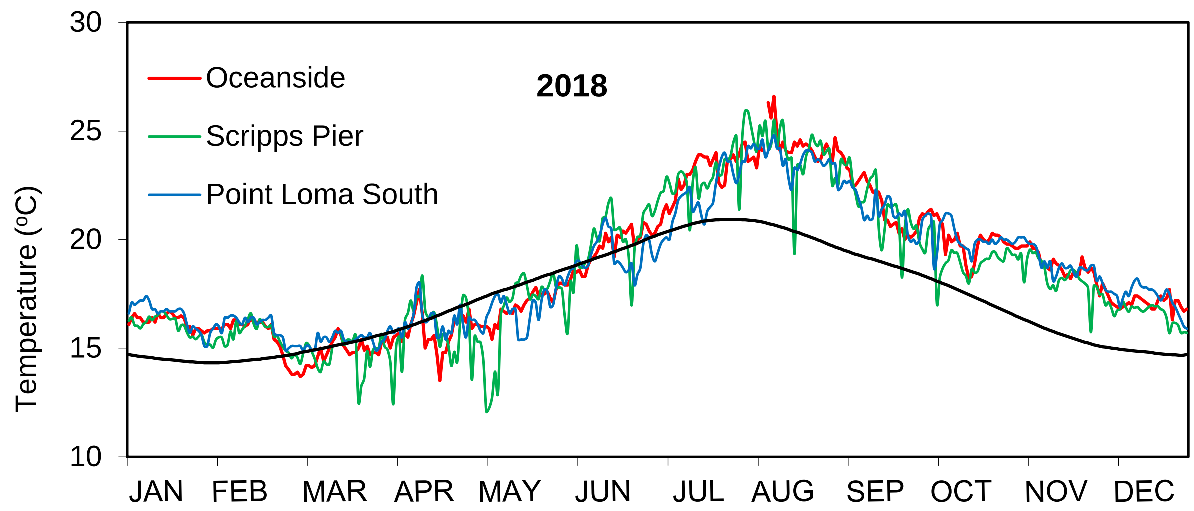
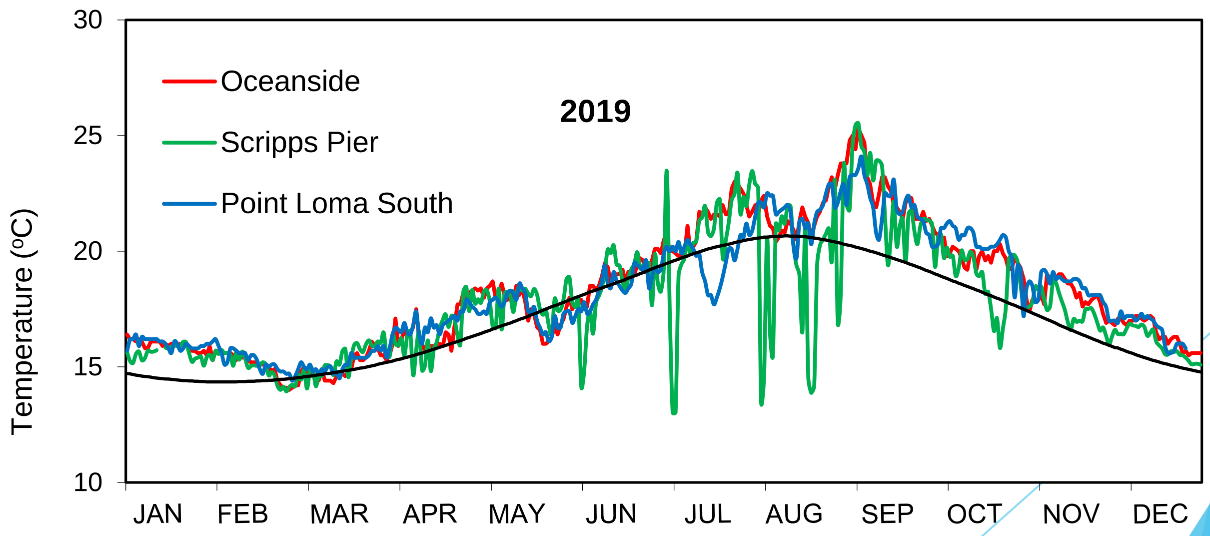
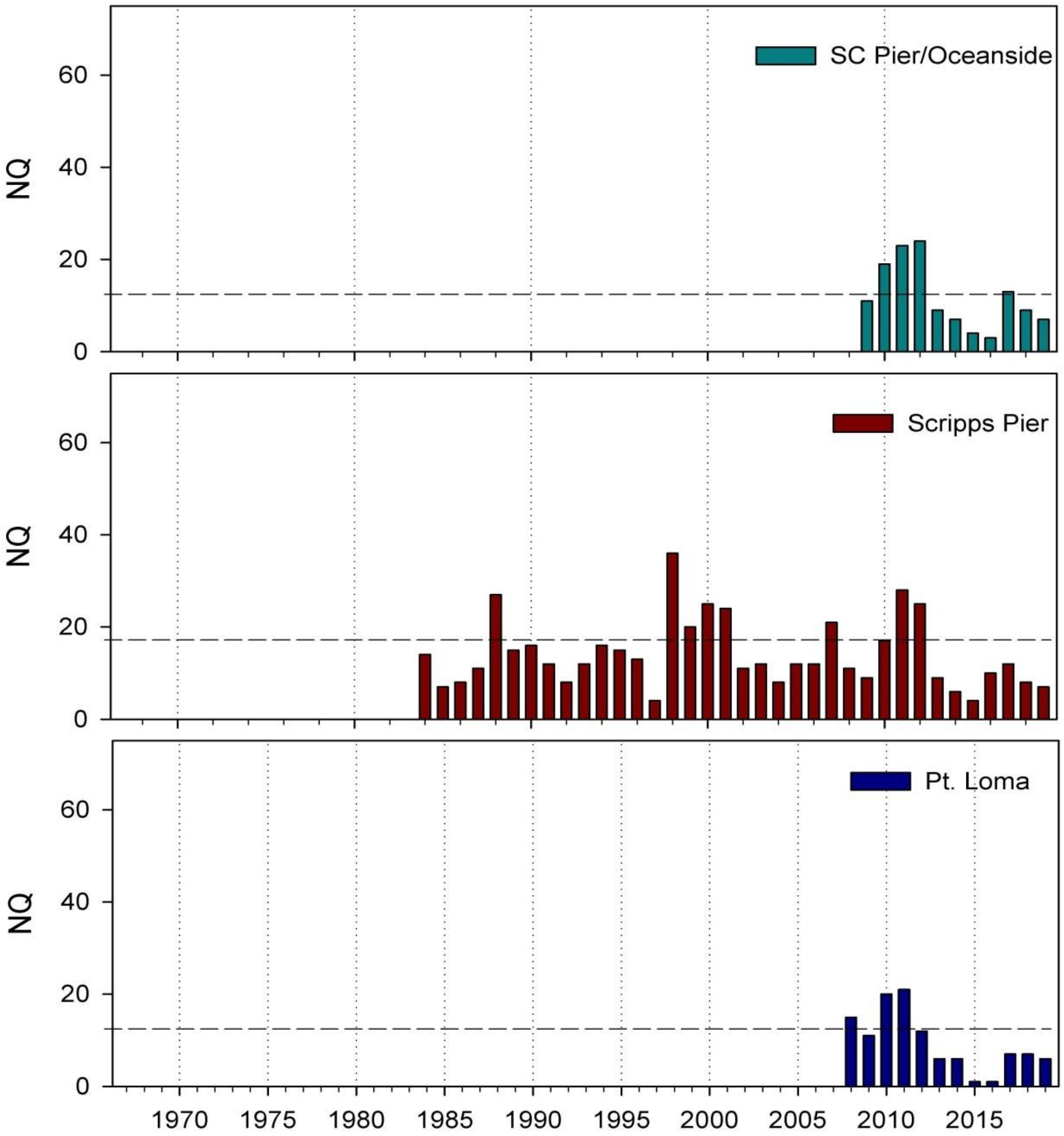
SST Values
2018 Versus 2019

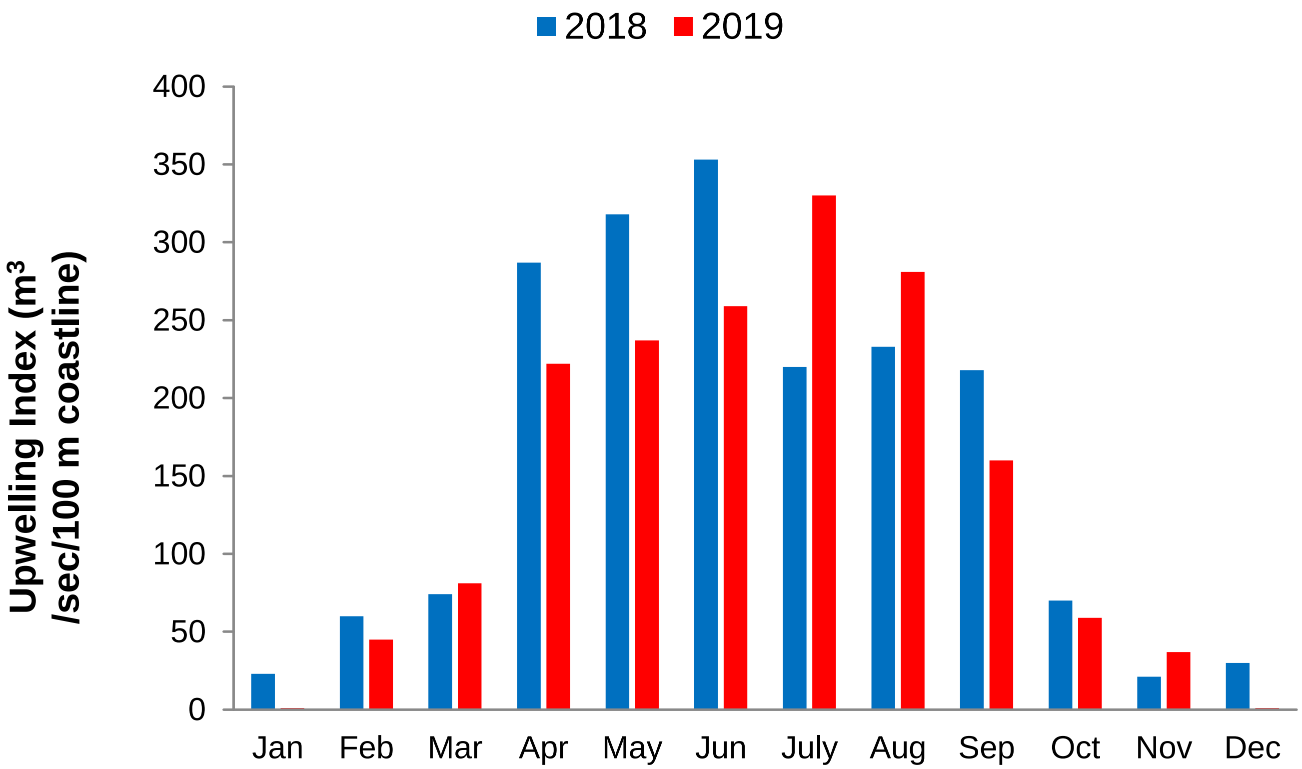




Nutrient Quotient Index Values



Monthly PFEL Upwelling Index



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Environmental Indices

- ENSO – continued in warm phase in 2019
- PDO – neutral in 2018, but warm regime in 2019
- NPGO – strongly negative from 2017 through 2019 indicating lower productivity

