Interagency Ecological Program for the San Francisco Estuary

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Fall Midwater Trawl 2001-2011 Gelatinous Zooplankton (jellyfish) Summary

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Introduction

The California Department of Fish and Wildlife (CDFW) initiated the Fall Midwater Trawl (FMWT) Survey in 1967, and have since conducted annual surveys in all years, except 1974 and 1979. CDFW created the FMWT survey to determine the relative abundance and distribution of age-0 striped bass (*Morone saxatilis*) in the San Francisco Estuary, but also developed the same information for American shad (*Alosa sapidissima*), threadfin shad (*Dorosoma petenense*), delta smelt (*Hypomesus transpacificus*), longfin smelt (*Spirinchus thaleichthys*), and splittail (*Pogonichthys macrolepidotus*). The FMWT survey began formally recording pelagic gelatinous zooplankton (jellyfish) catch in 2001, due to increased frequency of jellyfish observations in the field (D. Contreras, CDFG, personal communication). Prior to 2001, records were sporadic as there was no formal method for noting jellyfish presence.

Despite many years of observation, relatively little information is available regarding jellyfish in the upper San Francisco Estuary. Abundance for most gelatinous zooplankton species varies seasonally; jellyfish typically spend winter as polyps and mature into medusa in spring or early summer. Abundance peaks in summer, although the adult medusa often persist in the system and continue to grow in size through fall, before dying off in winter (Mills 2001). Therefore, jellyfish catch data from the FMWT survey may be appropriately timed to help ascertain the status of these invertebrates in the estuary. We summarize the catch of 6 jellyfish taxa collected by the FMWT from 2001 to 2011. Jellyfish include four hydromedusae: *Aequorea* spp., *Maeotias marginata*, *Polyorchis penicillatus*, and *Scrippsia pacifica*; one scyphomedusae complex, *Aurelia* spp., and one cydippid ctenophore, *Pleurobrachia bachei*.

Methods

The FMWT survey sampled 116 stations monthly, from September to December from 2001-2008. Sampled area ranged from San Pablo Bay to Hood on the Sacramento River, and to Stockton on the San Joaquin River (Figure 1). Five additional stations were added in the Sacramento Deep Water Ship Channel in 2009 and one additional station was added in Cache Slough in 2010. One tow was performed at each station, with an average tow volume of 6,050 m^3 per station.

The midwater trawl net mouth is 3.7 m (12 feet) x 3.7 m when taut, but these dimensions shrink under tension during a tow. Net mesh sizes graduate in nine sections from 200 mm (8 inch) stretch mesh at the mouth, to 12.7 mm (0.5 inch) stretch mesh at the cod-end. All four net mouth corners connect to planing doors, which work to counteract drag on the net material, and hold the net mouth open during tows. A 12-minute tow was conducted at each station, during which the net was retrieved obliquely through the water column, from bottom to surface. Field crews identified and enumerated all fish and invertebrates when the catch was small, and sub-sampled when the lead sampler determined that catch was sufficiently high. When fish catch was exceptionally high, field crews visually estimated catch for each jellyfish species rather than counting each jellyfish, by sub-sampling all jellyfish in a container and scaling up to total catch.

Species catch is summed across all stations and summarized for *Aequorea* spp., *Maeotias marginata*, *Polyorchis penicillatus*, *Scrippsia pacifica*, *Aurelia* spp., and *Pleurobrachia bachei*. In this paper, we define "bloom" as a drastic increase in fall catch, many times that of average annual catch. Catch was evaluated by year, region, salinity, temperature, and month. For regional catch, FMWT stations were grouped into 16 geographic areas (Figure 1). Catch was also evaluated based on salinity intervals of 5‰; from 0 to less than 5‰, from 5 to less than 10‰, and so on. Similarly, catch was grouped into temperature intervals of 5 °C. Catch was summed by month over all years to evaluate how catch changes throughout fall. Finally, we examined how catch was related to delta outflow. Outflow data was obtained from DWR's Dayflow at: http://www.water.ca.gov/dayflow/output/Output.cfm.

