RESTORATION AND MONITORING OF COMMON MURRE COLONIES IN CENTRAL CALIFORNIA: ANNUAL REPORT 2020

REPORT TO THE *LUCKENBACH* TRUSTEE COUNCIL

Cassie M. Bednar, Lauren C. Scopel, Gerard J. McChesney, Mark A. Baran, Megan L. Boldenow, Sarah R. Guitart, Samantha D. Chavez, Grace A. Kumiashi, and Richard T. Golightly

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FINAL REPORT
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Cover photo: Land-based photograph of Devil's Slide Rock, 18 July 2020 (photo credit: Humboldt)

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ABBREVIATIONS USED

BM227X = Bench Mark-227X

CDFW = California Department of Fish and Wildlife

CHCC = Castle-Hurricane Colony Complex (includes Bench Mark-227X, Castle Rocks and Mainland, and Hurricane Point Rocks)

CMRP = Common Murre Restoration Project

CRM = Castle Rocks and Mainland

DBCC = Drakes Bay Colony Complex (includes Point Resistance, Millers Point, and Double Point)

DPR = Double Point Rocks

DSCC = Devil's Slide Colony Complex (includes Devil's Slide Rock & Mainland, and San Pedro Rock)

DSM = Devil's Slide Mainland

DSR = Devil's Slide Rock

DSRM = Devil's Slide Rock and Mainland

GFNMS = Greater Farallones National Marine Sanctuary

HPR = Hurricane Point Rocks

LHR = Lighthouse Rock

MPR = Millers Point Rocks

NOAA = National Oceanic and Atmospheric Administration

NPFC = National Pollution Funds Center

OSLTF = Oil Spill Liability Trust Fund

PRH = Point Reyes Headlands

PRS = Point Resistance

SPN = Seabird Protection Network

SPR = San Pedro Rock

UAS = Uncrewed Aircraft System (drone)

USCG = U.S. Coast Guard

USFWS = U.S. Fish and Wildlife Service

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ACKNOWLEDGMENTS

In 2020, the *Luckenbach* Oil Spill Trustee Council, comprised of California Department of Fish and Wildlife (CDFW), National Oceanic and Atmospheric Administration (NOAA), and Department of Interior through the U.S. Fish and Wildlife Service (USFWS) and National Park Service, provided funding and oversight.

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We conducted monitoring in collaboration with Seabird Protection Network outreach and education efforts of the Greater Farallones National Marine Sanctuary, including Paul Hobi, Wendy Kordesh, and Karen Reyna. We conducted research at the Devil's Slide Trail County Park with assistance and permit support from Ramona Arechiga, Matt Del Carlo, Mark Rogers, and Darrick Emil (San Mateo County Parks). We conducted research at Point Reyes National Seashore under Permit No. PORE-2018-SCI-0001, with assistance from Ben Becker. We owe special thanks to our committed volunteer, Linda Schmid, for conducting surveys of Bird Island.

EXECUTIVE SUMMARY

Efforts in 2020 were the 25th year of restoration and associated monitoring of central California seabird colonies by the Common Murre Restoration Project. This project first conducted fieldwork in 1996 with the goal to restore breeding colonies of seabirds, especially those of Common Murres (*Uria aalge*), that were harmed by the 1986 *Apex Houston* oil spill, as well as by gill net fishing and other impacts. Subsequent to the original *Apex Houston* settlement, natural resource damage assessment settlement funds from the 1998 *Command* and extended *Luckenbach* oil spills have supported the project since 2005 and 2010, respectively. From 1995 to 2005, the primary goals were to restore the previously extirpated Devil's Slide Rock (DSR) colony using social attraction techniques, and to assess restoration needs at other central California colonies. Since 2005, we have incorporated standardized procedures for the surveillance and assessment of human disturbance at central California Common Murre colonies. We continue to monitor the outcome of initial recolonization efforts at DSR and recovery of other central California murre colonies. The human disturbance assessments are used to inform outreach, education, and regulatory efforts by the Seabird Protection Network (SPN; coordinated by the Greater Farallones National Marine Sanctuary; GFNMS) and allow for evaluation of the success of those efforts. The goal of the SPN is to protect seabird breeding colonies in central California primarily through reduction of human disturbance, which enhances the restoration of previously injured colonies.

The 2020 field season was greatly affected by the global pandemic caused by the novel coronavirus SARS-CoV-2 (hereafter COVID-19). The start of monitoring was delayed until

mid-May at Devil's Slide Rock & Mainland and early to mid-June at Point Reyes Headlands and Castle-Hurricane Colony Complex (CHCC). This delay facilitated the safe travel of staff to field sites and the implementation of other safety measures. Initial training of staff in 2020 was conducted remotely, and in-the-field training was modified to allow for social distancing procedures. We report in methods any modifications to standard protocols and procedures. We conducted monitoring of human disturbance (mainly aircraft and watercraft), non-anthropogenic disturbance, seabird productivity, seabird attendance patterns, and relative population sizes at three Common Murre colony complexes. A volunteer also conducted less-intensive monitoring of Common Murre attendance at Bird Island.

Human disturbance to seabird colonies was monitored by recording all aircraft and watercraft entering specific "detection" zones and any associated disturbance observed. We observed stark increases in the number of detected watercraft around our monitored colonies during 2020. At Point Reyes, the overall (aircraft and watercraft combined) detection rate was the highest recorded (0.33 detections/hr) since our methods were standardized in 2005, elevated especially by watercraft sightings (83%). However, only two disturbances were observed at Point Reyes in 2020 (0.01 disturbances/hr), resulting in the lowest disturbance rate since 2017; both events were caused by watercraft. The overall detection rate at Devil's Slide was the highest recorded since 2012 (0.49 detections/hr), and largely a result of watercraft (56%). Disturbance rates were greatest at Devil's Slide out of all study areas (0.09 disturbances/hr) and of similar magnitude to 2019. Despite the large number of watercraft detections, the 28 observed disturbances at Devil's Slide were caused primarily by aircraft (75%). About 25% of the disturbances at Devil's Slide caused the flushing of murres. Watercraft were not as prevalent around CHCC, where detection (0.06 detections/hr) and disturbance rates (0.01 disturbances/hr) were the lowest observed since 2013 and 2016, respectively. Examination of data indicated that the delayed start to monitoring may have resulted in overestimated watercraft detection and disturbance rates, and underestimated aircraft detection and disturbance rates in 2020, especially at Point Reyes. Long-term trends with corrected data indicated quadratic relationships in plane, aircraft, and watercraft detection rates at Point Reyes, with initial decreases and recent increases of varying magnitudes. Disturbance trends at Point Reyes included modestly increasing aircraft disturbance rates in recent years, but no long-term trends in watercraft disturbance rates. At Devil's Slide, long-term trends indicated decreasing helicopter detection rates but a major recent increase to watercraft detection rates, which reflected an overall recent increase in total detections; disturbance rates decreased for helicopters, watercraft, and the overall disturbance rate. At CHCC, there were no long-term trends in either detection or disturbance rates.

Among all detected aircraft, general aviation (e.g., private or charter) planes were the most commonly observed (75%), and caused 59% of aircraft disturbances at all monitored colonies. U.S. Coast Guard (USCG) and military aircraft represented most of the remaining detections (11% and 8%, respectively) and disturbances (23% and 14%, respectively). Most of the observed watercraft were private recreational (67%) or charter (26%); there were very few disturbances by watercraft, but most were also private recreational (83%). With the elevated watercraft traffic, we observed multiple violations of Special Closures and State Marine Reserves (SMR). We reported 8 violations of the Special Closure at Devil's Slide, 7 violations of the Special Closure at Point Reyes, and 12 additional fishing violations of the SMR at Point Reyes.

We incidentally recorded 68 non-anthropogenic disturbance events during this shortened season. At Point Reyes, we recorded 40 disturbance events; Common Ravens (*Corvus corax*) were part of 35% of events, and Turkey Vultures (*Cathartes aura*) were involved in 55%. The remaining events involved Western Gulls (*Larus occidentalis*) or Brown Pelicans (*Pelecanus occidentalis*). At Devil's Slide, we recorded only 27 events, and ravens were part of 63% of them. Ravens depredated 16 chicks and eggs, causing the most severe non-anthropogenic disturbance. Western Gulls, Brown Pelicans, and Brandt's Cormorants (*Urile penicillatus*) were involved in the remaining disturbances. We observed only one non-anthropogenic disturbance event at CHCC.

Owing to the reduced monitoring time in 2020, we had limited data to examine attendance patterns of Common Murres. We obtained no data during the pre-lay period, when murre abundance can be especially high and variable, so long-term comparisons including data from 2020 should be made with caution. At Point Reyes, attendance patterns at index plots were similar to long-term trends, but with greater late-season abundance at Edge and Cone plots. At Devil's Slide Rock, late-season abundance was also elevated, and the departure time of murres from the rock may have been later than usual. Devil's Slide Mainland had major increases in murre abundance relative to the long-term mean during all monitored months. At CHCC, late-season patterns were similar to long-term trends, but abundance was greater and departures were delayed at HPR-02.