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CONCLUSIONS

Conclusions

- 2019 was a bad year for kelp
  - 53 % decrease in total surface canopy for Region Nine
  - All kelp beds with visible surface canopy in 2018 decreased in size in 2019
- 10 kelp beds disappeared
- High SST values continued in 2019 (higher than normal during March, April, and May)
- Nutrient quotient values lower in 2019
- Monthly upwelling index values lower in 2019 during April, May, and June

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PREVIEW OF 2020

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Kelp Bed	April 15 estimated canopy	July 5 estimated canopy
North Laguna Beach	1.0	2.5
South Laguna Beach	-	0.5
South Laguna	-	-
Salt Creek-Dana Point	0.5	-
Capistrano Beach	0.5	-
San Clemente	-	-
San Mateo Point	-	-
San Onofre	-	-
Horno Canyon	-	-
Barn Kelp	-	-
Santa Margarita	-	-
North Carlsbad	NI	-
Agua Hedionda	-	-
Encina Power Plant	NI	-
Carlsbad State Beach	NI	-
Leucadia	NI	-
Encinitas	-	-
Cardiff	-	-
Solana Beach	NI	-
Del Mar	-	-
Torrey Pines Park	-	-
La Jolla Upper	1.0	1.0
La Jolla Lower	1.0	1.0
Point Loma Upper	2.5	3.0
Point Loma Lower	3.0	3.0
Imperial Beach	-	-

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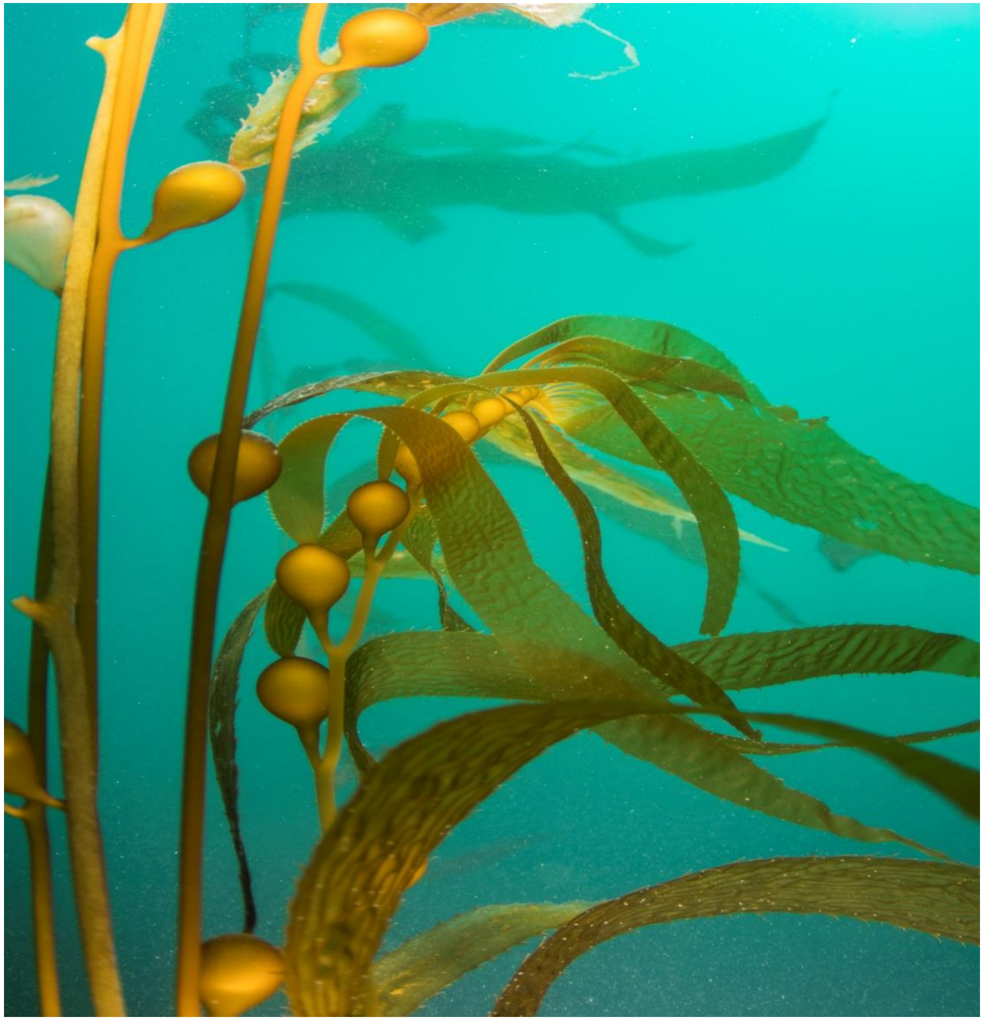
QUESTIONS?



Permit Request 9/17/20

Proposal to study timing on *Sargassum horneri* removal as a technique for eradication

Prepared by:

Nancy Caruso, Marine Biologist, Get Inspired

nancy@getinspiredinc.org 714-206-5147

6192 Santa Rita Ave Garden Grove, CA 92845

www.GetInspiredInc.org

Background: A report, published in the journal Nature in April 2020, identifies nine key components that are essential to rebuilding the oceans: salt marshes, mangroves, seagrasses, coral reefs, kelp, oyster reefs, fisheries, megafauna and the deep ocean. The authors recommend a range of actions including protecting species, harvesting wisely and restoring habitats (Duarte et al. 2020).

I have been doing ocean restoration work in Orange County since 2002 under the umbrella of several different organizations. In those 18 years, I have trained over 350 volunteer divers to help me with the tasks of restoring giant kelp (2002-2012), restocking and monitoring green abalone (2013-2015) for a study that was published in CDFG journal in 2017, and surveying green abalone intertidally and subtidally (2017-present) to map and calculate density of abalone in Orange county. We are currently raising green abalone for restocking in 2021-2025. In 2009, I started Get Inspired, a nonprofit 501c3 charity organization to continue this work and have partnered with CDFW on several projects. I have taught more than 12,000 students to grow abalone, white seabass, and kelp in custom classroom nurseries for outplanting to restore species along the coast of Orange County. Additionally, through a partnership with Hubbs SeaWorld Research Institute, I started the "seabass in the classroom" program (also in partnership with CDFW). All of these programs have integrated classroom lessons which accompany the culture systems. I go into the schools to teach topics in aquaculture, kelp forest ecology, and ocean chemistry.

Saraggsum horneri an invasive species native to Japan and Korea, is now prevalent along the mainland of Western North America from Baja California to Santa Barbara, and at three of the five Channel Islands (Anacapa, Santa Cruz and Santa Barbara) (Marks et al. 2015). Its continued expansion in the eastern Pacific may pose a major threat to the sustainability of native marine ecosystems. (Marks et al. 2015). Marks et al. 2017 recommends that *Sargassum horneri* be tracked, monitored, and studied so that impacts to resources can be assessed and potential management actions, such as eradication, can be evaluated. Kaplanis et al. 2016 mentioned that the rapid and uncontrolled spread of Sargassum has serious implications for their expansion along the west coast of North America and that the ecological and economic consequences of these invasions require further research.

Forests of *Macrocystis pyrifera* naturally wax and wane throughout the natural cycles experienced along our coast. However, now with the invasion of Sargassum, there is competition for space for kelp to make its comeback resulting in a lack of food for grazers such as abalone which are already experiencing challenges in their recovery. Most herbivores do not prefer Sargassum as a food choice and this perhaps has led to its success (Marks et. al 2020). Through personal observations, Sargassum seems to whether the warm water events and large swells produced from the recent El nino event much better than the giant kelp. It forms such dense forests that fish cannot even swim through it, also limits light penetration to the reef further inhibiting competitors. In some cases, there has been a shift, since our kelp restoration activities, from a Macrocystis forest with healthy understory of other alga and encrusting organisms to a desolate Sargassum covered reef. I have an emotional and personal interest in the kelp forests of Orange County, having spent 12 years of my life restoring them. Wheeler North once told me that, “You don’t just go in and restore the kelp and then walk away, it’s going to need to be managed over time” I believe the that figuring out the best strategies for managing *Sargassum horneri,* especially, after the devastation of a warm water event, would be useful for the State of California. Up to this point, projects to add to this knowledge based have not met with success due to timing (Marks et al. 2017). So, to help in that effort, I am requesting permission to conduct a pilot project to study the timing of removal of *Sargassum horneri* as a method for controlling it. Just as we manage our terrestrial forests, we may need to start managing our kelp forests. This may especially be helpful to manage the return of Macrocystis after a warm water event or significant disruption to the ecosystem. My theory is that if it is cut and/or scrubbed off the reef at its base **just before or when** giant kelp is recruiting, the kelp will be able to regain its “real estate” on the reef and the Sargassum will be outcompeted. To ensure there is “room” on the reef for the kelp to recruit and because we know that Sargassum can recruit throughout the fall and early winter, we will test the timing of eradication to determine the best time for removal for reestablishment of the giant kelp. These tactics may then be employed in the future after a devastating event such as an El Nino, to bring the ecosystem back into balance faster.

Proposed project: Get Inspired team requests permission to conduct this experiment in Crystal Cove SMCA. We have seen a regime shift on this reef. It was once a lush garden of native alga and has recently become a Sargassum pasture with an articulated coralline understory. The premise of this project is that Macrocystis has lost its “real estate” or it’s position in this reef community. By timing the removal of *Sargassum* with giant kelp recruitment, we may see the regime shift back to a kelp dominated forest. This SMCA has the least amount of protection, allowing for the take of finsfish, lobster and sea urchin. Over the last 5 years, we have observed a loss of diversity of algal species. The recent *2019 Status of the Kelp Beds* report from MBC Aquatic Sciences showed 98% kelp loss in this SMCA. Throughout the project period, we will monitor ocean conditions such as: sea surface temperature, kelp sporophyll release periods and kelp recruitment events whilst conducting targeted Sargassum removal to determine the best time to remove Sargassum to allow for kelp recruitment back on the reef and if it has an impact on algal composition on the reef. We will notify CDFW the coordinates of sites before we begin as initial surveys will be required. Although “spreading” Sargassum is really no longer a threat in Southern California as it is ubiquitous, care will be taken during the reproductive season to remove the reproductive season to remove the whole plant. During the non-reproductive season, April-October, we will just pull the invasive algae.

Method:

Two study areas will be chosen where we can set up 4 treatment sites in each one. All the treatment sites will be 10m x10m in size. The study area will have *Macrocystis pyrifera* and *Sargassum horneri* present. A HOBO temperature logger will be installed in the study area. This study will be over the expanse of the SMCA in areas where kelp once grew and has disappeared.

All sites will have an initial survey of Sargassum and other native algae with band transects or quadrats (depending on density).

Each dive will have a scoring system for the sporophyll release, kelp recruitment, and Sargassum development stage. We will survey the study area during each dive to determine the spore release quotient on the giant kelp. We will observe each plant give it a score and tally up the scores at the end of the dive. Development stage of Sargassum will also be noted on each dive.