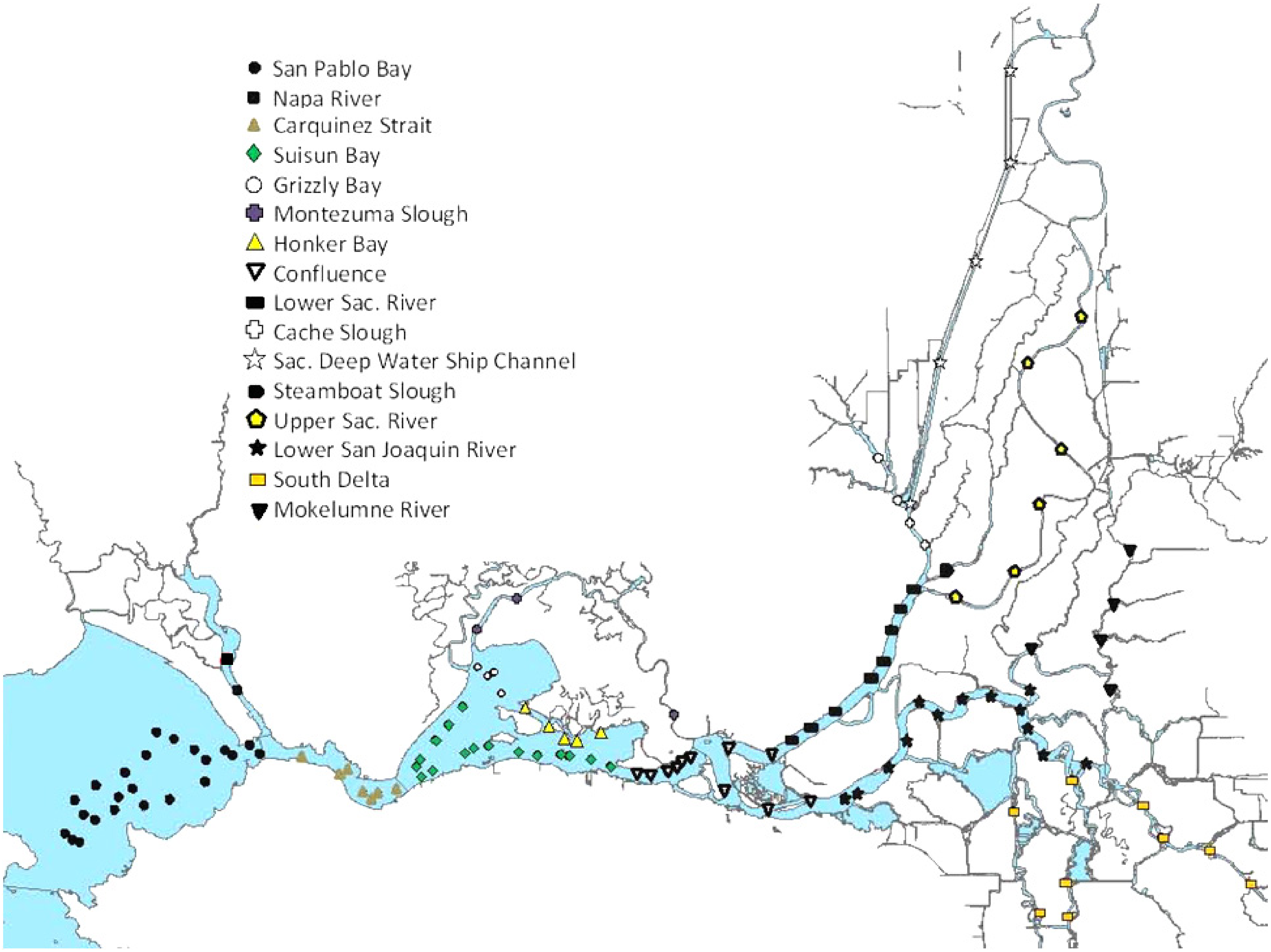

Figure 1 Fall Midwater Trawl stations grouped into regions

Results

Aequorea spp.