Common Murre productivity (chicks fledged/pair) was not monitored before eggs were laid at most sites, so any interpretation should be made with great caution. Monitoring at Point Reyes did not begin until late June, so the data are also likely less reliable than most years; productivity in our observed sample was above average. Productivity at Devil's Slide was monitored from mid-May and is likely a more reliable sample; the murres rebounded from a poor year in 2019 to above average productivity at both Devil's Slide Rock and Devil's Slide Mainland in 2020. Monitoring at CHCC began after chicks started hatching, which was too late to obtain appropriate data.

Monitoring of Brandt's Cormorant nests was also affected by the delayed start of observations in 2020. We missed the lay dates and the incubation period for most of the early Brandt's Cormorant nests, and many chicks were present by the time we arrived at field sites. Productivity should therefore be interpreted with caution. Based on our sample, Brandt's Cormorants had average productivity at CHCC, Point Reyes, and Devil's Slide. At Devil's Slide and CHCC, we monitored the productivity of Pelagic Cormorants (*U. pelagicus*), Western Gulls, and Black Oystercatchers (*Haematopus bachmani*), but delays affected monitoring similarly for these species. Productivity of Pelagic Cormorants at Devil's Slide was below average, whereas at CHCC productivity was above average. At Devil's Slide, productivity of Western Gulls was below the long-term average, and no Black Oystercatcher nests were found. At CHCC, no Western Gull or Black Oystercatcher nests were monitored.

Aerial photographic surveys of Double-crested Cormorant, Brandt's Cormorant and Common

Murre colonies were not conducted in 2020.

INTRODUCTION

In central California, Common Murre (*Uria aalge,* hereafter "murre") breeding colonies occur on nearshore rocks and adjacent mainland cliffs between Marin and Monterey counties, as well as on the North and South Farallon Islands 20-40 km offshore of San Francisco (Carter et al. 1992, 2001). A steep decline in the central California population occurred between 1980 and 1986, which was attributed primarily to mortality associated with gill-nets and oil spills, including the 1986 *Apex Houston* oil spill (Page et al. 1990; Takekawa et al. 1990; Carter et al. 2001, 2003). Between 1982 and 1986, a colony of about 3,000 breeding murres on Devil's Slide Rock (DSR) in northern San Mateo County was extirpated. Since 1995, the Common Murre Restoration Project (CMRP) has sought to restore DSR and other central California colonies using several techniques, including social attraction. Social attraction techniques were used at DSR between 1996 and 2005 (McChesney et al. 2006; Parker et al. 2007), but they were discontinued after the colony appeared to be restored and self-sustaining. Restoration efforts at other murre colonies in central California have focused on documenting the impacts of human disturbance, gill-net mortality, and other threats to colonies, as well as working with government agencies and the public to reduce these impacts.

Since the early 1990s, the size of the central California murre population has increased following the implementation of restrictions on gill-net fishing, as well as favorable prey conditions and other factors (Carter et al. 2001; USFWS, unpublished data). However, anthropogenic impacts to murres may continue to affect the population. Gill-net mortality persisted until the California Department of Fish and Wildlife (CDFW) enacted an emergency closure of the gill-net fishery in September 2000, followed by a permanent closure in September 2002 in waters <110 meters deep (60 fathoms) from Point Reyes to Point Arguello (Forney et al. 2001). Extensive oil pollution (e.g., 1998 *Command* oil spill and a series of oil releases from the sunken vessel *S.S. Jacob Luckenbach* from the early 1990s to the early 2000s) killed thousands of murres in central California (Carter 2003; Carter and Golightly 2003; Hampton et al. 2003; Roletto et al. 2003). Disturbances from aircraft and watercraft have also affected colonies (Rojek et al. 2007; Fuller et al. 2018; USFWS, unpublished data).

Beginning in 1995, restoration and subsequent monitoring of murre colonies in central California have been funded primarily through oil spill restoration plans and associated trustee councils, including the *Apex Houston* (1995-2009), T/V *Command* (2005-2009), and, beginning in 2010, the *Jacob Luckenbach*. On 14 July 1953, the *S.S. Jacob Luckenbach* collided with the freighter *Hawaiian Pilot* and sank in 55 m of water approximately 27 km southwest of San Francisco. The *S.S. Jacob Luckenbach* was loaded with 457,000 gallons of bunker fuel, which subsequently leaked periodically during winter storms. Using chemical analysis, oil that was associated with several mystery spills was linked to this vessel, including the Point Reyes tar ball incidents of winter 1997-1998 and the San Mateo Mystery Spill of 2001-2002. In the summer of 2002, the U.S. Coast Guard (USCG) and the *Luckenbach* trustees removed much of the oil from the vessel and sealed the remaining oil inside (Hampton et al. 2003). An estimated 51,569 seabirds were killed between 1990 and 2003 from Bodega Bay to Monterey Bay, including 31,806 murres (*Luckenbach* Trustee Council 2006).

The USCG National Pollution Funds Center (NPFC) awarded $22.7 million to implement 14 restoration projects. The award was a result of a claim filed by the *Luckenbach* trustees in 2006 for funding from the Oil Spill Liability Trust Fund (OSLTF), because the company responsible for the *Luckenbach* no longer existed. The OSLTF pays for oil spill cleanup and restoration of impacted natural resources when there is no responsible party.

The Central California Seabird Colony Protection Project, now called the Seabird Protection Network (SPN), was initiated by the *Command* Oil Spill Restoration Fund (Command Trustee Council 2004) in 2005 and was extended in 2010 with *Luckenbach* funds. The Greater Farallones National Marine Sanctuary (GFNMS) implement the SPN in coordination with the CMRP, to restore seabird colonies harmed by these oil spills primarily by reducing human disturbance. The GFNMS focuses on the outreach, education, and regulatory components, while the CMRP conducts the colony surveillance and monitoring component of the program. Surveillance and monitoring data from these colonies guide education and outreach and are used to assess the success of those efforts.

Colony surveillance and monitoring have focused on three colonies or colony complexes established as murre restoration or reference sites in 1996: Point Reyes Headlands (PRH), Devil's Slide Colony Complex (DSCC), and Castle-Hurricane Colony Complex (CHCC). From 2005-2016, less intensive surveys were also conducted at three additional colonies in the Drakes Bay Colony Complex (DBCC): Point Resistance (PRS), Millers Point Rocks (MPR), and Double Point Rocks (DPR). Colony count surveys documented potential murre attendance and breeding and were conducted once per week at Bird Island (near Point Bonita) in Marin County.

Here we summarize colony surveillance and monitoring efforts conducted at nearshore murre colonies in central California in 2020. Like past years, we recorded and categorized aircraft, watercraft, and other disturbances to seabirds. We also investigated murre seasonal attendance patterns and productivity (reproductive success). Furthermore, we recorded relative breeding population sizes and productivity of Brandt's Cormorants (*Urile penicillatus*), as well as relative breeding population sizes and/or productivity of Pelagic Cormorants (*U. pelagicus*), Black Oystercatchers (*Haematopus bachmani*), Western Gulls (*Larus occidentalis*), and Pigeon Guillemots (*Cepphus columba*). Aerial surveys, which are used to estimate breeding population sizes more accurately, were not conducted in 2020.

The 2020 observations were delayed at all sites by the COVID-19 pandemic, which affected the quality and completeness of our collected data. While we collected data for all studies as usual, we also note below how this delay affected our typical protocols. We describe where conclusions from our data may be unreliable or incomplete owing to interruptions caused by the pandemic, especially when compared to long-term means.

METHODS

Study Sites

We monitored three colony complexes – PRH, DSCC, and CHCC – for disturbance, productivity, and attendance of seabirds in 2020 (Figure 1). Bird Island was monitored opportunistically, for seabird attendance only, by a volunteer. PRH (Figure 2) is located within the Point Reyes National Seashore, Marin County. DSCC, located in San Mateo County, consists of the colonies Devil's Slide Rock & Mainland (DSRM) and San Pedro Rock (SPR; Figures 3-4). CHCC, in Monterey County, consists of the colonies Bench Mark-227X (BM227X), Castle Rocks & Mainland (CRM), and Hurricane Point Rocks (HPR; Figure 5). The offshore rocks of DSCC and CHCC are within the California Coastal National Monument. Mainland portions of DSCC are either part of the Devil's Slide Trail County Park or are privately owned. Mainland portions of CHCC are either privately, state-, or county-owned. Bird Island is located near the mouth of the Golden Gate within Golden Gate National Recreation Area, in Marin County. At each colony, individual rocks and mainland cliffs with nesting seabirds were identified by their recognized subcolony number, subcolony name, or subarea. In this report, colonies are ordered north to south within each section.