Spore release

1- Indicates sporophylls are golden brown and the same color as the kelp blades
2- Indicates sporphylls are smooth or darker in color
3- Indicates sporphylls are smooth texture, darker in color, and have necrotic ends indicating max spore release is taking place.

Kelp recruitment

0- Indicates no sign of kelp recruitment
1- Indicates spade shaped brown kelp recruits on the reef (species unknown)
2- Indicates giant kelp recruits confirmed on reef site

Once a #2 score is confirmed band transects or quadrats will be conducted to count recruits and determine density. Same treatment will be done on the control site.

Sargassum Development stage (as described by Miller and Engle 2009)

1- Fern-like stage <5cm
2- Immature, no receptacles
3- Fertile, actively reproducing
4- Senescent, after reproduction

We will set up 2 control sites in Laguna Beach SMR where no Sargassum removal will occur

Treatment site 1 will have continuous removal of sargassum through the study period

Treatment site 2 we will remove Sargassum starting when there is a dip in sea surface temperatures below 15 C ~December 2020

Treatment site 3 we will remove Sargassum starting in January 2021

Treatment site 4 we will remove Sargassum starting in February 2021

Importance and Benefit: Kelps are a vital California resource and an essential component to our Eastern Pacific ecosystem as seen in the recent Northern California kelp ecosystem collapse. We rely on them to sustain us we use them for fishing, diving, and we have thought enough to protect them with no take zones to allow the ecosystems to flourish. They also are an important habitat and food source for reef species. These critical habitats are facing more and more threats. From warm water events to urchin invasions and invasive species competition, we need to know how to effectively and quickly reestablish these habitats to sustain them for as long as we can. Just like we manage our forests on land, we should be managing the health of these important California ecosystems. We believe that this work is essential to the recovery of our kelp forests and for the management of our kelp ecosystem that will benefit everyone and we respectfully request your permission to investigate these methods.

Duarte, C.M., Agusti, S., Barbier, E. *et al.* Rebuilding marine life. *Nature* **580,** 39–51 (2020). https://doi.org/10.1038/s41586-020-2146-7

Kaplanis NJ, Harris JL, Smith JE (2016) Distribution patterns of the non-native seaweeds Sargassum horneri (Turner) C. Agardh and Undaria pinnatifida (Harvey) Suringar on the San Diego and Pacific coast of North America. Aquatic Invasions 11: 111–124,

Marks, L.M., P. Salinas-Ruiz, D.C. Reed, S.J. Holbrook, C.S. Culver, J.M. Engle, D.J. Kushner, J.E. Caselle, J. Freiwald, J.P. Williams, J.R. Smith, L.E. Aguilar-Rosas, N.J. Kaplanis. 2015. Range expansion of a non-native, invasive macroalga *Sargassum horneri* (Turner) C. Agardh, 1820 in the eastern Pacific. BioInvasions Records 4(4)243-248.

Marks LM, Reed DC, Obaza AK. Assessment of control methods for the invasive seaweed *Sargassum horneri* in California, USA. Manag Biol Invasion. 2017;8(2): 205–213. 10.3391/mbi.2017.8.2.08

Marks, L.M.; Reed, D.C.; Holbrook, S.J. Niche Complementarity and Resistance to Grazing Promote the Invasion Success of *Sargassum horneri* in North America. *Diversity* **2020**, *12*, 54.

MBC Aquatic Sciences 2020. *2019 Status of the Kelp Beds Orange and San Diego Counties Prepared for the Region Nine Kelp Survey Consortium.* https://1drv.ms/u/s!AkLZpj2SiR6xpG_MWqq-Hs8Rqsuo?e=ouAaVG

Miller, K.A. and J.M. Engle. 2009. The natural history of Undaria pinnatifida and Sargassum filicinum at the California Channel Islands: Non-native seaweeds with different invasion styles. In: (G.C. Damiani and D.K. Garcelon eds.) Proceedings of the 7th California Islands Symposium. Institute for Wildlife Studies, Arcata, CA. pp. 131 – 140.

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http://dx.doi.org/10.4236/ajps.2015.617271

Presence of *Sargassum horneri* at Todos Santos Bay, Baja California, Mexico: Its Effects on the Local Macroalgae Community

Giuliana I. Cruz-Trejo[1,2], Silvia E. Ibarra-Obando[1*], Luis E. Aguilar-Rosas[3], Miriam Poumian-Tapia[1], Elena Solana-Arellano[1]

[1]Marine Ecology Department, CICESE, Ensenada, México
[2]Ocean Resources Department, CINVESTAV-IPN, Mérida, México
[3]Instituto de Investigaciones Oceanológicas, Universidad Autónoma de Baja California, Ensenada, México
Email: [*]sibarrra@cicese.mx

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Abstract

To describe the annual cycle of *Sargassum horneri* in Mexican waters, we selected two sites differing in their degree of wave exposure and sediment type: Rincón de Ballenas (RB), and Rancho Packard (RP). From June 2009 to April 2010 we followed the seasonal changes in *S. horneri* density and biomass along two intertidal transects per site. The effects of this non-indigenous species on the local macroalgae community were assessed by comparing their species composition, density, biomass, species richness, and diversity index in quadrats with and without *S. horneri*. There were significant differences in *S. horneri* density and biomass between sites ($P < 0.001$). At RB the invasive alga density average was 2 ± 0.94 individual m^{-2}, with a mean biomass of 4 ± 0.95 g DW m^{-2}. At RP, *S. horneri* density average was 10 ± 0.96 individual m^{-2}, and mean biomass of 102 ± 0.97 g DW m^{-2}. At RB, the invasive alga promoted a significant reduction in the four selected structural variables, and the corticated macrophytes and the foliose functional forms were severely reduced. At RP, there were only marginally significant effects ($P = 0.06$) of *S. horneri* presence on the local macroalgae community, and higher density, biomass, and diversity values were found when *S. horneri* was present. Most of the functional forms were found, even if the invasive alga was present. At both locations, the highest biomass corresponded to the articulated calcareous functional form. These contrasting results could be due to the fact that the native macroalgae community has already been altered by the early invasion of *S. muticum*, with the most resilient species and functional forms remaining in place. One of the most important changes we noticed is the severe reduction of the canopy forming species at both sites.

[*]Corresponding author.

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Keywords

Annual Cycle, Community Structure, Diversity Index, Functional Forms, Invasive Alga, Species Richness

1. Introduction

Non-indigenous species (NIS) represent a major concern to marine scientists as the ecosystem in which they arrive in is modified adversely. This change takes place through the ecological interactions they establish with the native species and through direct or indirect physical or chemical changes in the habitat itself. The speed of habitat change is also coupled to the stability or resilience of the ecosystem, so the impact can have different scales in space and time [1].

While experimental work supports the idea that diverse communities show greater resistance to invasion, it is not clear if this results from resource use complementarity, or from an increasing occurrence of suppressive species in more diverse communities [2]. To understand the mechanisms driving this response, interest has shifted from species richness to the functional roles that species or groups of species play. Functional groups are defined as non-phylogenetic grouping of species that perform similarly in an ecosystem based on a set of common biological attributes. Functional groups can be defined in relation to either the contribution of species to ecosystem processes, such as carbon or water cycling, or the response of species to changes in environmental variables, such as climatic variables or disturbance [3]. The number and identity of functional groups within a community may dictate the level of invasibility, implying that the invasion of a coastal habitat will only be promoted through loss of a whole functional group rather than the loss of one or a few members of that group [2].

As marine ecosystems are relatively open, with fewer limits than terrestrial systems to organism dispersal and energy flow, the irreversible impacts of exotic species have profound consequences on ecological systems [2]. Macroalgae are considered to be especially worrying NIMS (non-indigenous marine species) as they may alter ecosystem structure and function by monopolizing space, developing into ecosystem engineers, changing food webs, and spreading beyond their initial point of introduction through efficient dispersal capacities [4] [5]. The success of a non-indigenous species depends on its mode of reproduction, growth rate and dispersive potential [6] [7].

The fucoid genus *Sargassum* is monoecious, highly fecund, and possesses vesicles that allow the reproductive fronds produced annually to drift with currents and inoculate new locations [7]-[9]. Due to its ability to colonize hard and soft substrata, the total area of marine sediments open to occupation by members of the genus *Sargassum* is vast, and cumulative habitat modification could be very significant [10]. The main barrier to colonization of the rock is the presence of algal cover [11].

Once established, these species can accumulate high biomass and thus become a strong competitor for space and light [12]. *Sargassum* invasions have significantly impacted the structure of indigenous algal communities in North America and Europe, through competitive displacement and/or exclusion [7] [13]. Several studies have reported the reduction of functional groups, like the thick leathery and coarsely branched algae and native understory algae through strong competitive interactions with adult individuals of *S. muticum* [7] [14]-[17].

Sargassum horneri is native from Asia, and distributed in Japan, Korea, Hong Kong (China), Chinese Taipei and China Mainland [18]. It was observed in Catalina Island, California, in 2003 [19]. In Baja California, well-established populations of this species were observed in Todos Santos Bay in 2007 [20], from where it had extended along the temperate waters of the Baja California Peninsula [21]. However, no description exists of the population structure of *S. horneri* in Mexican waters. For this reason, we decided to study the annual growth cycle inside the Todos Santos bay. We were also interested in assessing the ecological impact of this non-indigenous algal species on the structure of the local community of macroalgae. For this purpose, we selected two locations that differed in substrate type and wave exposure degree, and measured the seasonal influence of Sea Surface Temperature (SST), Photosynthetically Active Radiation (PAR), and air-exposure hours, on *S. horneri* density and biomass. Simultaneously, we determined the changes in the species composition, density, and biomass of the local macroalgae community. Algal species were classified into functional groups to identify if their number and types differed as a function of the presence or absence of *S. horneri*. We expected *S. horneri* to be better represented in the most exposed site, where its high density and biomass would result in a significant reduction of macroalgae, density, and biomass, and a change in species composition. We anticipated the loss or reduction of the canopy forming species, representing the more morphologically complex functional forms.

2. Materials and Methods

2.1. Study Site

The Todos Santos bay is located about 130 km south of the USA-Mexico border, on the northwest coast of the Baja California peninsula, at ~31˚47'N; 116˚43'W (**Figure 1**).

The NW oceanic boundary is defined by the ridge of a broad shoal between the Todos Santos islands and the mainland shoreline. The SW boundary is defined as the shortest distance between a prominent point, known as Punta Banda, and the Todos Santos islands, and is marked by a 6 km wide submarine canyon. The bay has a surface area of ~240 km^2. Maximum depth within the bay is ~100 m, except for the canyon, reaching to 400 m and draining down the continental slope [22].

Winds dominate the coastal circulation. Prevailing northwesterly winds, during spring and summer, drive water into the bay from the NW. Only during some winter storms and offshore Santa Ana conditions, water enters from the southwestern [23]. There is an apparent convergence zone within the bay, near the mouth of the Punta Banda estuary, along the eastern shore [24]. Sediment transport into and within the bay follows the same circulation pattern [25]. The bay is under the upwelling influence during periods of NW winds, a prominent feature of much of the Pacific coast of the USA and northern Baja California [26], and some authors have documented the influence of the local upwelling on water properties near the mouth during the springtime upwelling period [22] [27].