Aequorea spp. are nonindigenous, transparent, hydromedusae, with bioluminescent bells that grow up to 25 cm in diameter (Rees and Kitting 2002). The *Aequorea* spp. catch totaled 33, the rarest species observed. As these species are small, clear, and flat, the field crew may have overlooked them within the sample. Nearly all *Aequorea* spp. (n=32) were collected in 2011 (Table 1), with the exception of one individual caught in 2010. All *Aequorea* spp. were collected in San Pablo Bay (Figure 2). They were mostly found in salinities of 23-24‰ (n=29), (Figure 3). *Aequorea* spp. were all found in temperatures from 10.5 °C to 11.4 °C (n=32), except for one found at 15.8 °C (Figure 4). One individual was caught in November, the rest in December (Figure 5).

Maeotias marginata

An invasive jellyfish presumed to originate from the Black Sea, *Maeotias marginata* may have arrived in the San Francisco estuary as early as 1959, based on CDFW field notes (see Rees and Gershwin 2000). The adults have a milky coloring, which combined with a distinct reddish edge around the bell places them among the easier jellyfish to spot in FMWT catch. The adult medusa range from 2-5 cm in bell diameter, are present in summer and fall in the estuary, and feed on benthic and pelagic organisms (Rees and Gershwin 2000). Presence of this brackish-water species has been confirmed throughout the

Table 1 Total annual jellyfish catch by species or genera and total volume sampled in m^3 for the years 2001 through 2011 in the Fall Midwater Trawl

Year	*Polyorchis penicillatus*	*Aurelia spp.*	*Maeotias marginata*	*Scrippsia pacifica*	*Pleurobrachia bachei*	*Aequorea spp.*	*Total Volume Sampled (m^3)*
2001	34	1	904	0	0	0	2332873
2002	16	89	2686	27	0	0	2018912
2003	0	7	2355	0	0	0	2561915
2004	674	0	2011	0	172	0	2462010
2005	0	0	1844	0	0	0	2450543
2006	2	0	6053	0	0	0	2360423
2007	489	209	1978	0	87	0	2455030
2008	412	129	722	1	14	0	2519816
2009	1154	105	536	4	6724	0	2489484
2010	163	27	186	0	1282	1	2644787
2011	725	64	2825	2	615	32	2644415

estuary, from the Napa River up to the Sacramento and San Joaquin Rivers, in salinities as low as 1‰ (Rees and Kitting 2002).

During the study period, *M. marginata* was the most common jellyfish, with a total count of 22,100. This may be partly due to the fact that at 2-5 cm, the adults fall within the target size for the gear at all sizes. Prior to 2006, *M. marginata* annual counts ranged around 2,000, save for excluding a low catch of 904 in 2001. In 2006 there was a bloom of 6,053 *M. marginata* concentrated in Suisun Bay, which represented 27% of total catch over 10 years. The only other species caught that year was *Polyorchis penicillatus* (n=2). In 2007 the *M. marginata* count returned to pre-bloom levels (n=1978) followed by a steady decline to a 10-year low in 2010 (n=186). In 2011, the count rebounded to 2,825 (Table 1). *M. marginata* were mostly caught in the Sacramento-San Joaquin confluence (hereafter confluence) and Suisun Bay regions. *M. marginata* were also common in Grizzly Bay, Montezuma Slough, Honker Bay, and the Lower Sacramento River (Figure 2).

M. marginata seemed to show a preference for salinities ranging from 0-12‰, and they were most abundant at salinities around 5‰, but occurred in salinities up to 25.1‰ (Figure 3). *M. marginata* were also caught over a broad range of temperatures, from 10.2 °C to 29.0 °C, but were most common between 19 °C and 20 °C (Figure 4). Overall, *M. marginata* counts were greatest in September and gradually declined to near absence by December (Figure 5). In some years, *M. marginata* counts peaked in October rather than September, but still declined by December. This may be due to an apparent preference for warmer waters, above 15 °C (Rees and Gershwin 2000).