Monitoring Effort

To track monitoring effort, observers recorded a start time to the nearest minute upon arrival at a field vantage point, and an end time when departing. From these data, we total observation hours irrespective of the number of observers (i.e., *not* a calculation of person-hours). When calculating the total observation hours for a colony or colony complex, we combined observation hours from all vantage points. When multiple observers were present at multiple vantage points simultaneously, the total hours of observation were calculated as hours on site regardless of the number of people observing (i.e., not double counted). Time transiting between vantage points (even on foot) was not included in observation hours.

The start of monitoring was delayed in 2020 owing to the COVID-19 pandemic, which truncated our monitoring efforts and missed events occurring during the pre-laying and incubation periods. While our reporting and calculation of observation hours match protocols from previous years, comparisons to long-term data should be made with caution, since monitoring effort in 2020 is not entirely representative of a typical season.

Disturbance

Anthropogenic Disturbance Events

Anthropogenic (human-caused or -associated) disturbance events affecting murres or other seabirds were recorded at each study colony. These disturbances included any instances where adult birds were alarmed or agitated (e.g., head-bobbing in murres, raised head or wing-flapping in cormorants), displaced (i.e., birds moved from a breeding or roosting site but did not fly away), or flushed (i.e., birds flew from the colony or roost) because of human activity. For each disturbance event, we recorded the number of disturbed seabirds within each of the three disturbance categories. Numbers of eggs or chicks exposed, displaced, depredated, or otherwise lost (taken) were also recorded. When seabirds were disturbed by a human source that we identified (e.g., helicopter with recorded tail number), we filed an SPN wildlife disturbance report. These reports included pertinent information on the event and photos (when available).

To examine long-term spatiotemporal trends, we calculated anthropogenic disturbance rates. These rates represented the number of disturbance events per hour of observation at each colony complex (except at Bird Island, where observation effort was not recorded). Using generalized linear models, we examined and predicted trends in annual detection and disturbance rates between 2005-2020. For each colony complex and each disturbance source (e.g., helicopters, planes, watercraft), we fit models with linear, quadratic, or cubic polynomial terms, for each of the gamma and gaussian distributions (log link). We also fit a null model, making a total of seven models per disturbance source. All models were compared using Akaike's Information Criterion corrected for small sample sizes (AICc). If the top-ranked model was the null model, we determined that there was no statistically significant change over time. If one of the linear or polynomial models was top-ranked, we selected this model to represent the long-term trend for that disturbance source. If statistically significant changes occurred, we then calculated the annual rate of change between consecutive years based on the top-ranked model, which could be complex in cases where quadratic or cubic functions were supported. We report annual, between-year changes in rate and their 95% confidence intervals (CIs). Annual differences compare the preceding year and the current year, e.g., the 2019 rate of change examines the change in disturbance rate between 2018 and 2019. Owing to the shortened monitoring season, and missing the earliest months when more aircraft and fewer watercraft were present, we were concerned that annual rates may have been skewed. We thus also conducted an analysis using only June-August (DSRM) or July-August (PRH and CHCC) for comparison.

The annual Pacific Coast Dream Machines festival, which typically takes place at the Half Moon Bay Airport, was cancelled because of COVID-19 in 2020. This event included an aircraft fly-in and air tours previously, which in some years caused high rates of seabird disturbance at Devil's Slide.

In addition to disturbance events, we recorded all watercraft within a ~1,500 ft (460 m) radius, and all aircraft ≤1,000 ft (305 m) above sea level and within a 1,500 ft radius of the nearest seabird breeding or roosting area. We calculated detection rates as the number of aircraft or watercraft observed within these zones per observation hour. We recorded and reported all watercraft entering the Egg Rock/DSR and PRH Special Closure areas to Cal-TIP ("Californians Turn in Poachers") or to CDFW wardens directly. Special Closures are no-entry zones designated by CDFW under the California Marine Life Protection Act to protect important seabird and marine mammal colonies from disturbance.

Non-anthropogenic Disturbance Events

In 2020, we recorded non-anthropogenic disturbance events that resulted in flushing or displacement of adult seabirds, or any disturbance to eggs or chicks (exposure, displacement, depredation, or scavenging). At all locations, observers recorded non-anthropogenic disturbance incidentally, from all observation overlooks. For each event, observers recorded the species and number of individuals causing disturbance, the types of behaviors exhibited by the disturbance source, the species and number of individuals disturbed, and behaviors of disturbed birds.

Common Murre Seasonal Attendance Patterns

We monitored seasonal attendance patterns of murres at PRH, DSCC, and CHCC. Monitoring occurred at nesting areas throughout the field season until all chicks fledged and adult attendance ceased. Counts were conducted from standardized mainland observation points using 65-130X or 15-60X spotting scopes. Survey frequency and methods varied somewhat depending on location. Most counts were conducted during a standardized period between 1000-1400 h, but count times were extended if necessary to complete the count, especially at PRH. At productivity plots and a subset of subcolonies and subareas, we compared murre counts to weekly long-term patterns (2008-2019) with 95% CIs. Results are reported as above or below average if they fell outside the CIs of the long-term mean.

At several subcolonies within PRH and CHCC, we recorded attendance at established index plots. Plots were used at subcolonies with especially large numbers of birds, where whole counts were not practical or feasible. We created plot maps using photographs and recognizable landmarks to maintain consistent boundaries between years.

Point Reyes Headlands

We recorded counts of murre attendance at PRH once per week from 14 June to 14 August. We performed counts of all murre subcolonies visible from mainland observations points (Figure 2). We counted index plots three times per survey; we reported the average of all counts. Plots included Lighthouse Rock (LHR; Ledge, Edge, and Dugout plots), Boulder, Flattop, Middle, Beach, and Cone Rocks. We counted all other visible areas of subcolonies once per survey.

Devil's Slide Rock & Mainland and San Pedro Rock

We counted murres on DSR every other day from 23 May to 11 August from the Traditional Pullout (Figure 3). We photographed the DSR colony with a Canon EOS 80D camera with a 300 mm telephoto lens. Birds were counted later using ImageJ software (v. 1.53c, Schneider et al. 2012). On Devil's Slide Mainland (DSM), we monitored attendance patterns once per week wherever we could view murres (Figure 3-4); we counted murres three times per survey and reported the average. At San Pedro Rock (SPR), we conducted murre counts once per week throughout the breeding season from the Bunker (Figure 3).

Castle-Hurricane Colony Complex

We recorded seasonal attendance at CHCC twice per week from 2 June to 31 July.
We performed counts at all subcolonies visible from mainland observation points (Figure 5); we counted all areas three times per survey and reported the average. At four subcolonies, we also performed separate subarea counts: CRM-04 (productivity plot and entire rock), CRM-03B (south and east sides), CRM-06-B (also called CRM-06-South; south side only), CRM-06-A

(also called CRM-06-North; north side only), and HPR-02 (Ledge and Hump plots). We observed a small portion of subarea CRM-06-A from the Castle Pullout (Figure 5).

Bird Island

In 2020, monitoring of this very small and ephemeral colony was conducted by a trained volunteer approximately once per week from 18 June to 7 August. Counts were conducted during late afternoon (after 1500 h) from a south-facing overlook on the bluff above the north end of Rodeo Beach (on the Rodeo Beach Coastal Trail, ~920 meters north of Bird Island).

Common Murre Productivity

Like previous years, productivity (chicks fledged/pair) of murres was monitored at PRH, DSRM, and CRM. We monitored murres from standardized mainland observation points using a modification of the Type I method (Birkhead and Nettleship 1980). Type I monitoring is characterized by daily or near-daily observations from fixed observation points throughout the breeding season to record egg laying, chick hatching, and chick fledging. Type I plots should consist of ~80 breeding pairs of cliff-nesting murres, with a clear view of individuals from a vantage point higher than the colony (Birkhead and Nettleship 1980). We used either 65-130x or 15-60x spotting scopes. At the PRH LHR and at the DSR plots, we mapped and numbered all monitored sites using photographs from 2018 and 2019. At CRM-04-P, we identified sites using maps and photographs updated from the 2018 breeding season. We did not follow productivity at CRM-03-B for the 2019 season owing to time restrictions and murre behavior observed in previous years.

We classified sites as “breeding” when an egg was observed or inferred based on adult behavior. A site was “territorial” when attendance was ≥ 15% of monitored days, but no egg was observed or inferred based on adult behavior. Sites were “sporadic” when murres attended ≥2 days but <15% of monitored days. Some territorial and sporadic sites were likely breeding sites; some eggs were likely lost shortly after laying, but we did not detect them. We considered chicks fledged if they survived to ≥15 days of age and were not known to perish before fledging. In cases when the hatch date was unknown and the chick disappeared before the 15 days of observation, we used chick plumage stages to age the chick and determine whether to consider the chick fledged. We compared results from 2020 to long-term means: PRH 1996-2002, 2005-2015, 2017-2019 (n=21 years); DSR and CRM, 1996-2019 (n=24 years).