The two selected study sites, Rincón de Ballenas (RB), and Rancho Packard (RP), are located in the protected side of the Punta Banda peninsula, which is made up of shale and sandstone, forming high, almost vertical cliffs, which are interrupted locally by small pocket beaches made out of boulders [28]. Wave turbulence and littoral currents separate the material supplied by cliff erosion, allowing only grain sizes greater than 3.5ϕ (coarse fraction) to be deposited on the beach, while smaller sizes (fine fraction) are suspended and transported offshore [28]. Loose gravel predominates at Rincón de Ballenas and hard rock at Rancho Packard (**Figure 1**) [28].

The west coast of Baja California is characterized for having a mixed semidiurnal tidal cycle, with astronomical tides of higher amplitude during winter, season in which the strong storms originate bigger waves. The sum

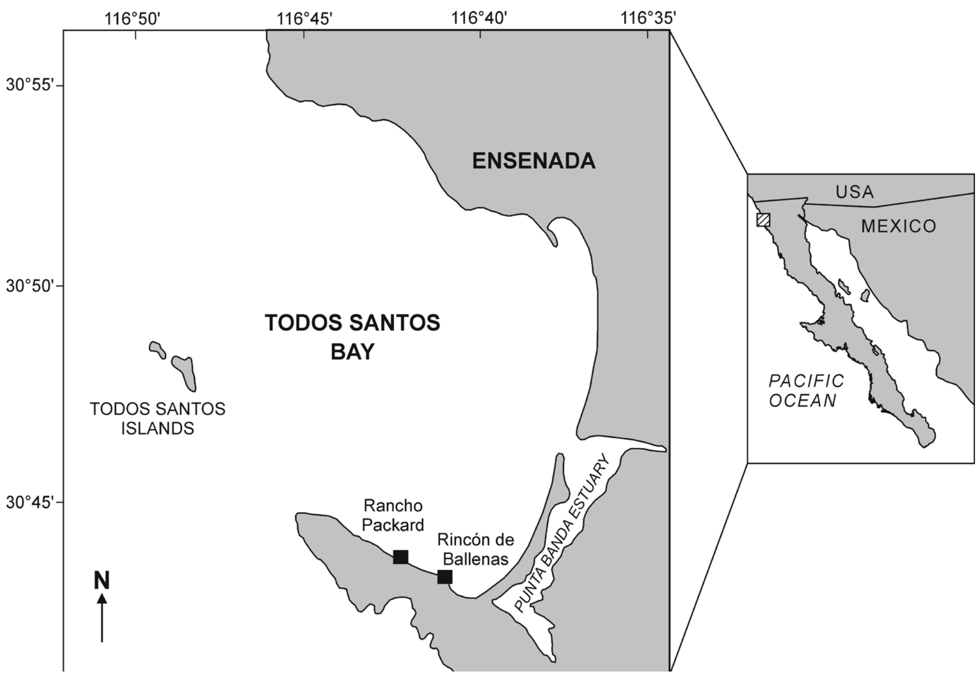

Figure 1. Map of the Baja California peninsula, indicating where the city of Ensenada is located. The inset shows the Todos Santos Bay and the two sampling stations in the protected side of the Punta Banda point.

of these two components results in a larger total wave amplitude. As a consequence, exposure hours are greater during winter. Of our two study sites, RP is more exposed to waves, than RB [29].

2.2. Sampling Design

Sampling took place from June 2009 to April 2010 during the Mean Lower Low Water tidal level (MLLW). Each season was represented by two months: June and July 2009, represented summer; October and November, autumn; December 2009 and January 2010, for winter, and March and April 2010, represented spring.

At each site we installed two transects perpendicular to the shore, separated by about 100 m. Their length and depth varied as a function of the topography. At RB, *S. horneri* was distributed between −0.2 and −0.8 m MLLW, corresponding to the low intertidal level; at RP, its distribution was between +0.5 and −0.2 m MLLW, in the middle and high intertidal levels (**Figure 2**).

2.3. Field Work

In order to cover the whole transect, samples were collected in the following manner; in every visit to the field we placed a 10 m rope along each transect, with marks every 0.5 m. At the beginning of every season, ten 0.25 m^2 quadrats were collected every meter starting at the 0 distance, and in the second seasonal visit, ten samples were also collected every meter, but starting at the 0.5 m mark.

Sampling was destructive, following the methodology described by [29]. Macroalgae were detached from the

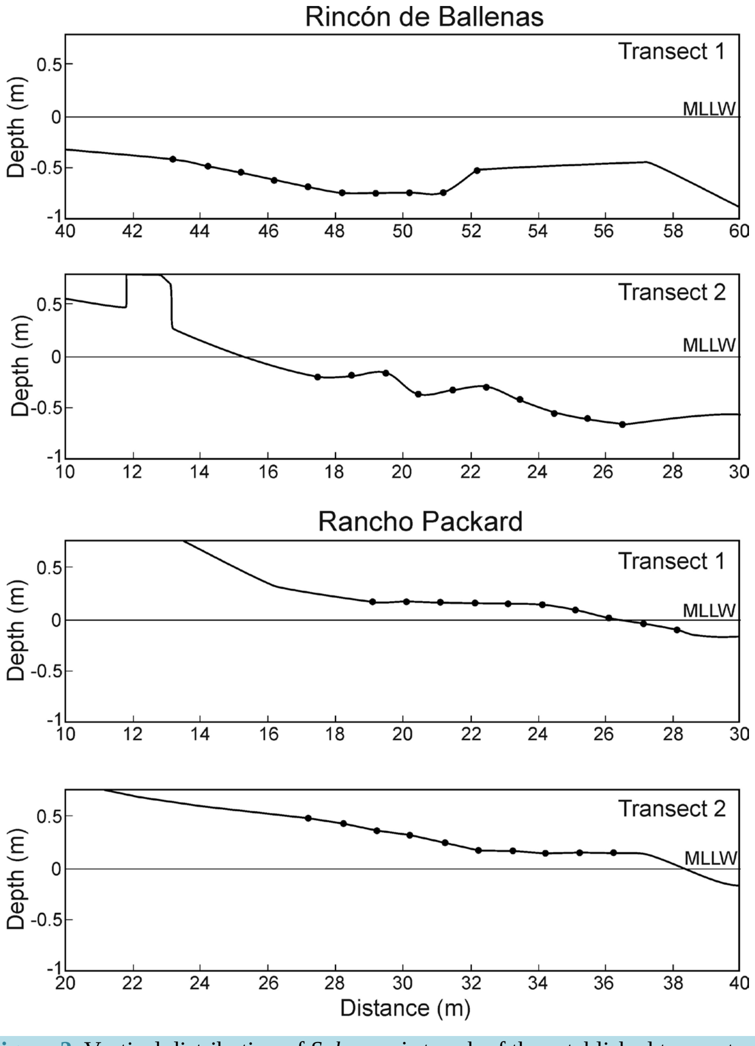

Figure 2. Vertical distribution of *S. horneri* at each of the established transects.

substrate by hand. All collected material was placed in labeled plastic bags, kept cool until arrival to the laboratory. Once in the lab, macroalgae were frozen until processing.

Sea Surface Temperature (SST) and Photosynthetically Active Radiation (PAR) data from May 2009 to May 2010 were downloaded from NASA's Ocean Color Satellite (http://oceancolor.gsfc.nasa.gov/seadas/). The use of the MODIS sensor provides a 4 km resolution, so the same data set was used for both sampling sites. For every site and sampling depth, we assessed the seasonal variations in tidal exposure, adding the number of hours that the sea level was lower than the selected reference level (Sea Level Laboratory, CICESE).

2.4. Laboratory Work

Macroalgae were defrosted and rinsed with fresh water to remove salts and sediment. Later, placed in plastic trays, and with tweezers, all epiphytic material, whether vegetal or animal, was removed. Algae were first separated into groups: Chlorophyta, Phaeophyta, and Rhodophyta, and then, all members of each group were identified at the species level. For this, histological cuts were performed, and tissue characteristics were analyzed under microscope. We used the taxonomic keys and classification system of [30]. Density was expressed as No. individuals of each species m^{-2}. Each species was oven dried at 60˚C for 24 hours, and weighed (±0.1 g) to determine its biomass, expressed as g DW m^{-2}. Average density and biomass values were determined per site, depth, and month. Species were classified infunctional groups following [31], as: filamentous algae, foliose algae, corticated foliose algae, corticated macrophytes, leathery macrophyes, articulated calcareous algae, and crustose algae.

2.5. Data Analyses

S. horneri density and biomass data were analyzed using non-parametric statistics, since data did not followed a normal distribution. Significant differences between sites were explored with the U Mann-Whitney test. Differences among depths and months were analyzed with a one-way non-parametric ANOVA, Kruskall-Wallis. When non-significant differences between depth levels were found, such levels were pooled together to increase the power of the statistical tests [32].

The tendency between density and biomass with sea surface temperature, irradiance, and air exposure hours, was analyzed with the Spearman rank correlation test [33]. For all statistical analyses alpha was set at 0.05, and tests were run using the program STATISTICA 7 for Windows (2002).

2.6. Community Analyses

To determine community diversity, we used two attributes of community structure: species richness (*S*), and the Shannon-Wiener diversity index (H') [34]:

$$H' = -\sum_i \rho_i \left(\log p_i\right)$$

where ρ_i is the proportion of the total count arising from the *i*th species.

Both attributes were assessed when *S. hornerii* was present, and absent. Differences in H' under both conditions were tested with Hutchinson test [33].

We analyzed the spatial distribution of the functional groups when *S. horneri* was present, or absent, using their biomass values. For this, a non-metric MDS using the package "Vegan" for R platform was used [35].

3. Results

Following the annual cycle of maximum values during summer, and minimum values during winter, surface water temperature varied between 15.5˚C and 21.1˚C, and irradiance between 22.8 and 55.2 mol·m^{-2}·d^{-1}. Air exposure hours varied by one order of magnitude between sites, with a total of 77 ± 0.5 hours at RB, and 685 ± 53 hours at RP. Winter was the season with more exposure hours at RB, and spring had the highest number of exposure hours at RP.

We found highly significant differences in annual mean *S. horneri* density and biomass between sites ($P < 0.001$), but not between tidal depths at any site ($P > 0.05$), and only at RP there were significant differences between sampled seasons ($P < 0.05$). At RB the invasive alga was present during October, November, and March, with an irregular distribution along the sampled depths. Its average density was 2 ± 0.94 individual m^{-2}, and average biomass, 4 ± 0.95 g DW m^{-2}. At RP, *S. horneri* was present during all sampled months, except June, but because of bad weather we could not collect samples in April. Also at this site, *S. horneri* vertical distribution was irregular. Average density was 10 ± 0.96 individual m^{-2}, with the lowest value during summer, 4 ± 0.9 individual m^{-2}, and the highest during autumn, 17 ± 0.98 individual m^{-2}. Average biomass for all the study period at RP was 102 ± 0.97 g DW m^{-2}, with the lowest values in summer, 12 ± 0.96 g DW m^{-2}, and the highest in spring, 292 ± 0.98 g DW m^{-2}.