The distribution of the 2006 *M. marginata* bloom and the elevated 2011 catch followed wet springs and coincided with high fall outflows (Figure 6). These were the only years when counts were higher in Suisun Bay than in the confluence. This may be because average fall salinities in both regions dropped due to high outflows in the wet years of 2006 and 2011, especially in the confluence. Schroeter (2008) posited that salinity was the primary predictor of *M. marginata* abundance, followed by temperature. Average September salinity for 2001-2011 in the confluence was 8.8‰, or 9.7‰ excluding the wet years of 2006 and 2011. These values dropped in the confluence to 1.1‰ in 2006 and 0.2‰ in 2011. Low salinities in the confluence in 2006 and 2011 may have driven them downriver, or Suisun Bay may offer preferable habitat that is less accessible at higher salinities. In Suisun Bay, average September salinity was 2.3‰ for 2001-2011, or 2.7, excluding 2006 and 2011. Suisun Bay salinity dropped to 6.1‰ in 2006 and 3.7 in 2011. Despite lower salinities in 2011, *M. marginata* failed to bloom as it had in 2006. In 2010, the FMWT survey experienced its lowest annual catch of *M. marginata* (n=186) on record. Based on this data, populations of *M. marginata* may have been insufficient in 2010 to support the greater population growth required for a bloom in 2011.

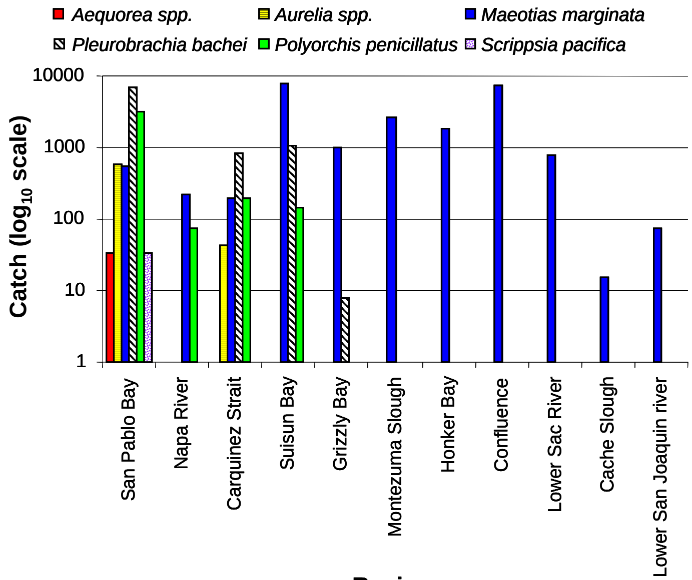

Figure 2 Total jellyfish catch by region for the years 2001 through 2011 in the Fall Midwater Trawl (log_{10} scale). See Figure 1 for region map.

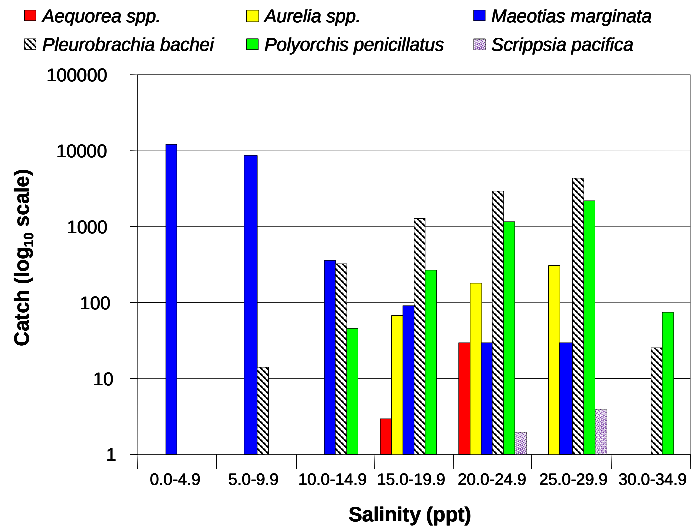

Figure 3 Total jellyfish catch by 5 °C temperature intervals for the years 2001 through 2011 in the Fall Midwater Trawl (log_{10} scale)