Point Reyes Headlands

We monitored murre productivity at PRH within two established Type I plots (Birkhead and Nettleship 1980) on LHR. Ledge Plot and Edge Plot were located at the interior and edge of the colony, respectively. We monitored 195 sites, including 111 sites in Ledge Plot and 84 sites in Edge Plot.

Devil's Slide Rock and Mainland

Due to widespread colony growth and the increasing difficulty of monitoring the entire colony, three Type I plots (A, B, and C) were established on DSR in 2006 (McChesney et al. 2006; Figure 6). Since 2006, as plots continued to fill with more murres, we adjusted plot boundaries based on the visibility of sites. In 2014, we eliminated Plot C because of poor viewing conditions, and in 2015 we added Plot D in an attempt to monitor the edge effects previously captured in Plot C (Figure 6). We periodically dropped other sites from the sample if especially poor viewing conditions obstructed our ability to record productivity data. We added new sites as birds established new territorial or breeding sites (Figure 6).

In 2020, we monitored 222 sites within DSR plots (Figure 6) . We monitored all active sites in plots beginning 31 May. We also followed 100 sites on Devil's Slide Mainland, in subareas DSRM-05-A and DSRM-05-B, which we added to our sample as we observed birds attending sites consistently.

Castle-Hurricane Colony Complex

We monitored 91 active murre breeding and territorial sites within one Type I plot on CRM-04 (established in 1996), beginning 2 June.

Nest Surveys

When performing murre colony attendance surveys, we concurrently surveyed nests and birds of other seabird species. These surveys of other seabirds assessed locations of nesting areas, relative breeding population sizes, and potential impacts from disturbance. We conducted surveys weekly at PRH and DSRM, and twice per week at CHCC. Surveys occurred during the first week of monitoring (23 May (DSRM), 2 June (CHCC), 18 June (PRH)) through 10 July. We classified Brandt's Cormorant nests and territorial sites into five groups that described nesting stages: territorial site, poorly-built nest, fairly-built nest, well-built nest, and nests with brooded chicks. We also counted large, wandering ("creching") cormorant chicks. See McChesney et al. (2007) for more detailed descriptions of nest categories. For other species, we counted only well-built nests (i.e., those beyond the poorly-built stage). Nest counts report the sum of peak counts of well-built nests (including nests with chicks) at each subcolony or subarea.

Brandt's Cormorant Productivity

When vantage points provided adequate viewing, we monitored Brandt's Cormorants for breeding phenology and reproductive success (clutch sizes, brood sizes, and chicks fledged per pair) at PRH, DSRM, and CHCC. We create new plots each year near overlooks with clear vantages. In 2020, at PRH we monitored Area E (PRH-06-E), Arch Rock (PRH-11-D), Cone Shoulder (PRH-13-CS), Cone Upper (PRH-13-CU), West Cone (PRH-13-WC), Miwok Rock (PRH-14-D), and Area B Mainland (PRH-14-E). At DSRM, we monitored Lower Mainland South (DSRM-05-A Lower), Upper Mainland South (DSRM-05-A-Upper), Mainland South

Roost (DSRM-05-A-Roost), and Turtlehead (DSRM-05-B; Figure 3-4). At CHCC, we monitored CRM-03-A and CRM-03-B (Figure 5).

We observed monitored nests every 1-7 days from mainland observation points using binoculars and spotting scopes. We considered chicks fledged if they survived ≥30 days of age and were not known to perish afterwards. After that age, chicks typically begin to wander from their nests and become impossible to associate with specific nests without marking (Carter and Hobson 1988, McChesney 1997). Because of the shortened 2020 season, when crews arrived at field sites the eggs had already started hatching, preventing complete data on reproductive performance from being recorded; we consider any comparisons made to long-term means with great caution.

Pelagic Cormorant, Black Oystercatcher, and Western Gull Productivity

At DSRM and CHCC, we monitored the productivity of Pelagic Cormorants, Western Gulls, and Black Oystercatchers at subcolonies or subareas that were easily visible from mainland observation points. We examined nests at least once per week. We considered chicks fledged if they survived to ≥30 days of age and were not known to perish afterwards. If hatch dates were unknown, we used feathering status as a proxy for chick age (i.e., chicks >75% feathered were considered fledged). Because of the shortened 2020 season, we considered any comparisons to long-term means with extreme caution. In 2020, we monitored no WEGU nests at CHCC, and no BLOY nests at DSRM or CHCC.

Pigeon Guillemot Surveys

To assess relative population sizes and seasonal attendance patterns of Pigeon Guillemots, we conducted standardized counts from the first week of monitoring to late June at PRH, DSCC, and CHCC. Because of the delayed start of the 2020 season, monitoring began May 24 at DSRM (6 surveys), June 17 at PRH (2 surveys), and June 20 at CHCC (2 surveys). We counted birds rafting on the water and roosting on land (intertidal and nesting areas). We conducted surveys at all colonies between 30 minutes after sunrise and 0830 h. In previous years, we conducted Pigeon Guillemot surveys only in Beaufort states ≤4. In 2019, however, we started conducting surveys in all weather states to roughly examine if weather affected counts. At PRH, we surveyed the area within view of the Point Reyes Lighthouse (PRH-01, -02, -03 and -04; Figure 2). At DSCC, we surveyed the entire area from the south side of SPR to the South Bunker (DSRM-04; Figures 3- 4). At CHCC, we surveyed the entire area south and west of Rocky Point to just south of Hurricane Point (Figure 5).

Common Murre and Brandt's Cormorant Breeding Population Sizes

We did not conduct aerial surveys in 2020; population sizes are recorded as land-based counts of visible breeding areas. Because of the shortened 2020 season, any interpretation of population trends should be made with caution.

RESULTS

Anthropogenic Disturbance

During the 2020 field season, we performed 680 hours of monitoring effort across PRH, DSCC, and CHCC combined (Table 1). Detection and disturbance rates were greatest at DSCC, as is typical. We recorded 79 aircraft (detection and disturbance events combined) within our detection zones at PRH, DSRM, and CHCC; these included 60 planes, 16 helicopters, and 3 uncrewed aerial systems (UAS, i.e., drones; Tables 2-4). Overall, 22 (28%) of these overflights resulted in disturbance to seabirds (agitation, displacement, or flushing), including 13 planes and nine helicopters. Four helicopters and two planes caused displacement or flushing of murres. The most frequently detected aircraft categories were general aviation (75%), USCG (11%), and military (8%; Figure 7, Appendix 1). At PRH from 2005-2020, when considering all available data, there were significant but modest increases in plane and aircraft detection rates since 2017, but no long-term trends in aircraft disturbance rates (Appendix 2). When using data directly comparable to the 2020 season at PRH (July-August), these increasing trends in aircraft detection rates were slightly stronger, and recent increases in aircraft disturbance rates became statistically significant, but all effects were still relatively small (Appendix 3). At DSRM from 2005-2020, when considering all available data, there were significant declining trends in aircraft, plane, and helicopter detection rates, and declines in aircraft and helicopter disturbance rates (Appendix 4). When considering data directly comparable to the 2020 season at DSRM (June-August), trends were very similar to the complete data, but with narrower CIs (Appendix 3). At CHCC from 2005-2020, when considering all available data, there were significant small declines in plane detection rates, but no significant trends in aircraft disturbance rates (Appendix 5). When considering data directly comparable to the 2020 season at CHCC (July-August), there were no significant trends for aircraft detection or disturbance rates, but CIs were wider (Appendix 3).

We observed 156 watercraft within the 1,500-ft detection zone around our monitored colonies, including 105 recreational motor vessels, 40 charter boats, and small numbers of commercial, law enforcement, research, and USCG vessels (Figure 8). Four recreational motor vessels, one charter motor vessel, and one kayak caused disturbance (Appendix 6). Three watercraft caused displacement or flushing of murres. When including all available data, long-term trend analysis (2005-2020) indicated that there were stark increases in watercraft detection rates at PRH and DSRM, and smaller increases at CHCC (Appendix 2, 4-5). Analyses of watercraft disturbance rates showed significant but small increases at PRH, significant decreases at DSRM, and no trend at CHCC (Appendix 2, 4-5). At PRH, when including data comparable to the shortened 2020 season (July-August), recent increases in watercraft detection rates still occurred, but were much smaller; they appeared roughly equivalent to rates observed near the beginning of the time series, rather than twice as large (Appendix 3). There were no significant changes in watercraft disturbance rates at PRH using the truncated data. At DSRM, using data comparable to the 2020 season (June-August) showed trends roughly equivalent to the complete data, except the declines in watercraft detection and disturbance rates at the beginning of the time series were steeper (Appendix 3). At CHCC, there were no trends in watercraft detection or disturbance rates in the dataset comparable to 2020 (July-August; Appendix 3). Owing to inconsistencies in the recording of watercraft detections at DSRM for 2015-2018, trends including those years should be considered with caution.

We submitted 30 SPN Wildlife Disturbance Reports in 2020 (27 from DSRM, two from PRH, and one from CHCC). These included nine reports of flushing or displacement and 21 reports of agitation. Twenty-one of the reports involved aircraft disturbance, six involved watercraft, and three involved land-based noise.