At RB there were no significant correlations between *S. horneri* density and biomass with the environmental variables, but at RP, *S. horneri* density and biomass were negatively correlated with SST: ($r = -0.34$, $P < 0.001$), and ($r = -0.53$, $P < 0.001$) respectively; biomass was also negatively correlated with PAR ($r = -0.25$, $P < 0.05$). Air exposure hours yield no significant correlations with the biological data set either at RB or at RP.

3.1. Community Structure

A total of 39 macroalgal species was recorded during this study, of which 23 species were Rhodophyta, 11 Phaeophyta, and 5 Chlorophyta. The highest species richness corresponded to RB, with 29 species, while 25 species characterized RP. Highly significant differences between sites were found for macroalgae density ($P < 0.001$), and biomass ($P < 0.001$): 10 ± 0.9 individuals m^{-2}, and 66 ± 0.98 g DW m^{-2}, at RB, versus 14 ± 0.97 individuals m^{-2}, and 120 ± 0.96 g DW m^{-2} at RP.

Of the 29 macroalgae species recorded at RB, the Rhodophyta were the most diverse, with 16 species, followed by the Phaeophyta with 9, and the Chlorophyta with 4 species (**Table 1**).

Table 1. List of macroalgae species found at Rincón de Ballenas, between June 2009 and April 2010, when *S. horneri* was present (+), or absent (−). Their functional form was determined according to [31].

Division	Species	Functional form	Condition
Chlorophyta	*Codium fragile*	Corticated macrophyte	(−)
	Ulva californica	Foliose	(−)
	Ulva fasciata	Foliose	(−)
	Ulva nematoidea	Foliose	(−)
Phaeophyta	*Colpomenia sinuosa*	Corticated macrophyte	(−)
	Colpomenia tuberculata	Corticated macrophyte	(−)
	Dictyota flabellata	Corticated foliose	(+) (−)
	Dictyopteris undulata	Corticated foliose	(+) (−)
Rhodophyta	*Petrospongium rugosum*	Crustose	(−)
	Sargassum muticum	Leathery macrophyte	(+) (−)
	Silvetia compressa	Leathery macrophyte	(+)
	Sphacelaria californica	Filamentous	(−)
	Zonaria farlowii	Corticated foliose	(+) (−)
	Centroceras clavulatum	Corticated macrophyte	(−)
	Chondria californica	Corticated macrophyte	(−)
	Chondria decipiens	Corticated macrophyte	(−)
	Chondrocanthus canaliculatus	Corticated macrophyte	(−)
	Corallina officinalis	Articulated calcareous	(+)
	Corallina polysticha	Articulated calcareous	(−)
	Corallina vancouverensis	Articulated calcareous	(+) (−)
	Cryptopleura ramosa	Foliose	(−)
	Endarachne binghamiae	Corticated macrophyte	(−)
	Hypnea valentiae	Corticated macrophyte	(−)
	Jania crassa	Articulated calcareous	(+) (−)
	Jania rosea	Articulated calcareous	(+) (−)
	Laurencia pacifica	Corticated macrophyte	(+) (−)
	Lithotrix aspergillum	Articulated calcareous	(+) (−)
	Pterocladiella capillacea	Corticated macrophyte	(+) (−)
	Smithora naiadum	Foliose	(−)

Densities were higher for *Corallina officinalis*, and *Sargassum muticum*. The highest biomass values corresponded to the red alga *Corallina officinalis*, and to the green alga *Ulva fasciata*. The analysis per group shows that density was slightly higher for the red algae, 8.23 ± 0.73; followed by the brown, 7.55 ± 1.32, and lower for the green algae, with 7 ± 0.86 individuals m^{-2}. With respect to biomass, the green algae showed the highest values with 163 ± 72.8 g DW m^{-2}, followed by the red, 75.76 ± 25.5, and the brown algae, 41.3 ± 16.09 g DW m^{-2}. At RP, there were 14 species of Rhodophyta, 7 species of Phaeophyta, and 4 Chlorophyta (**Table 2**).

The red algae with highest density were *Corallina frondescens*, *Centroceras clavulatum*, and *Lithothrix aspergillum*, and the brown algae *Dictyopteris undulata*, and *Petroglosum rugosum*. The species with highest biomass were the red algae: *Lithothrix aspergillum*, *Corallina frondescens*, *C. pinnatifolia*, and *Centroceras clavulatum*. At the group level, density decreased from the brown, to the red, and the green algae: 12.57 ± 2.34; 10.66 ± 1.67, and 6 ± 1.73 individuals m^{-2} respectively. The red algae had the highest biomass: 133.86 ± 32.9, followed by the brown, 56 ± 7.1, and the green, 8 ± 1.2 g DW m^{-2}.

3.1.1. Influence of *S. horneri* at RB

The most frequently present macroalgae had the greatest contribution in determining the community structure: *Dictyota flabellata*, *Dictyopteris undulata*, and *Sargassum muticum*, among the brown algae; *Corallina vancouverensis*, *Hypnea valentiae*, *Jania rosea*, and *Laurencia pacifica*, among the red algae. Peak density values were for *Corallina officinalis* and *Laurencia pacifica*, when *S. horneri* was present; when it was absent, highest density values were for *S. muticum*. When *S. horneri* was present, *Corallina officinalis*, and *Jania rosea* had the greatest biomass; when *S. horneri* was absent, peak biomass values corresponded to *Ulva fasciata*, and *Ulva californica*.

Table 2. List of macroalgae species found at Rancho Packard, between June 2009 and April 2010, when *S. horneri* was present (+), or absent (−). Their functional form was determined according to [31].

Division	Species	Functional form	Condition
Chlorophyta	*Codium fragile*	Corticated macrophyte	(+)
	Codium hubbsi	Corticated macrophyte	(−)
	Ulva californica	Foliose	(−)
	Ulva nematoidea	Foliose	(+) (−)
Phaeophyta	*Colpomenia sinuosa*	Corticated macrophyte	(+) (−)
	Dictyopteris undulata	Corticated foliose	(+) (−)
	Dictyota flabellata	Corticated foliose	(+) (−)
	Petrospongium rugosum	Crustose	(+) (−)
	Sargassum muticum	Leathery macrophyte	(+) (−)
	Silvetia compressadeliquescens	Leathery macrophyte	(−)
	Zonaria farlowii	Corticated foliose	(+) (−)
Rhodophyta	*Amphiroa zonata*	Articulated calcareous	(+) (−)
	Centroceras clavulatum	Corticated macrophyte	(+) (−)
	Corallina frondescens	Articulated calcareous	(+) (−)
	Corallina pinnatifolia	Articulated calcareous	(+)
	Corallina vancouverensis	Articulated calcareous	(+) (−)
	Endarachne binghamiae	Corticated macrophyte	(+)
	Hypnea valentiae	Corticated macrophyte	(+) (−)
	Laurencia pacifica	Corticated macrophyte	(+) (−)
	Lithrotrix aspergillum	Articulated calcareous	(+) (−)
	Mazzaella affinis	Corticated macrophyte	(−)
	Mazzaella leptorhynchus	Corticated macrophyte	(+) (−)
	Pterocladia caloglossoides	Corticated macrophyte	(+)
	Pterocladia californica	Corticated macrophyte	(+)
	Pterocladia capillacea	Corticated macrophyte	(+) (−)

Macroalgae density showed significant differences between the *S. horneri* presence and absence condition ($P < 0.01$), with a mean of 2.977 ± 4.33 individuals m^{-2}, under presence condition, and 9.647 ± 2.232 individuals m^{-2} when *S. horneri* was absent. The same was true for macroalgae biomass ($P < 0.01$), with a mean of 18.125 ± 28.99 g DW m^{-2} for the invasive alga presence condition, and 76.428 ± 48.75 for the absence condition. Species richness (S) was higher when *S. horneri* was absent, with 28 species, than when the invasive algae was present, 13 species. Also, the diversity index (H'), was higher when *S. horneri* was absent, 0.884, than when it was present, 0.281 ($P < 0.0001$).

There were highly significant differences in macroalgae density through time ($P < 0.01$), with peak values between October and December, with values ranging between 8 and 13 individuals m^{-2} (**Figure 3(a)**). Macroalgae biomass also showed significant differences through time ($P < 0.01$), with a first peak in November, and a second peak in March, for both presence-absence conditions (**Figure 3(b)**). Species richness (*S*) was highest in June, under *S. horneri* absence, and in November, under *S. horneri* presence (**Figure 3(c)**). The species diversity

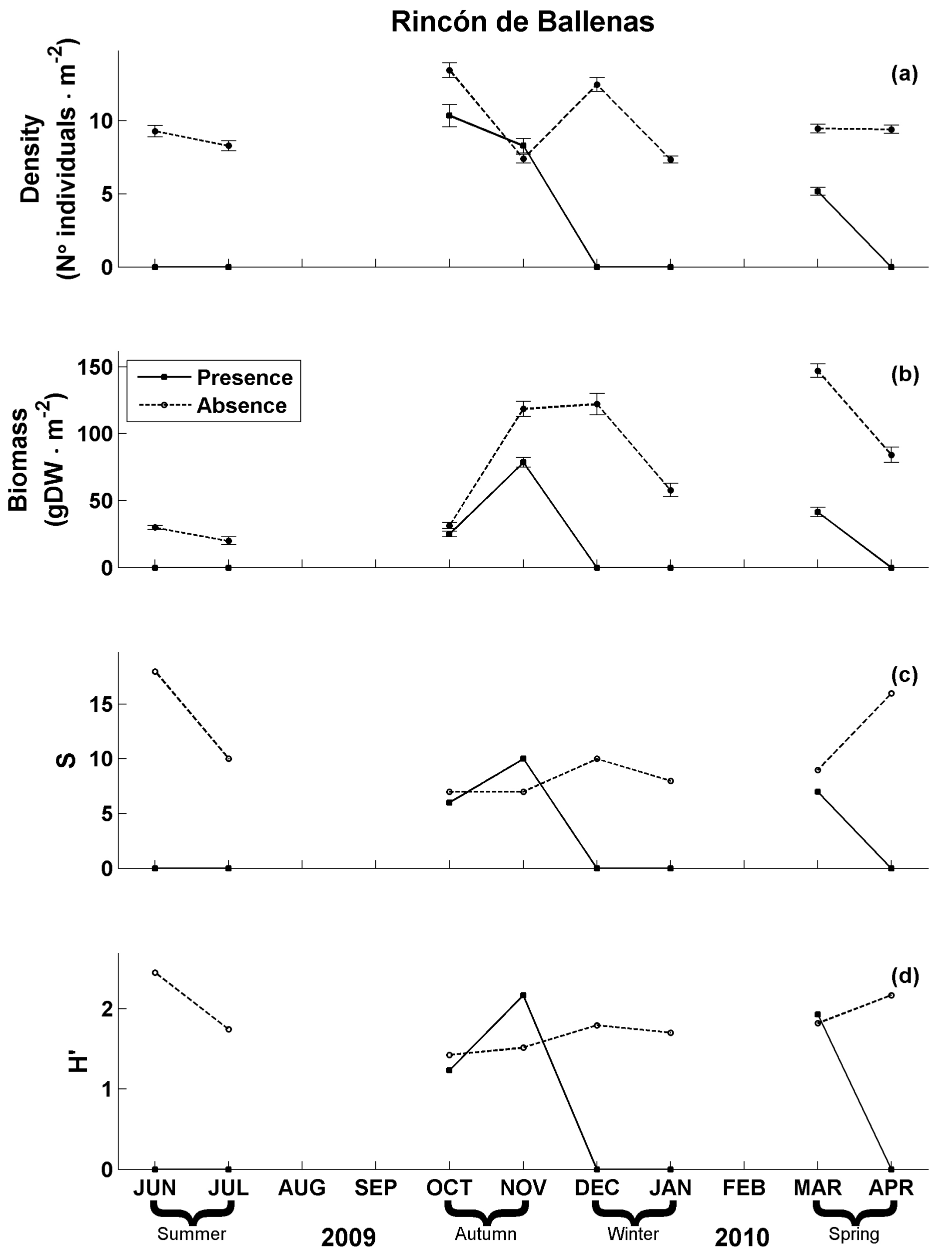

Figure 3. Seasonal variations in the selected structural variables in quadrats with and without *S. horneri* at RB.

index, H', peaked in November when the invasive alga was present, and in June and April when it was absent, these differences being highly significant ($P < 0.001$) (**Figure 3(d)**).