During the study period, temperature variability did not seem to be a driving factor in the geographic regional shifts in 2006 and 2011. This may be because average September temperature in 2006 and 2011 in the confluence and Suisun Bay varied by less than one degree from ten-year averages. September temperature in the confluence dropped from an average of 20.3 °C for 2001-2011, to 20.2 °C in 2006 and then rose to 20.9 °C in 2011. In Suisun Bay, average September temperature was 19.4 °C in 2006 and 19.9 °C in 2011, just below an overall average of 20.1 °C for 2001-2011.

Polyorchis penicillatus

The native jellyfish, *Polyorchis penicillatus*, spends most of its time perched on its tentacles, feeding on benthic organisms, although it sometimes swims and feeds in the water column (Mills 2001). It is distinguished by a tall and narrow bell that grows up to 5 cm in height, and the reddish tinge at the base of the tentacles (Rees and Kitting 2002). *P. penicillatus* had a total count of 3,669 for the study period. The highest catch was recorded in 2009, with moderate counts occurring in 2004 and again in 2007, 2008, and 2011. No *P. penicillatus* were observed in 2003 or 2005. In 2006, year of the *M. marginata* bloom, *P. penicillatus* was the only species recorded other than *M. marginata* (Table 1).

P. penicillatus were primarily seen in San Pablo Bay (n=3,256), and to a lesser extent in the Napa River, Carquinez Strait, and Suisun Bay (Figure 2). These regions tend to be more saline and cooler during fall than upstream areas. *P. penicillatus* were most highly concentrated at 29‰, and 89% were collected between 20‰ and 31‰, but they ranged as low as 10.7‰ (Figure 3). Ninety-eight percent of *P. penicillatus* were caught in cooler water ranging from 11 °C to 14 °C (Figure 4). Ninety-seven percent of *P. penicillatus* were caught in December. They were absent in September in all years, excluding 2008 (n=1) and 2010 (n=3). So, *P. penicillatus* were absent in September 2006 during the *M. marginata* boom (Figure 5), although they were captured later that year.

Scrippsia pacifica

Scrippsia pacifica is a native jellyfish, with feeding patterns similar to those of *Polyorchis* (Mills 2001). Like *P. penicillatus*, its tall bell and the red tinge at the base of its tentacles are distinguishing characteristics. *S. pacifica* grow up to 10 cm in bell height and their tentacles can originate above the bell margin. They are rarely observed in the estuary (Rees and Kitting 2002). Indeed, *S. pacifica* was one of the most infrequently captured jellyfish in FMWT records, having a 10-year count of just 34 individuals. The most *S. pacifica* were recorded in 2002 (n=27), and since then annual catch since has been sporadic and low (Table 1). All were caught in San Pablo Bay, save for one in Suisun Bay (Figure 2). Salinity and temperature data were missing for the 2002 samples. However, the remainder S. pacifica were found in salinities of 16-29.5‰ (Figure 3), and temperatures of 10-14 °C (Figure 4). All 34 individuals were captured in December (Figure 5).