Point Reyes Headlands

We detected 1 UAS (drone), 12 aircraft, and 62 watercraft at PRH in 2020 (Table 2). We observed two disturbance events during the shortened season, both by watercraft, and both of which caused flushing of seabirds (Figure 9-10). We recorded 0.334 detections/hr and 0.009 disturbances/hr (Figure 11-12); while the detection rate was the largest we have recorded since methods were standardized in 2005, our shortened season (beginning in mid-June) and reduced number of observation hours likely skewed this number high relative to previous years (Appendix 3).

Long-term detection trends at PRH were the least consistent of all study areas when comparing all data with truncated datasets comparable to the 2020 field season (Appendix 2-3). Watercraft detection trends changed from a cubic to a quadratic relationship, indicating that results in 2020 were not as anomalous as they first appeared (Appendix 3). Using the truncated dataset, watercraft detection rates initially decreased early in the time series, but they increased greatly in 2020. Watercraft also made up the plurality of all detections at PRH (mean 47% annually, range 0-83%), so increases in watercraft detection rates in 2020 drove the quadratic increase in detection rates of all sources at PRH (Appendix 3). Aircraft and plane detection rates were more similar between the complete and truncated datasets, each showing a quadratic relationship where rates initially decreased, and after 2017 increased modestly (~10-30% annually, Appendix 2-3). Trends from the truncated dataset suggest that aircraft detection rates were underestimated in 2020.

Long-term trends in disturbance rates are divergent; watercraft disturbances in the truncated dataset dominated, and high watercraft disturbance rates early in the time series dwarf recent negligible annual changes (Appendix 3). However, trends in the full dataset do not show these stark differences in disturbance rates early in the time series, suggesting that the truncated dataset for PRH may not track long-term disturbance trends well. In the full dataset, disturbance rates across all anthropogenic sources instead have a modest cubic trend, with declines between 2006-2010 (mean annual rate of change 33%, range 17-48%), a small increase beginning in 2011 (mean annual rate of change 14%, range 4-22%), and a declining trend after 2018 (mean annual rate of change 11%, range 6-17%). In the full dataset, watercraft disturbance rates decline between 2006-2014 (mean annual rate of change 21%, range 6-38%), then show a modest increasing trend after 2015 (mean annual rate of change 25%, range 6-43%), but the effect size is small (Appendix 2). Aircraft in the full dataset show no trend in disturbance rates over time, but in the truncated dataset, disturbance rates are quadratic, indicated most strongly by decreasing rates early in the time series (Appendix 3). Watercraft disturbance rates may be slightly overestimated in 2020, and aircraft rates may be slightly underestimated, but disturbance rates at PRH are already quite small.

Devil's Slide Rock and Mainland

In 2020 at DSRM, we recorded 13 helicopters, 49 planes, and 2 UAS in our detection zones (Table 3). We recorded 0.493 detections/hr and 0.092 disturbances/hr (Figure 11-12). Detection rates were the highest recorded since 2012, but the disturbance rate was similar to 2019; aircraft disturbance rates were lower than recent years, but watercraft disturbance rates were higher. We recorded 21 aircraft (9 helicopters, 12 planes), 4 watercraft, and 4 land-based events that caused disturbance to seabirds in 2020 (Table 3, Figure 13).

Seven events in 2020 caused flushing of seabirds at DSRM (Appendix 1, 6); these included 4 helicopters (two general aviation, one military, one USCG), 2 planes (general aviation, military), and 1 watercraft (private recreational). The largest disturbance event occurred on June 19 when a general aviation helicopter caused agitation to 1000 murres and 10 Brandt's Cormorants, at least 3 murres were displaced, and 10 murres flushed (Figure 14).

Long-term detection and disturbance trends at DSRM generally coincided between the complete and truncated datasets (Appendix 3). Despite a general decreasing trend in aircraft detection rates, only helicopters showed a statistically significant change (mean annual rate of change 6%, range 4-9%; Appendix 4). Watercraft detection rates showed a cubic trend, including initial decreases between 2006-2013 (mean annual rate of change 24%, range 2-43%), then increasing afterwards to the local maximum in 2020 (mean annual rate of change 36%, range 6-70%). Total detection rates reflected decreasing trends prior to 2020, but the recent increase in watercraft detection rates also caused an increase in the total overall detection rate in 2020 (Appendix 4). Among disturbance rates, aircraft rates generally declined, but only helicopter disturbance rates were statistically significant (mean annual rate of change 4%, range 3-5%). Watercraft disturbance rates showed a stronger decline (mean annual rate of change 15%, range 6-44%). The total disturbance rate declined significantly between 2012-2020 (mean annual rate of change 8%), reflecting general declines in both aircraft and watercraft (Appendix 4). Differences between the truncated and full datasets were small but most apparent in disturbance rates; the truncated dataset indicates that aircraft disturbance rates may be underestimated, and watercraft disturbance rates may be slightly overestimated (Appendix 3).

Castle-Hurricane Colony Complex

In 2020, we recorded one helicopter, one plane, and six watercraft within the detection zones at CHCC (Table 4). We recorded only one disturbance, caused by the plane; 30 murres were agitated during the event (Figure 15). We recorded 0.058 detections/hr and 0.007 disturbances/hr, the lowest rates observed since 2016 and 2015, respectively (Figure 11-12). We did not arrive at the field site until late May, which may have skewed observed detection and disturbance rates compared to other seasons, but we note that detection rates at CHCC were also much lower than at PRH or DSRM this year.

Long-term trends at CHCC typically were not significant, so it is difficult to interpret whether the observed disturbance rates may have been skewed (Appendix 3, 5). In the complete dataset, among aircraft detection rates, only planes showed a significant trend, indicating a linear decline over time (mean annual rate of change 10%, range 5-20%). Watercraft detection rates showed a cubic trend, including an initial increase between 2006-2009 (mean annual rate of change 280%, range 35-501%), a decrease between 2011-2016 (mean annual rate of change 30%, range 17-39%), and increases afterwards (mean annual rate of change 127%, range 8-305%). There were no trends in the disturbance data in either dataset. The truncated data showed no significant trends in detection rates, but graphs indicate that aircraft rates may have been underestimated, while watercraft may have been overestimated.

Non-Anthropogenic Disturbance

Point Reyes Headlands

We incidentally recorded 40 events of non-anthropogenic disturbance at PRH in 2020; all events caused the displacement or flushing of seabirds. Turkey Vultures (*Cathartes aura*) were involved in most of the disturbance events (55% of observations), caused frequent displacement and flushing, and scavenged two eggs. Common Ravens (*Corvus corax*) are typically the most disruptive species at PRH, and they caused the worst non-anthropogenic disturbance event of the season (flushing 1000 murres from LHR), but ravens were involved in only 14 events (35%). Raven predation is typically more common earlier in the season, whereas vultures typically come by later to scavenge dead eggs and chicks, so some of these rates may have been skewed by the late start to our monitoring. Other disturbance events involved Western Gulls (10%) and Brown Pelicans (*Pelecanus occidentalis,* 8%).

Devil's Slide Rock and Mainland

We recorded 27 incidental events of non-anthropogenic disturbance at DSRM in 2020. Ravens were involved in most events (63% of observations), depredating 16 eggs and 8 chicks. Ravens also caused the most disruptive event of the season, flushing 50 and agitating 960 murres. Other disturbance events involved Western Gulls (22%), Brown Pelicans (11%), and Brandt's Cormorants (4%).

Castle-Hurricane Colony Complex

At CHCC in 2020, we observed one incidental non-anthropogenic disturbance event. A group of Brown Pelicans landed on CRM-02, flushing 20 murres and displacing 30 murres. Five large chicks were exposed, but attempts by Western Gulls to take the chicks were unsuccessful.

Common Murre Seasonal Attendance Patterns

Point Reyes Headlands

In 2020, we recorded murre attendance between 18 June – 12 August. We were unable to complete our first count, so the first complete murre count occurred on 29 June. We could not determine the peak attendance counts for the season, because of the delay in the start of monitoring. For the periods of time that we did monitor, in most cases murre attendance in 2020 was greater than the long-term mean, and the departure of murres from their breeding colonies was later than typical (Figure 16-17). Despite the limited amount of data, many subcolonies had equivalent or greater high counts compared to 2019 (Figure 18-21), perhaps indicating growth of the murre population at PRH. We first observed unattended subcolonies on 27 July (PRH-10-A, PRH-10-D) and by the last count on 12 August, 85% of active subcolonies were unattended, indicating the near cessation of breeding activity for the year.