The functional form of each species, and whether it was found when *S. horneri* was present (+), absent (−), or under both conditions (+) (−), is indicated in **Table 1**. It can be noticed that the corticated macrophytes and the foliose functional forms were the most affected, as the 14 species contained in these groups could only be found when the invasive alga was absent.

The MDS shows, to the left, a compact group formed by the low biomass values of all functional groups present; however, to the right, it can be noticed that the articulated calcareous reached the higher biomass values, regardless of whether the invasive algae was present, or absent (**Figure 4**).

3.1.2. Influence of *S. horneri* at RP

The macroalgae with the highest contribution to the community structure were: *Dyctiopteris undulata*, *Sargassum muticum*, *Zonaria farlowii*, and *Dictyota flabellata*, among the brown algae, and: *Lithothrix aspergillum*, *Centroceras clavullatum*, and *Corallina vancouverensis*, among the red algae.

When *S. horneri* was present, the species with more individuals per m^2 were: *Centroceras clavulatum*, *Corallina frondescens*, *Mazzaella leptorhynchus*, and *Dictyopteris undulata*. When *S. horneri* was absent, *Lithothrix aspergillum* and *Petrospongium rugosum* were the species with highest densities. When *S. horneri* was present, the algae with the highest biomass values were: *Corallina frondescens*, and *Lithothrix aspergillum*. This last species, also had the highest biomass when *S. horneri* was absent, followed by *Centroceras clavullatum*.

The comparison of macroalgae density between the presence-absence conditions was slightly marginal ($P = 0.06$). Mean values were 9.641 ± 5.52 individual m^{-2} when *S. horneri* was present and 4.880 ± 6.88 individual m^{-2} when it was absent. The same significance level ($P = 0.06$) was found for the biomass comparison, with means of 74.489 ± 60.21 g DW m^{-2} under presence of the invasive alga, and 46.239 ± 82.33 g DW m^{-2} when it was absent. Species richness was similar when *S. horneri* was present, with 22 species, at when it was absent, 21 species. However, there were significant differences in the diversity index, with a higher value when the invasive alga was present, 0.740, than when it was absent 0.676 ($P < 0.005$). We also found that the selected variables showed changes as a function of time, with peak values in October, when the invasive alga was present, and in June when it was absent ($P < 0.001$) (**Figure 5**).

At this site, most of the species were present independently of the presence of *S. horneri*, with only three species, all with different functional forms, being affected by its presence (**Table 2**).

The MDS showed that, as in RB, the articulated calcareous group reaches the highest biomass values, followed by the corticated macrophytes (**Figure 6**).

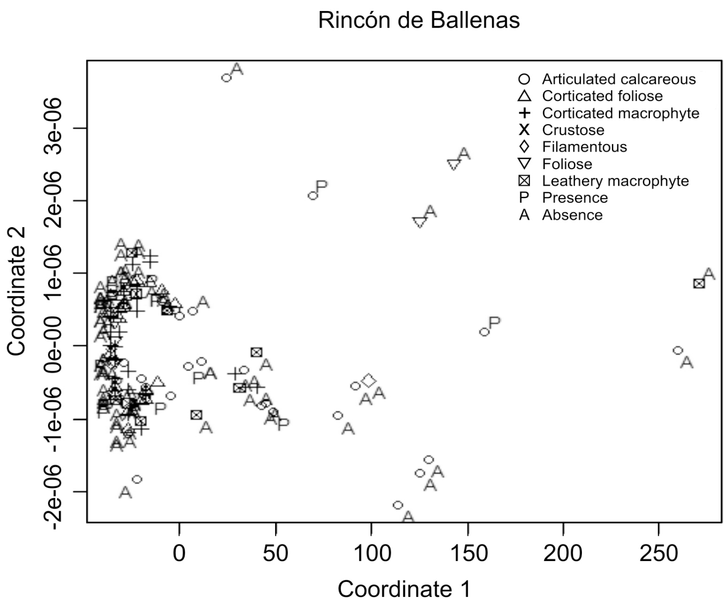

Figure 4. Distribution of the macroalgae functional forms at RB along the two coordinate principal axes.

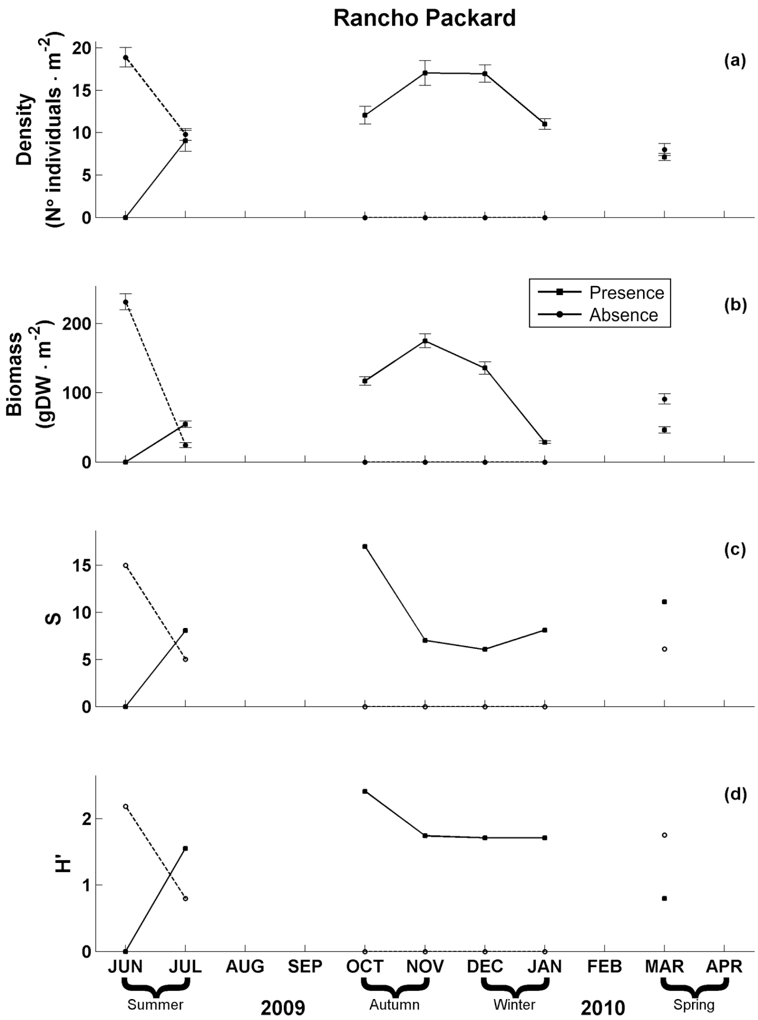

Figure 5. Seasonal variations in the selected structural variables in quadrats with and without *S. horneri* at RP.

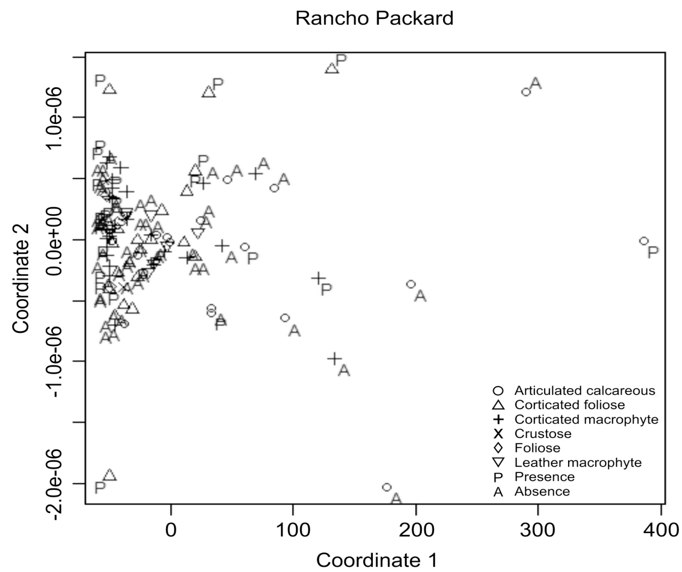

Figure 6. Distribution of the macroalgae functional forms at RP, along the two coordinate principal axes.

4. Discussion

Our results show that there are important site differences in the presence of *S. horneri* inside the Todos Santos bay and its effects on the macroalgae community. At Rincón de Ballenas, the invasive alga was not present all year round, and had low density and biomass values. However, its presence resulted in a significant reduction in the macroalgae density, biomass, species richness and diversity. The corticated macrophytes and the foliose functional forms were severely reduced by the presence of the invasive alga. On the other hand, at Rancho Packard, the presence of *S. horneri* was more continuous throughout the year, and this non-indigenous species reached high density and biomass values. Despite this, there only were marginally significant effects of its presence on the local macroalgae community, and higher density, biomass, and diversity values were found when *S. horneri* was present. Most of the functional forms were represented, even when *S. horneri* was present. Despite these notorious site differences, at both locations, the highest biomass corresponded to the articulated calcareous functional form.

With respect to sites differences, we know that RB is characterized by reduced wave exposure and soft sediment, represented by loose gravel. In contrast, at RP, wave exposure is slightly higher and the substrate is represented by solid rock. Although *S. horneri* has the rare ability to colonize both, hard and soft substrate [10], our data indicate that at the Todos Santos bay, *S. horneri* grows better on hard substrate. This is in agreement with [7], whoat Limfjorden, Denmark, found a strong correlation between the cover of *S. muticum* and the presence of hard substrate. Although we did not find significant differences with depth, [7], found that the difference in cover between shallow, 0 - 2 m, and deep, 2 - 6 m, waters, was regulated by the amount of hard substrate.

Water movement has been considered a seasonally important variable which affects standing biomass, thallus size, morphology and, possibly, fertility [36] [37]. Although we did not made direct measurements of water movement, [29] used numerical simulation models to predict ocean surface waves inside the Todos Santos bay, and results of her study show a higher wave energy at RP, where we found the healthier populations of *S. horneri*. However, in Obama bay, Japan, [38] found that the *S. horneri* populations from the sheltered coast had longer primary laterals, and plants had higher weight, than those from the exposed shore. *In situ* measurements of wave exposure are needed at Todos Santos bay, to determine if our two study sites can be considered to be in a protected shore. For the northern coast of Spain [9], found that wave exposure was not significant for *S. muticum* growth and survivorship. In contrast, [39], for the foliose algae of South Wales, and [37], for the populations of *S. polyceratium* in Curaçao, found that foliose algae were more abundant where wave-action was greater and during the cooler months of the year.