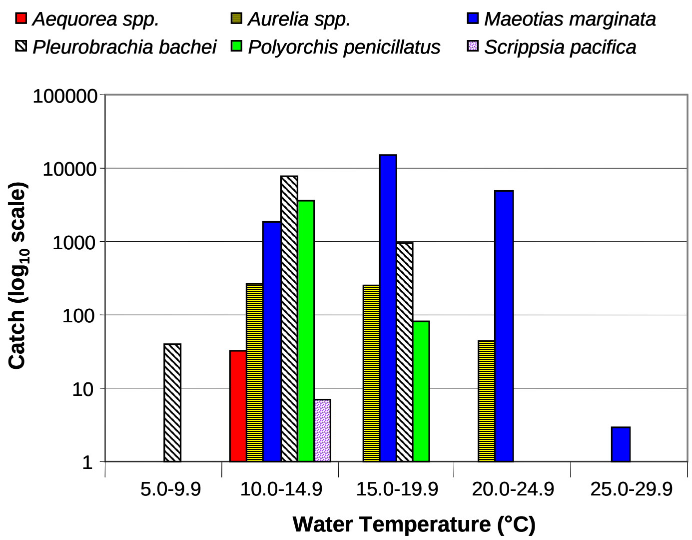

Figure 4 Total jellyfish catch by 5 ppt salinity intervals for the years 2001 through 2011 in the Fall Midwater Trawl (log_{10} scale)

Aurelia spp.

Aurelia spp. are commonly called "moon jellies" in reference to their four lunate-shaped gonads. *Aurelia labiata* is native to the Pacific coast, while its cosmopolitan cousin, *Aurelia aurita*, is thought to be endemic to the North Atlantic and may be increasing in abundance worldwide (Mills 2001). Both *A. labiata* and *A. aurita* have been confirmed in San Francisco Bay (Rees and Kitting 2002), although FMWT staff did not identify these scyphozoans to the species level. Both species can grow to a few meters in bell diameter in marine environments, and up to 50 cm in bell diameter in the estuary (Rees and Kitting 2002), although they were captured at smaller sizes in the FMWT.

Aurelia spp. catch totaled 631 for the study period. None were caught from 2004-2006, but this was followed by the highest annual catch on record in 2007 (n=209), and numbers have steadily declined since (Table 1). *Aurelia* spp. have been distributed primarily in San Pablo Bay, but were also caught in Carquinez Strait in 2001 and 2007

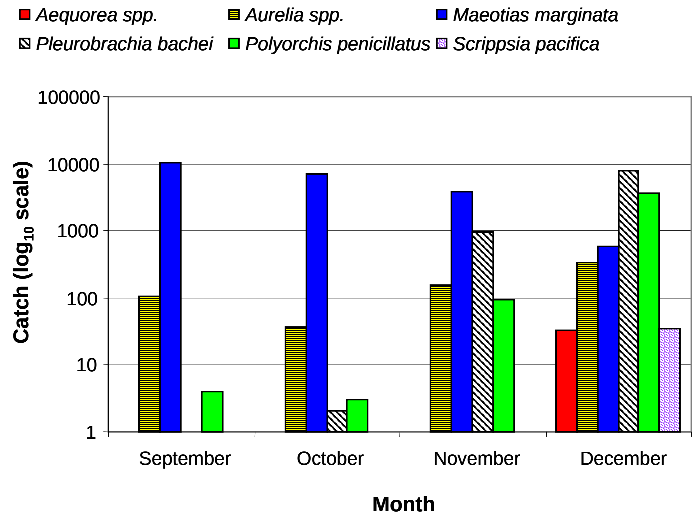

Figure 5 Total jellyfish catch by species or genera and month for the years 2001 through 2011 in the Fall Midwater Trawl (log_{10} scale)

(Figure 2). One individual was found in the Napa River in 2008. Seventy-five percent of *Aurelia* spp. were in salinities above 22‰, with the notable exception of a single catch in 2011 at 16.7‰ (Figure 3). *Aurelia* spp. were primarily collected at temperatures between 12 °C and 15 °C, but also occurred at temperatures as low as 10.5 °C and as high as 21.2 °C (Figure 4). *Aurelia* spp. were captured throughout the fall, but with greater frequency in December (Figure 5).