Devil's Slide Rock, Mainland, and San Pedro Rock

Devil's Slide Rock

We observed murres attending on all count days between 23 May and 8 August 2020 (Figure 22). We did not get estimates of murre attendance during the earliest part of the season, when peak counts often occur, but we did observe murres for most of their breeding season. The observed peak count of 1,352 murres occurred on 23 May; this count is 31% lower than the peak count in 2019 (1,972 murres). Attendance patterns fluctuated in late May and early June, and birds were noticeably absent on some days from our monitored productivity plots. From 14 June to 26 July, counts averaged 1,226 murres (range 1,118-1,352), but after 26 July murre numbers decreased quickly as chicks and adults departed from the colony. By 11 August, all murres had departed the colony for the season.

The seasonal attendance pattern in 2020 resembled the long-term pattern (2008-2019), except that counts in 2020 were ~30% greater than the long-term mean (Figure 22); this reflects increasing colony size over time, and perhaps a change in 2018 from real-time counts through spotting scopes to counts from photographs. Counts from photographs appear to be much less variable. Therefore, use of these data for long-term analyses should take consider methodological differences.

Devil's Slide Mainland and San Pedro Rock

We observed murres consistently attending and confirmed breeding at Lower Mainland South (DSRM-05-A Lower), Mainland Roost (DSRM-05-A-Roost), and Turtlehead (DSRM-05-B); we observed at least one large (Stage IV) chick at each of these subareas. We also observed murres intermittently amongst nesting and roosting Brandt's Cormorants at other subareas (DSRM-05-A-Upper, DSRM-05-C, and DSRM-07), but breeding was not confirmed; attendance of murres at DSRM-07 (Keyhole Point) is the first we have recorded.

Despite our delayed start to the field season, seasonal attendance at mainland murre subcolonies averaged 200-500% higher than the long-term mean (2008-2019), with the disparity becoming more pronounced in July (Figure 22). For the first time in several years, we observed two murres on San Pedro Rock on 30 July in the intertidal area (SPR-01-Lower).

Castle-Hurricane Colony Complex

In 2020, we performed counts of murre attendance between 2 June and 31 July. We missed monitoring the first half of the breeding season, so comparisons to previous years should be made cautiously. As far as we can tell, murre attendance patterns are similar to previous years. Murre attendance at CMR-04 was about 15% greater than the long-term mean, and in 2020 the departure of murres from the colony was later (Figure 23). At HPR-02, attendance was similar to the long-term mean during June and early July, but attendance was elevated in mid- and late July. By the final count on 31 July, murre attendance on HPR-02 was still high, despite most other colonies being unattended at the point in the season; this suggests prolonged or delayed breeding. At some subcolonies, our data did not match peak counts of 2019 (CRM-03A, CRM-03B, CRM-05), but in other cases, our counts in 2020 were equivalent to (CRM-06-B-S, CRM-07) or greater than (BM227X-02, CRM-02) peak counts in 2019, despite the shorter period of monitoring (Figure 24-25). We first observed unattended subcolonies on 18 July (CRM-03A, CRM-04-P), and by the last count on 31 July 75% of subcolonies were unattended (Figure 24-25)

Common Murre Productivity

Point Reyes Headlands

In 2020, we monitored a combined 190 sites in Ledge (n = 108) and Edge plots (n = 82) on LHR (Table 5). Eggs and chicks were already present in our monitored plots at our time of arrival, so we could not determine the number of egg laying sites, mean lay dates, or the total number of eggs laid. We were not aware of any replacement eggs in Edge or Ledge Plots, but we likely missed eggs lost earlier in the season. Of the eggs we observed, hatching success was 93%. Of the chicks we observed, fledging success was 92.5%, and overall productivity was 0.85 chicks fledged/pair. However, only 61% of monitored sites were designated as breeding, and the number of nests that failed before we arrived was likely much higher than recorded. This uncertainty in our productivity data leads us to conclude that the 2020 data are not comparable to past and future data, and thus we have not included it in Figure 26. Chicks fledged at an average age of 23 ± 0.4 days (n = 38), and the last chick was observed on 13 August.

Devil's Slide Rock and Mainland

Although the start of monitoring was delayed at DSRM in 2020, we saw no evidence that chicks had hatched before we arrived, and so productivity data should be more reliable than our other monitored locations. We report many of our typical productivity measures (Table 6), but we note that any nests that failed early would be missed, and the mean lay date is more likely to be skewed late.

Of 222 monitored sites on DSR, 191 (86%) were breeding, 23 (10%) were territorial, and 8 (4%) were sporadic. We first observed eggs on DSR early in our monitoring period on 23 May, but the earliest calculated lay date was 19 May in productivity plot B. The mean egg lay date for first eggs was 3 June ± 6.18 (range 19 May – 28 June, n = 126, Table 6), about a week later than the long-term mean (26 May ± 1.7 days). We recorded 191 eggs laid, including 2 replacement eggs. Overall productivity of 0.76 chicks fledged/pair is above average (0.64 ± 0.05; Figure 26). Productivity was bolstered by high hatching (92%) and fledging success (87%). Chicks that fledged remained on DSR for an average of 24 ± 0.34 days (n = 110), and the last chick was observed on 14 August.

At DSM, we monitored 100 sites, which is the greatest in our monitoring history. Of these sites, 84 were breeding (84%), and 16 (16%) were territorial. We observed eggs on DSRM-05-A during our first site visit on 21 May, whereas eggs were first observed on DSRM-05-B on 8 June (Table 6). The mean lay date for first eggs was 3 June ± 9.5 days (range 21 May – 2 July, n = 49, Table 6), very close to the long-term mean (3 June ± 3.2 days). We recorded 86 eggs laid, including 2 replacement eggs. Overall productivity of 0.64 chicks fledged/pair is more than twice as large as the long-term mean (0.22 ± 0.08). Moderately high hatching (80%) and fledging success (87%) helped improve productivity in 2020. Chicks that fledged remained on DSM for an average of 23 ± 0.54 days (n = 40), and the last chick was seen on 16 August.

Castle-Hurricane Colony Complex

In 2020, we monitored 91 sites in CRM-04 plot. Eggs and chicks were already present in our monitored sample when we arrived at the field site on 2 June, so we could not determine the number of egg laying sites, mean lay dates, or the total number of eggs laid. We believe the mean egg-laying date occurred prior to 2 June. Of the eggs observed, 88% hatched. We observed no replacement eggs, but lost or replacement eggs may have been missed owing to the delayed start to monitoring. Of the chicks we observed, fledging success was 82%, and overall productivity was 0.65 chicks fledged/pair, which would be above the long-term mean (Figure 26); 84% of monitored sites were designated as breeding, so the number of active sites we missed prior to monitoring is likely relatively low. Our hatching dates had low confidence, so we are unable to calculate a mean chick age at fledging. the last chick at monitored sites was observed on 13 July (Table 7), which is earlier than typical. Uncertainty in our productivity data leads us to conclude that the 2020 data are not comparable to past and future data, and thus we have not included it in Figure 26.

In 2020, we did not monitor productivity at subcolony CRM-03-B. We confirmed attendance of adult murres, but we did not observe any eggs or chicks.

Brandt's Cormorant Nest Surveys and Productivity

We reported seasonal peak nest counts of Brandt's Cormorants obtained from weekly land-based surveys (DSRM only; Table 8). Not all nests were visible from our observation points, so nest counts should be considered a minimum. Consequently, comparisons to previous years should also be considered with caution. Uncertainty in our productivity data leads us to conclude that the 2020 data are not comparable to past and future data, and thus we have not included it in Figure 27.

Point Reyes Headlands

Nest surveys

Because of the delayed start, we conducted Brandt's Cormorant nest surveys only three times between 18 June and 29 June. Two counts were incomplete. We recorded well-built nests on the mainland of PRH-04, Area C (PRH-06-C), Area E (PRH-06-E), Area F (PRH-06-F), the mainland of PRH-06, Tim Tam (PRH-10-H), the eastern half of Face Rock (PRH-11-B), Arch Rock (PRH-11-D), several subareas of Cone Rock (Cone Shoulder (PRH-13-CS), Cone Upper (PRH-13-CU), West Cone (PRH-13-WC), and an unnamed section (PRH-13)), SC14 Area (PRH-14-A), Area B (PRH-14-B), Border Rock (PRH-14-C), Miwok Rock (PRH-14-D), Area B Mainland (PRH-14-E), and an unnamed section of PRH-14. When counting only well-built nests, we recorded a high count of 224 nests on 29 June, but we performed only one complete survey this season at PRH. The sum of land-based peak counts from each subcolony was 255 nests, 16% fewer than 2019 (303 nests).

Productivity

At PRH, we monitored 96 nests at seven subareas; 74 of these were breeding sites (77%). Nineteen of our monitored nests did not appear to have any eggs laid in them, two were excluded because of poor viewing conditions, and one was classified as unknown because we recorded only one day of observations before the nest failed (Table 9). We started monitoring our first nests on 13 June, long after the breeding season started, so our lay date data are unreliable and incomplete. We monitored nests on Upper Cone, Cone Shoulder, West Cone, Arch Rock, Area B Mainland, Miwok Rock, and Area E (where no monitored pairs laid eggs). We saw chicks on our first visit to the site on 13 June. For all subareas combined, productivity was 2.05 chicks fledged/pair in our monitored sample, which would be near the long-term mean (Figure 27). Breeding success/nest (egg-laying nests that fledged at least one chick) was 0.97 (subarea range = 0.75 – 1.0, Table 11), likely skewed high by our late sample of active nests.