Reference [39] also found that algal survival was greater and growth was faster under conditions of increased moisture, decreased emersion, and decreased temperatures and light regimes during low tide. However, in our study we could not find a significant correlation between *S. horneri* density and biomass with tidal exposure, despite the high number of exposure hours at RP. The fact that *S. horneri* grows at the high intertidal at RP (**Figure 2**), and that at this site exposure hours were greater during spring, could help explain the negative correlation between density and biomass with water temperature and irradiance, in agreement with [39]. The negative correlation between these two biological variables with irradiance could also be due to a high epiphyte load, as found by [40] for three species of *Sargassum* in Hawaii. The negative correlation with water temperature is in agreement with [38] [41] [42], among others, and is characteristic of temperate species.

The ephemeral nature of the individual patches of *S. horneri* at RB, could be understood using the physical and biological arguments that have been presented to explain the colonization and establishment patterns of the genus *Sargassum*: anomalously warm sea water temperatures and their subsequent effects on food web in the region [43]; the disturbance represented by the presence of sand and its negative impact on recruits survival [16]; the unsuitability of smaller stones, gravel and sand, as substrate for grown specimens [7], and highly localized propagule dispersal and settlement [44]. For *Gracillaria verrucosa*, [45] found than an exponential decline in settlement densities and short dispersal distances was partly due to the diffusive environment found in the shallow subtidal.

The strong seasonality that characterizes the genus *Sargassum* has been mainly attributed to sea water temperature, and photoperiod, with regional variations due to latitudinal gradients [43] [46]-[48]. "Autumn-fruiting type" and "spring-fruiting type" populations of *S. horneri* have been described for the Seto Inland Sea, Japan by [47]. For both populations it has been considered that the shortening of day length around the autumn equinox, is the possible cue to start the growth phase, characterized by the rapid increase in thallus length. Simultaneously, water temperature starts its autumn reduction [47]. However, it is now considered that the difference in seasonality between these two populations does not reflect a phenotypic plasticity, but a genotypic difference [42].

The lifetime of the autumn-fruiting type is considered to have four phases, according to the rates of increase in length and morphogenetic stages: I—formation of early leaves, from December to May; II—differentiation of stems, from May to September; III—rapid elongation of stems and lateral branches, from September to December; IV—senescence phase, after December. In contrast, the spring-fruiting type has two growth phases and a senescence phase: I—from April to September; II—September to March, and III—senescence phase after March [47]. The selected populations of *S. horneri* at Todos Santos bay, corresponds to the spring-fruiting type, like the Japanese populations described by [38], and [47] for the Seto Inland Sea, and the populations of *S. filicinum*, now *S. horneri*, at Long Beach Harbor [19], and the California Channel Islands [49]. The sampled populations in Todos Santos bay show the lowest density and biomass values, when compared to reported values for *S. horneri* (**Table 3**).

When we analyzed the effects of the presence of the invasive alga on the local macroalgae community, we were surprised by the fact that at RB, where *S. horneri* was only present a few months and, showed low density and biomass values, there were significant differences between the macroalgae community structure when *S. horneri* was present versus when it was absent. The presence of the invasive algae resulted in significant reductions in macroalgae density, biomass, *S* and H'. On the other hand, at RP, where *S. horneri* had a more continuous presence throughout the year, and reached higher density and biomass values, the comparison between the macroalgae community structure under the presence and absence conditions was only marginally significant. The macroalgae showed higher density, biomass, and H' when *S. horneri* was present.

It seems that the macroalgae community at RB was more susceptible to invasion, than the one at RP. To understand the invasion process, it is necessary to analyze the number and identity of the functional groups present [2]. At RB there was a loss of functional diversity, with most of the species belonging to the foliose and corticated macrophytes functional groups being present only when *S. horneri* was absent (**Table 1**), while at RP, most of the species, and functional forms, remained when the non-indigenous alga was present (**Table 2**).

As indicated by [7], during an invasion process, the community structure is affected by the increasing abundance of the invasive alga, and by the changes in the remaining community. After the invasion of *S. muticum* in Limfjorden, Denmark, [7] found that members of the coarsely branched and thick leathery algae tended to decrease consistently over time, as a result of competition. Reference [2] found that canopy species, regardless of their density, suppressed invader biomass, while crustose species promoted invasibility. Turf and subcanopy species effects were similar to those of the canopy species, but less intense [2]. Competitive suppression is mainly due to light competition [17] [51] [52] with space competition becoming important in a later stage [52].

At RB, only two species belonging to the leathery macrophyte functional form (canopy) were present, with most of the corticated macrophytes (subcanopy), and all of the foliose (turf), being gone when *S. horneri* was present. In contrast, at RP, the macroalgae community seems to stand well the presence and abundance of the non-indigenous alga, as most species, and most functional forms remained present, regardless of the presence of *S. horneri*. It is important to note that what we refer to as the local macroalgal community has already being modified, as we found *S. muticum* at both sites. *S. muticum* persist under presence or absence of *S. horneri*, so no competition seems to exist between these two species, but this needs to be assessed in the field.

Table 3. Range of values for abundance, density, and biomass reported for *Sargassum horneri*. Authors are listed chronologically. ND = Not Determined.

Reference	Species	Site	Abundance (No. plants)	Density (No. individuals m^{-2})	Biomass (g DW m^{-2})
[38]	*S. horneri*	Obama Bay, Japan	ND	20	680 (sheltered) 431 (exposed)
[41]	*S. horneri*	Ohori, Corea	15 (October) - 68 (March)	ND	ND
[19]	*S. filicinum*	Santa Catalina Island, CA	>30 (April, exposed) 2 - 4 (April, sheltered)	ND	ND
[50]	*S. horneri*	Gouqui Island, South China Sea	25 (June) - 830 (August)	96 (June) - 3320 (August)	540 (August) 4420 (June)
This study	*S. horneri*	Todos Santos Bay, Mexico	ND	1 (July) - 10 (March)	3 - 78

The already altered macroalgae communities we found inside the Todos Santos bay, are dominated by the articulated calcareous, functional form with the highest biomass at both sites (**Figure 4** and **Figure 6**). This functional form corresponds to what [2] refer to as turf-forming species, which are recognized for being primary space-holders with limited vertical height (usually ~5 cm length). Algal turf has the ability to monopolize space and persist under a wide range of environmental conditions, and its thickness, rather than its cover, seems to be the most affected by the intensity of disturbance and smothering by sediments [53]. The rapid growth of turf-dominated assemblages provides its capability to compete for space and recover from disturbance [54].

5. Conclusion

Our results do not fully support our hypothesis. As in RP, where the highest density and biomass values of *S. horneri* were found, there was not the significant reduction in macroalgae density, biomass, S and H' we expected; on the contrary, density, biomass, and H' showed higher values when the non-indigenous alga was present (**Figure 5**). This unexpected result could be due to the fact that the native community had already been altered by the early invasion of *S. muticum*, with the most resilient species and functional forms remaining in place. One of the most important changes we noticed is the severe reduction of the canopy forming species at both sites, confirming the fact that the local macroalgae community has already been modified, in agreement with [7]. A long-term monitoring, with more study sites, is needed to fully comprehend the changes that the local macroalgae communities are experiencing along the Baja California peninsula.

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References

[1] Wallentinus, I. and Nyberg, C.D. (2007) Introduced Marine Organisms as Habitat Modifiers. *Marine Pollution Bulletin*, **55**, 323-332. http://dx.doi.org/10.1016/j.marpolbul.2006.11.010

[2] Arenas, F., Sánchez, I., Hawkins, S.J. and Jenkins, S.R. (2006) The Invasibility of Marine Algal Assemblages: Role of Functional Diversity and Identity. *Ecology*, **87**, 2851-2861. http://dx.doi.org/10.1890/0012-9658(2006)87[2851:TIOMAA]2.0.CO;2

[3] Lavorel, S., McIntyre, S., Landsberg, J. and Forbes, T. (1997) Plant Functional Classifications: From General Groups to Specific Groups Based on Response to Disturbance. *Trends in Ecology & Evolution*, **12**, 474-478. http://dx.doi.org/10.1016/S0169-5347(97)01219-6

[4] Thresher, R. (1999) Key Threats from Marine Bioinvasions: A Review of Current and Future Issues. Marine Bioinvasions. *Proceedings of the First National Conference*, 24-36.

[5] Schaffelke, B., Smith, J.E. and Hewitt, C.L. (2007) Introduced Macroalgae—A Growing Concern. *Eighteenth International Seaweed Symposium*, Springer, 303-315. http://dx.doi.org/10.1007/978-1-4020-5670-3_37

[6] Mooney, H.A. and Drake, J.A. (1986) Ecology of Biological Invasions of North America and Hawaii. Springer-Verlag. http://dx.doi.org/10.1007/978-1-4612-4988-7

[7] Stæhr, P.A., Pedersen, M.F., Thomsen, M.S., Wernberg, T. and Krause-Jensen, D. (2000) Invasion of Sargassum Muticum in Limfjorden (Denmark) and Its Possible Impact on the Indigenous Macroalgal Community. *Marine Ecology Progress Series*, **207**, 79-88. http://dx.doi.org/10.3354/meps207079

[8] Norton, T. (1981) Gamete Expulsion and Release in Sargassum Muticum. *Botanica Marina*, **24**, 465-470. http://dx.doi.org/10.1515/botm.1981.24.8.465

[9] Andrew, N. and Viejo, R. (1998) Ecological Limits to the Invasion of Sargassum Muticum in Northern Spain. *Aquatic Botany*, **60**, 251-263. http://dx.doi.org/10.1016/S0304-3770(97)00088-0

[10] Strong, J.A., Dring, M.J. and Maggs, C.A. (2006) Colonisation and Modification of Soft Substratum Habitats by the Invasive Macroalga Sargassum Muticum. *Marine Ecology Progress Series*, **321**, 87-97. http://dx.doi.org/10.3354/meps321087

[11] Deysher, L. and Norton, T.A. (1981) Dispersal and Colonization in *Sargassum muticum* (Yendo) Fensholt. *Journal of Experimental Marine Biology and Ecology*, **56**, 179-195. http://dx.doi.org/10.1016/0022-0981(81)90188-X

[12] Critchley, A., De Visscher, P. and Nienhuis, P. (1990) Canopy Characteristics of the Brown Alga *Sargassum muticum* (Fucales, Phaeophyta) in Lake Grevelingen, Southwest Netherlands. *Hydrobiologia*, **204**, 211-217. http://dx.doi.org/10.1007/BF00040236

[13] Walker, D. and Kendrick, G. (1998) Threats to Macroalgal Diversity: Marine Habitat Destruction and Fragmentation, Pollution and Introduced Species. *Botanica Marina*, **41**, 105-112. http://dx.doi.org/10.1515/botm.1998.41.1-6.105

[14] Ambrose, R. and Nelson, B.V. (1982) Inhibition of Giant Kelp Recruitment by an Introduced Brown Alga. *Botanica Marina*, **25**, 265-268. http://dx.doi.org/10.1515/botm.1982.25.6.265

[15] De Wreede, R.E. (1983) *Sargassum muticum* (Fucales, Phaeophyta): Regrowth and Interaction with *Rhodomela larix* (Ceramiales, Rhodophyta). *Phycologia*, **22**, 153-160. http://dx.doi.org/10.2216/i0031-8884-22-2-153.1

[16] Viejo, R.M. (1997) The Effects of Colonization by *Sargassum muticum* on Tidepool Macroalgal Assemblages. *Journal of the Marine Biological Association of the United Kingdom*, **77**, 325-340. http://dx.doi.org/10.1017/S0025315400071708

[17] Britton-Simmons, K.H. (2004) Direct and Indirect Effects of the Introduced Alga *Sargassum muticum* on Benthic, Subtidal Communities of Washington State, USA. *Marine Ecology Progress Series*, **277**, 61-78. http://dx.doi.org/10.3354/meps277061

[18] Tseng, C., Yoshida, T. and Chiang, Y.M. (1985) East Asiatic Species of *Sargassum* Subgenus Bactrophycus J. Agardh (Sargassaceae, Fucales), with Keys to the Sections and Species. *Taxonomy of Economic Seaweeds*, **1**, 1-15.