Pleurobrachia bachei

Pleurobrachia bachei is a native cydippid ctenophore common near Alameda in late summer and fall. They have the smallest maximum size of the jellyfish here described, having "the size and shape of a clear marble" (Rees and Kitting 2002). They are commonly referred to as "cat's eyes" or "sea gooseberries." The *P. bachei* total catch was 8,894 for the survey period. The first recorded catch was in 2004, none were observed in 2005 or 2006, and 2007 and 2008 had low catches (Table 1). In 2009, 6,724 P. bachei were collected, which represents 76% of total catch from the last 10 years. Numbers remained relatively high in 2010 and 2011 (Table 1). *P. bachei* were most numerous in San Pablo Bay, but were also present in Suisun Bay, Carquinez Strait, and the Napa River, with small catches in Grizzly Bay (n=8) and Montezuma Slough (n=1) (Figure 2). *P. bachei* inhabited a wide range of salinities, from 8.1‰ to 31.2‰, with the greatest catches in 29-30‰ (n=2,079) (Figure 3). It primarily inhabited temperatures between 11 °C and 13 °C (n=7,125) (Figure 4). *P. bachei* catches typically increased from November (rarely October) through December (Figure 5).

The cause of the 2009 *P. bachei* bloom is unknown. Salinity, water temperature, and water outflow in 2009 were consistent with 2001-2011 annual averages. Polyorchis penicillatus counts rose in 2009 as well, but the increase in *P. bachei* populations was tenfold that of the increases observed in other jellyfish species.

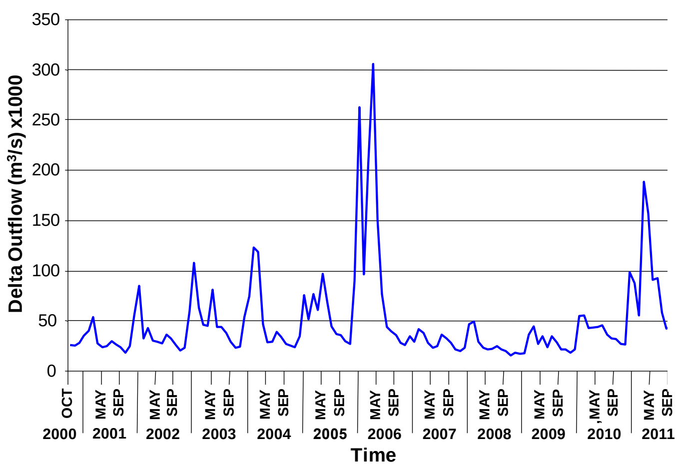

Figure 6 Mean monthly Delta outflow for the years 2000 through 2011

Discussion

Whether from natural or anthropogenic causes, there is evidence that gelatinous zooplankton populations may be on the rise in certain ecosystems (Brodeur et al. 1999, Condon et al. 2012). This is of special concern in the San Francisco Estuary, already referred to as the most invaded estuary in the world (Cohen and Carlton 1998). Many jellyfish can compete with fish for food resources, or directly consume ichthyoplankton (Shiganova 1998, Schroeter 2008). In at least one case, an invasive jellyfish has been linked to the decline of anchovy and other pelagic fishes in the Black Sea (Kideys 1993). The populations of at least three invasive species of jellyfish seem to be on the rise in the San Francisco Estuary (Mills and Rees 2000). Hence, the need for further monitoring and research of gelatinous zooplankton.

The FMWT survey has been able to recognize and enumerate 4 jellyfish species and 2 genera since it began recording jellyfish catch in 2001. Although there was no clear trend in the catch data for any of these 6 taxa, 4 of them were collected for the first time or were collected more consistently after 2006 (Table 1). Currently, many but not all IEP fish trawl surveys identify and enumerate jellyfish as part of their routine data collection. Specifically, Spring Kodiak Trawl, Summer Townet Survey (STN), FMWT, and Bay Study Midwater Trawl record jellyfish catch. However, trawl gear targeting juvenile fishes may not be well suited to collection of jellyfish. Careful collection by divers is the preferred method for catching intact gelatinous zooplankton (Kingsford and Battershill 2000), although trawl nets (Kingsford and Battershill 2000, Brodeur et al. 1999) and otter trawls (Schroeter 2008) have collected larger quantities of jellyfish.