Devil's Slide Rock and Mainland

Nest surveys

We counted nests and territorial sites weekly during surveys between 23 May – 2 July. Well-built nests were already present on our first count on 23 May. The peak count of well-built nests was 178 (9 June), 81% higher than the peak count of 2019 (98 nests). The peak count of nests on DSR was 16 on 3 June. On the mainland, nesting occurred on Lower Mainland South (DSRM-05-A-Lower, peak count of 86 nests), Turtlehead (DSRM-05-B, 66 nests), South of Turtlehead Cliffs (DSRM-05-C, 13 nests), Upper Mainland South (DSRM-05-A-Upper, 10 nests), and Mainland Roost (DSRM-05-A-Roost, 5 nests). The sum of land-based seasonal peak counts by subcolony totaled 197 nests, 116% higher than the 2019 peak count (91 nests).

Productivity

We monitored 153 nests at DSRM in 2020; five of these did not appear to have any eggs laid in them. We monitored nests on Lower Mainland South, Turtlehead, Upper Mainland South, and Mainland Roost (Table 10). We observed eggs and chicks on our first day of monitoring on 21 May. Because of the delayed start to our monitoring in 2020, we do not report mean lay dates. For all subareas combined, productivity was 1.62 chicks fledged/nest, which would be near the long-term mean (Figure 27). Breeding success/nest (egg-laying nests that fledged at least one chick) was 0.78 (subarea range = 0.77 – 0.89, Table 10), indicating moderately low nest failure.

Castle-Hurricane Colony Complex

Nest surveys

We conducted Brandt's Cormorant nest surveys between 2 June and 8 July. Subcolonies or subareas with confirmed breeding included CRM-03-A, CRM-03-B, CRM-04, BM227X-02, and HPR-01. On 2 June, the first day of monitoring, we observed nests with chicks at CRM-03-B and BM227X-02, as well as well-built nests at CRM-03-A and HPR-01. The peak count of well-built nests was 169, recorded on 2 June, 13% less than the peak count of 2019 (194 nests). The sum of land-based seasonal peak counts from each subcolony totaled 176 nests, 17% less than the peak count of 2019 (212 nests).

Productivity

We monitored 48 Brandt's Cormorant nests for productivity on CRM-03-A and CRM-03-B (Table 11). Monitoring began on 29 May, and we observed the first chick on 3 June. Because of our very late start to monitoring, we do not report mean lay dates. Overall productivity at CRM was 1.41 chicks fledged/nest, which is near the long-term mean (Figure 27). Breeding success/nest (egg-laying nests that fledged at least one chick) was 0.68 (Table 11), indicating moderate nest failure.

Pelagic Cormorant, Black Oystercatcher, Western Gull, and Pigeon Guillemot

Nest and bird surveys

We summarized seasonal peak counts of nests (Pelagic Cormorant, Western Gull, and Black Oystercatcher) or birds (Pigeon Guillemot) from land-based observations (Table 8). Pelagic Cormorant and Black Oystercatcher nesting areas typically vary annually, and nests are often not visible from land-based vantage points, especially at PRH. Nest counts should thus be considered a minimum estimate, and comparisons to previous years should be made with caution. Note that at PRH, surveys do not cover the eastern third of the headlands, so counts reflect only the western and central survey areas.

We counted ten Pelagic Cormorant nests at PRH in 2020. The peak count of Pelagic Cormorant nests at each subcolony at DSRM totaled 23 nests. At CHCC, we observed ten Pelagic Cormorant nests from our mainland vantage points.

Counts of Pigeon Guillemots occurred in the latter half of the typical monitoring period and are likely missing crucial data from April and May. The 2020 peak standardized count for Pigeon Guillemots at PRH was 33 birds on 17 June, near the end of the survey period. The 2020 peak standardized count at DSRM was 79 guillemots on 31 May. At CHCC, the peak standardized count was 33 birds on 20 June, near the end of the survey period (Table 8).

Productivity

We summarized the results of productivity monitoring for Western Gulls, Black Oystercatchers, and Pelagic Cormorants at DSRM and CHCC (Table 12).

Pelagic Cormorant

At DSRM, we monitored the productivity of Pelagic Cormorants at 19 nests on DSRM-05-A-Lower, DSRM-05-B, DSRM-05-D, DSRM-04, and DSRM-02-MN. We observed the first eggs on 3 June. Overall productivity of 0.5 chicks fledged/pair was well below the long-term mean (1.45 ± 0.2; Table 12, Figure 28). At CHCC, we monitored productivity of Pelagic Cormorants at 8 nests on CRM-04 (Table 12). We observed chicks on our first day of monitoring on 7 June. Overall productivity of 2.12 chicks fledged/pair would have been well above the long-term mean (Figure 28), but we may have missed nests that failed earlier in the season.

Western Gull

We monitored 6 Western Gull nests at DSRM in 2020. We first started monitoring gull nests on 23 May, when they were mid-incubation. Gull productivity at DSRM was 0.40 chicks fledged/pair, which was below the long-term mean (0.64 ± 0.12; Table 12, Figure 29). We did not monitor gull nests at CHCC this year.

Black Oystercatcher

We did not observe any Black Oystercatcher nests at DSRM or CHCC in 2020.

DISCUSSION

The COVID-19 pandemic was immensely disruptive to field operations in the 2020 season. Delays in the start of the season affected all aspects of our monitoring protocols, and some studies had only a couple of surveys performed during the entire season, especially at Point Reyes and CHCC. We also needed to adjust staff training guidelines to minimize exposure to disease, which may have affected the quality of some data collection. Thus, we are unsure how comparable the data collected in 2020 are to previous and future data, especially measures of productivity; missing potential nests that had already failed prior to our monitoring start could skew these measures high, and we are wary of any reported data being taken out of context. We also have concerns regarding the interpretation of the disturbance data, because the relative rate of aircraft and watercraft detections and disturbances changed monthly in previous years, and was dependent on the weather. We have documented these differences for disturbances (Appendix 3), but we are unable to make adjustments to survey or productivity data. The interpretation of all data collected in 2020 should be made with caution, with the understanding that we were not physically present at our monitoring sites early in the season; human and wildlife interactions with seabirds may also have changed in the absence of our regular monitoring team's reporting.

Anthropogenic Disturbance

The most striking feature of our disturbance monitoring in 2020 was the high rate of watercraft detections at all sites; although this number may in some cases be skewed high, given our reduced number of monitoring hours (Appendix 3), watercraft detection rates were elevated compared to recent years. We suspect that this increased rate of watercraft activity is in response to the pandemic, where lockdown orders, the closure of businesses, and desires of individuals to avoid high-risk social activities (Hutchins et al. 2020, Chernozhukov et al. 2021) led people to seek more solitary and low-risk recreational activities (Grima et al. 2020, Randler et al. 2020, Pouso et al. 2021), such as boating. Despite high detection rates of watercraft, disturbance rates of watercraft remained low at all sites, with no noticeable increase in long-term trends.

Like recent years, Devil's Slide was subject to the highest anthropogenic detection and disturbance rates among our study sites, including the highest observed detection rates since 2012. Although typically the high rate of anthropogenic activity at Devil's Slide has been by aircraft (especially in April and May), in 2020, watercraft were the major contributor to the increase in detection rates. However, most disturbances were still caused by aircraft. Long-term declining trends in helicopter and watercraft disturbance rates are encouraging for seabird protection, but with the ongoing pandemic, it's unclear how human-derived disturbance might change in the future. Anthropogenic data at Devil's Slide were the least affected of our study sites by the delayed start to the season, particularly because the field crew was able to begin monitoring relatively quickly in May. Given our delayed start, it is possible that the impact of aircraft on seabirds at Devil's Slide may have been underestimated, but with early pandemic shutdowns likely reducing plane traffic, the cancellation of the Pacific Coast Dream Machines event, and the general concordance between the truncated dataset and the complete dataset, we do not believe that we missed extensive disturbance to seabirds in April.

At Point Reyes, the shortened monitoring season may have affected our data to a greater extent than Devil's Slide. Differences between the complete and truncated data were the most obvious at Point Reyes, indicating an overestimation of watercraft detection and disturbance rates, and potentially an underestimation of aircraft activity (Appendix 3). Watercraft activity tends to be greater later in the season, which explains the bias toward elevated watercraft rates in our 2020 data. Using our truncated dataset, recent trends in elevated aircraft detection and disturbance rates continued; we observed no aircraft disturbances in 2020, but it's possible we missed some disturbances prior to our start of monitoring. Despite the recent increases in aircraft disturbance rates, the rate per hour is very low, especially compared to Devil's Slide. Monitoring and outreach should continue at Point Reyes, especially given the uncertain future of the pandemic, but the current outlook is encouraging.