[19] Miller, K.A., Engle, J.M., Uwai, S. and Kawai, H. (2007) First Report of the Asian Seaweed *Sargassum filicinum* Harvey (Fucales) in California, USA. *Biological Invasions*, **9**, 609-613. http://dx.doi.org/10.1007/s10530-006-9060-2

[20] Aguilar-Rosas, L.E., Aguilar-Rosas, R., Kawai, H., Uwai, S. and Valenzuela-Espinoza, E. (2007) New Record of *Sargassum filicinum* Harvey (Fucales, Phaeophyceae) in the Pacific Coast of Mexico. *Algae*, **22**, 17-21. http://dx.doi.org/10.4490/ALGAE.2007.22.1.017

[21] Aguilar-Rosas, L.E., Núñez-Cebrero, F. and Aguilar-Rosas, C. (2013) Introduced Marine Macroalgae in the Port of Ensenada, Baja California, Mexico: Biological Contamination. *Procedia Environmental Sciences*, **18**, 836-843. http://dx.doi.org/10.1016/j.proenv.2013.04.112

[22] Smith, S.V., Ibarra-Obando, S.E., Díaz-Castañeda, V., Aranda-Manteca, F.J., Carriquiry, J.D., Popp, B.N. and Gonzalez-Yajimovich, O. (2008) Sediment Organic Carbon in Todos Santos Bay, Baja California, Mexico. *Estuaries and Coasts*, **31**, 719-727. http://dx.doi.org/10.1007/s12237-008-9054-7

[23] Argote-Espinosa, M., Gavidia-Medina, F. and Amador-Buenrostro, A. (1991) Wind-Induced Circulation in Todos Santos Bay, BC, Mexico. *Atmósfera*, **4**, 101-115.

[24] Alvarez-Sánchez, L., Hernández-Walls, R. and Durazo-Arvizu, R. (1988) Drift Patterns of Lagrangian Tracers in Todos Santos Bay. *Ciencias Marinas*, **14**, 135-162.

[25] Pérez-Higuera, R. and Chee-Barragán, A. (1984) Sediment Transport in Todos Santos Bay, BC. *Ciencias Marinas*, **10**, 31-52.

[26] Bakun, A. (1990) Global Climate Change and Intensification of Coastal Ocean Upwelling. *Science*, **247**, 198-201. http://dx.doi.org/10.1126/science.247.4939.198

[27] Espinosa-Carreón, T., Gaxiola-Castro, G., Robles-Pacheco, J. and Nájera-Martínez, S. (2001) Temperature, Salinity, Nutrients and Chlorophyll a in Coastal Waters of the Southern California Bight. *Ciencias Marinas*, **27**, 397-422.

[28] Cruz-Colin, M.E. and Cupul-Magaña, L.A. (1997) Erosion and Sediment Supply of Sea Cliffs of Todos Santos Bay, Baja California, from 1970 to 1991. *Ciencias Marinas*, **23**, 303-315.

[29] Castro-Osuna, D.A. (2003) Numerical Simulation of Waves Inside the Todos Santos Bay: Influence of Boundary Conditions. BSc Thesis, Marine Science College. Autonomus University of Baja California, Ensenada.

[30] Guiry, M. and Guiry, G. (2015) AlgaeBase [Internet]. National University of Ireland, Galway.

[31] Steneck, R.S. and Dethier, M.N. (1994) A Functional Group Approach to the Structure of Algal-Dominated Communities. *Oikos*, **69**, 476-498. http://dx.doi.org/10.2307/3545860

[32] Minchinton, T.E. and Bertness, M.D. (2003) Disturbance-Mediated Competition and the Spread of *Phragmites australis* in a Coastal Marsh. *Ecological Applications*, **13**, 1400-1416. http://dx.doi.org/10.1890/02-5136

[33] Zar, J.H. (1996) Bioestadistical Analysis. Prentice Hall, Upper Saddle River.

[34] Clarke, K.R. and Warwick, R.M. (1994) Change in Marine Communities: An Approach to Statistical Analysis and Interpretation. Plymouth Marine Laboratory, Plymouth.

[35] Oksanen, J., Blanchet, F.G., Kindt, R., Legendre, P., Minchin, P.R., O'Hara, R.B., *et al*. (2013) Package "Vegan". Community Ecology Package, Version 2.

[36] Santelices, B. (1977) Water Movement and Seasonal Algal Growth in Hawaii. *Marine Biology*, **43**, 225-235.

http://dx.doi.org/10.1007/BF00402315

[37] Engelen, A.H., Åberg, P., Olsen, J.L., Stam, W.T. and Breeman, A.M. (2005) Effects of Wave Exposure and Depth on Biomass, Density and Fertility of the Fucoid Seaweed *Sargassum polyceratium* (Phaeophyta, Sargassaceae). *European Journal of Phycology*, **40**, 149-158. http://dx.doi.org/10.1080/09670260500109210

[38] Umezaki, I. (1984) Ecological Studies of *Sargassum horneri* (Turner) C. Agardh in Obama Bay, Japan Sea. *Bulletin of the Japanese Society of Scientific Fisheries*, **50**, 1193-1200. http://dx.doi.org/10.2331/suisan.50.1193

[39] Underwood, A. and Jernakoff, P. (1984) The Effects of Tidal Height, Wave-Exposure, Seasonality and Rock-Pools on Grazing and the Distribution of Intertidal Macroalgae in New South Wales. *Journal of Experimental Marine Biology and Ecology*, **75**, 71-96. http://dx.doi.org/10.1016/0022-0981(84)90024-8

[40] De Wreede, R.E. (1976) The Phenology of Three Species of *Sargassum* (Sargassaceae, Phaeophyta) in Hawaii. *Phycologia*, **15**, 175-183. http://dx.doi.org/10.2216/i0031-8884-15-2-175.1

[41] Koh, C. and Shin, H. (1990) Growth and Size Distribution of Some Large Brown Algae in Ohori, East Coast of Korea. In: Lindstrom, S.C. and Gabrielson, P.W., Eds., *Thirteenth International Seaweed Symposium*, Springer, Dordrecht, 225-231. http://dx.doi.org/10.1007/978-94-009-2049-1_32

[42] Yoshida, G., Murase, N., Arai, S. and Terawaki, T. (2004) Ecotypic Differentiation in Maturation Seasonality among *Sargassum horneri* (Fucales, Phaeophyta) Populations in Hiroshima Bay, Seto Inland Sea, Japan. *Phycologia*, **43**, 703-710. http://dx.doi.org/10.2216/i0031-8884-43-6-703.1

[43] McCourt, R.M. (1984) Seasonal Patterns of Abundance, Distributions, and Phenology in Relation to Growth Strategies of Three *Sargassum* Species. *Journal of Experimental Marine Biology and Ecology*, **74**, 141-156. http://dx.doi.org/10.1016/0022-0981(84)90082-0

[44] Kendrick, G.A. and Walker, D.I. (1995) Dispersal of Propagules of *Sargassum* Spp. (Sargassaceae: Phaeophyta): Observations of Local Patterns of Dispersal and Consequences for Recruitment and Population Structure. *Journal of Experimental Marine Biology and Ecology*, **192**, 273-288. http://dx.doi.org/10.1016/0022-0981(95)00076-4

[45] Norton, T. (1992) Dispersal by Macroalgae. *British Phycological Journal*, **27**, 293-301. http://dx.doi.org/10.1080/00071619200650271

[46] Arenas, F., Fernández, C., Rico, J., Fernández, E. and Haya, D. (1995) Growth and Reproductive Strategies of *Sargassum muticum* (Yendo) Fensholt and Cystoseira Nodicaulis (Whit.) Roberts. *Scientia Marina*, **59**, 1-8.

[47] Yoshida, G., Arima, S. and Terawaki, T. (1998) Growth and Maturation of the "Autumn-Fruiting Type" of *Sargassum horneri* (Fucales, Phaeophyta) and Comparisons with the "Spring-Fruiting Type". *Phycological Research*, **46**, 183-189. http://dx.doi.org/10.1111/j.1440-1835.1998.tb00112.x

[48] Choi, C., Kim, H. and Sohn, C. (2003) Transplantation of Young Fronds of *Sargassum horneri* for Construction of Seaweed Beds. *Journal of the Korean Society of Fisheries and Aquatic Science*, **36**, 469-473. http://dx.doi.org/10.5657/kfas.2003.36.5.469

[49] Miller, K. and Engle, J.M. (2009) The Natural History of Undaria Pinnatifida and *Sargassum filicinum* at the California Channel Islands: Non-Native Seaweeds with Different Invasion Styles. *Proceedings of the 7th California Islands Symposium*, Oxnard, 5-8 February 2008, Institute for Wildlife Studies, Arcata, 131-140.

[50] Zhang, S.Y., Wang, L. and Wang. W.D. (2008) Algal Communities at Gouquil Island in the Zhoushan Archipielago, China. *Journal of Applied Phycology*, **20**, 853-861. http://dx.doi.org/10.1007/s10811-008-9338-0

[51] Sanchez, I. and Fernandez, C. (2005) Impact of the Invasive Seaweed *Sargassum muticum* (Phaeophyta) on an Intertidal Macroalgal Assemblage. *Journal of Phycology*, **41**, 923-930. http://dx.doi.org/10.1111/j.1529-8817.2005.00120.x

[52] White, L.F. and Shurin, J.B. (2011) Density Dependent Effects of an Exotic Marine Macroalga on Native Community Diversity. *Journal of Experimental Marine Biology and Ecology*, **405**, 111-119. http://dx.doi.org/10.1016/j.jembe.2011.05.024

[53] Airoldi, L. and Virgilio, M. (1998) Responses of Turf-Forming Algae to Spatial Variations in the Deposition of Sediments. *Marine Ecology Progress Series*, **165**, 271-282. http://dx.doi.org/10.3354/meps165271

[54] Airoldi, L. (1998) Roles of Disturbance, Sediment Stress, and Substratum Retention on Spatial Dominance in Algal Turf. *Ecology*, **79**, 2759-2770. http://dx.doi.org/10.1890/0012-9658(1998)079[2759:RODSSA]2.0.CO;2