The FMWT may not be appropriate for jellyfish sampling for two reasons. First, the cod end mesh size (12.7 mm stretch mesh) allows many small jellyfish to pass through (e.g. *Moerisia* spp. with a 10 mm bell and *Blackfordia virginica* with a 4-5mm bell). Second, the netting potentially cuts through jellyfish, causing the net to extrude them in pieces. Both *Moerisia* spp. and *Blackfordia virginica* adult medusa have been detected in Suisun Bay as early as June and as late as November (Schroeter 2008), thus overlapping FMWT sampling, but neither has been identified from the FMWT survey.

The 2009 addition of a mysid net tow to a subset (n= 32) of FMWT stations provides an opportunity to gather jellyfish catch data on species and individuals small enough to be extruded by the FMWT. The mysid net has a 29 cm mouth and possesses 505 micron mesh, which would retain all sizes of jellyfish well. Jellyfish identification would occur post-preservation in the laboratory. Earlier in the year, when jellyfish are smaller, data from the STN survey may provide useful catch data for jellyfish due to its smaller mesh size, relative to the FMWT. STN runs from June through August and has identified and enumerated jellyfish catch since 2007.

For increased data confidence, sampling methods for species detection need to be more thorough, and a sound sampling procedure needs to be established to determine when and how to sub-sample the larger catches. To increase fish survivability and ease of processing, samples are often poured from the trawl net into a bucket of water. Small, clear jellyfish, such as *Aequorea* spp., are easy to miss in such a container. To increase detection, samples were passed through a hand fishnet and spread onto a white surface starting in 2012. For large catches, the entire catch is currently poured into a quart container until it is full. This water should then be passed through a hand net, so that jellyfish can be enumerated and identified effectively. This count would then be scaled up to give an estimated total catch. Currently, there is no record of when sub-sampling takes place, for accurate calculation of error frequency in the future, it would be necessary to record this information.

Conclusion

Since the FMWT survey began recording jellyfish catch in 2001, *M. marginata* was the most frequently encountered jellyfish, followed by *P. bachei*, P. *penicillatus*, and *Aurelia* species. *Aequorea* spp., *Aurelia* spp., and *S. pacifica* were only infrequently captured. Since 2007, *P. bachei*, *P. penicillatus*, and *Aurelia* spp. have been caught annually; before 2007 they were only encountered in some years. *Aequorea* spp. was first recorded in 2010 (Table 1). *P. bachei*, *P. penicillatus*, *Aurelia* spp., *Aequorea* spp., and *S. pacifica* are primarily marine jellies, and were mainly found in San Pablo Bay, the Napa River, Carquinez Strait, and Suisun Bay, with some *P. bachei* also caught in Grizzly Bay (Figure 2). Catches for these 5 jellyfish tended to increase with increasing salinity, peaking at salinities of 20-30‰. *P. bachei* and *P. penicillatus* were the only species captured at 30‰ or above, although catch decreased at these high salinities (Figure 3). Except for *M. marginata*, all jellies were found primarily at 10-20 °C (Figure 4) and during the months of November and December (Figure 5).

M. marginata was the most frequently captured jellyfish, and as the only brackish water species, its distribution varied noticeably from other jellyfish taxa reported in FMWT catch. *M. marginata* was the only jellyfish species found in all years (Table 1). It was also found in all regions, except for the Napa River (Figure 2).

The scarcity of information regarding the status and trends of jellyfish in the upper San Francisco Estuary, combined with their potential ecosystem impacts underlines the importance of increased monitoring efforts. The FMWT survey currently provides useful information regarding jellyfish catch and distribution, which could be improved upon with greater attention to detection and a more rigorous sub-sampling protocol. However, to gain a more comprehensive view of jellyfish status and trends in the San Francisco Estuary, it would be highly beneficial to begin identifying and enumerating jellyfish catch in the mysid net that, unlike the FMWT, has a mesh size capable of retaining smaller jellyfish species such as *Moersia* spp. and *B. virginica*.

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Notes

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