At CHCC, detection rates of all anthropogenic sources were the lowest we've observed since 2016, and considerably lower than at Point Reyes and Devil's Slide. The only significant long-term trend we observed was a long-term decline in plane detection rates, even when including the truncated dataset. This suggests that despite the negative impacts of the pandemic, people seeking recreation activities did not affect the birds substantially in 2020.

In 2020, despite the shortened season, we observed record numbers of watercraft in Special Closures and State Marine Reserves. This could be a result of new recreational users during the pandemic, who were unaware of local laws or had not been exposed to SPN's outreach efforts. We recorded 8 Special Closure violations at Devil's Slide, 7 at Point Reyes, and 12 marine reserve violations at Point Reyes. All were caused by recreational fishing boats. Conversely, the most severe disturbance events (causing displacement or flushing) were all caused by aircraft in 2020.

Non-Anthropogenic Disturbance

Non-anthropogenic disturbance events were most common at Point Reyes, as is typical over our period of study. Despite the severity and high frequency of raven predation events in previous years, ravens at Point Reyes were involved in a smaller percentage of disturbance events compared to scavenging Turkey Vultures. At Point Reyes in particular, where the start to monitoring was delayed until mid-June, we likely missed the majority of disturbance events caused by ravens earlier in the season, when they occur more frequently. At Devil's Slide, where we were able to begin monitoring in May, ravens did represent the majority of disturbance events, as is typical there. Raven predation at all sites is a concern, especially in years where productivity might be low because of challenging environmental conditions. At CHCC, we observed only one disturbance event, caused by pelicans; disturbance of all kinds at CHCC was low in 2020.

Attendance and Reproductive Success

Attendance and productivity monitoring in 2020 were challenging, resulting from the delayed start and incomplete data. Despite the limited data, murres appeared to have a good season; their maximum counts were higher than the 2019 counts at many subcolonies, especially at Devil's Slide Mainland, and departure times were later than many long-term means. Productivity also appeared to be relatively high, especially at Devil's Slide, and much improved over productivity from 2019. While late breeding can be evidence of poor breeding success (Boekelheide et al. 1990), which we observed in 2019, we do not believe this is the case in 2020. Murre productivity at Point Reyes was almost certainly overestimated, given the uncharacteristically high productivity but low percentage of sites classified as breeding; some portion of the sites classified as territorial may have been failed breeders. If that were the case, murre productivity at Point Reyes would have been considerably lower than we estimated. Incomplete data preclude us from fully interpreting trends at Point Reyes in 2020.

Most evidence in 2020 indicated that the murre population was robust, and rebounded well following low productivity and abandonment in 2019. High counts of murres in 2020 suggest that either the breeding population continued to increase, high numbers of subadult prospecting murres were present late in the season, or a combination of both. We observed prospecting murres in atypical areas, including Keyhole Point (DSRM-07) at Devil's Slide. Two murres observed near the intertidal zone at San Pedro Rock were the first records in several years; San Pedro was the site of murre social attraction efforts between 1998-2004, but few murres visited the site before restoration efforts were abandoned (McChesney et al. 2022). Murres on Devil's Slide Mainland, in particular, were much more abundant and had higher productivity than the long-term mean. This is especially encouraging given the history of poor breeding success of murres on Devil's Slide Mainland. Aerial surveys are necessary to confirm any long-term changes, which were not possible this year because of the pandemic and a lack of funding.

Trends in attendance and productivity for Brandt's Cormorants are harder to decipher. We were able to complete only one nest survey at Point Reyes, and the late start to monitoring at Point Reyes and CHCC likely underestimated the maximum numbers of breeding cormorants in 2020. The peak count at Devil's Slide was nearly twice as large as the maximum recorded in 2019 (during a marine heatwave, see below), indicating that the colony was not strongly negatively affected by poor environmental conditions. Our productivity sample at each colony appeared to be near the long-term mean, but our estimates may have been skewed high if failed nests were abandoned and disappeared prior to the start of our monitoring. This potential skew is also applicable to other seabirds monitored for productivity at Point Reyes and CHCC. At Devil's Slide, productivity of Pelagic Cormorants and Western Gulls continued to be below average, suggesting that local foraging and oceanographic conditions for them were still poor following their low productivity recorded in 2019.

Following the marine heatwave during the summer of 2019, most marine indices in the central California Current Ecosystem, including the Gulf of the Farallones, shifted from warm-water El Niño conditions in the fall and winter to cooler La Niña conditions by September 2020 (Thompson et al. 2019, Weber et al. 2021). Sea surface temperature anomalies were very high in the summer of 2019, and nitrate levels were very low (Thompson et al. 2019). In 2020, upwelling increased, especially in the winter, but sea surface temperature anomalies were elevated again in the summer, and nutrient flows remained below average (Weber et al. 2021). Zooplankton abundance, especially krill, was below average in 2019, as were juvenile anchovy (*Engraulis mordax*), sardine (*Sardinops sagax*), and rockfish (*Sebastes* spp.), which serve as preferred prey for most seabirds in this region (Thompson et al. 2019, Harvey et al. 2020). In 2020, cold-water copepod species increased, but some warm-water copepods were still abundant and krill abundance was still below average, reflecting an ecosystem in transition (Weber et al. 2021). Juvenile rockfish continued to be scarce in 2020, as were other juvenile groundfish (Weber et al. 2021). Adult anchovies were extremely abundant in 2019 and 2020 (Thompson et al. 2019, Weber et al. 2021), and the only seabird at our field sites likely capable of feeding them to chicks were Brandt's Cormorants, which may be why their productivity remained high in these years. Despite the low apparent abundance of preferred seabird prey in local surveys, murres did appear to have improved productivity in 2020, though the low productivity of

Western Gulls and Pelagic Cormorants may indicate that their preferred prey did not improve much in 2020.

At the nearby South Farallon Islands (SEFI), which can serve as a reference colony in this region, most seabird species were abundant and had much higher productivity in 2020 than in 2019 (Johns et al. 2020). Murre productivity at SEFI improved but was still below average, likely skewed by high egg predation in one monitored plot. Brandt's Cormorants at SEFI had productivity similar to 2019 – which was above average – and in 2020 their clutches were initiated about two weeks early. Pelagic Cormorants at SEFI did much better than average, as did Western Gulls, unlike our birds at Devil's Slide. Diet studies indicated that rockfish were present in murre diets early during monitoring, but ultimately made up a small proportion of the total diet (Johns et al. 2020). Anchovies made up the majority of the chick diet for murres, and preliminary data suggest the same for Brandt's Cormorants. Rockfish were scarce in murre diets at SEFI in the past two seasons, so this increase in juvenile rockfish may reflect an ecosystem in transition to cooler and more productive conditions.

Recommendations for Future Management, Monitoring, and Research

• The COVID-19 pandemic is constantly in flux, and the future effect on staffing and anthropogenic activities is uncertain. Flexibility, patience, and vigilance are necessary to proceed safely with our monitoring program.

• Corrections for abundance and productivity data in 2020 should be explored for Point Reyes and CHCC, where we were unable to begin monitoring until after chicks had hatched.

• Outreach and education efforts targeting aircraft and watercraft user groups should be continued and adapted to changing characteristics of disturbance. For example, watercraft detections increased drastically in 2020, and may include new users searching for safe recreational opportunities during the pandemic.

• Efforts to develop personal communications with CDFW wardens should be continued for real-time reporting of MPA and Special Closure violations. Wardens are often responsive and able to contact boat operators quickly, making this an effective outreach tool.

• The Devil's Slide pedestrian trail was completed in March of 2014, and the 2020 field season marked the seventh year of pedestrian access to the span of road above DSM. We have observed no pedestrian-related disturbances to seabirds associated with the trail, likely attributed to area closures and fencing designed to protect seabirds, falcons, and rare plants. These protective measures should be continued, and we should continue to monitor for new types of potential disturbance.

• Annual aerial surveys of central California murre and Brandt's Cormorant colonies cannot be sustained at current funding levels. These surveys provide the best (and preferred) method of monitoring these species' population sizes in a standardized fashion (Carter et al. 2001, Capitolo et al. 2014, Bridgeland et al. 2018). Aerial surveys also provide the best method of evaluating and documenting the success of murre restoration efforts, via the number of murres added to the population.

• Raven disturbance and nest predation, as well as disturbance by other avian predators, should be monitored closely for potential increases in impacts to murre colonies.

• As the numbers and densities of murres on monitored breeding colonies increase, continued evaluation of monitoring methods for productivity (especially at Devil's Slide Rock) will be necessary. This will include adjustments to plot boundaries and elimination of sites that are difficult to view. The number of murres at Devil's Slide Mainland have also been increasing rapidly, and we should consider more formal protocols and plots for their productivity monitoring.

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Table 1. Monitoring effort of study colonies by the Common Murre Restoration Project, May 2020 to August 2020.

Colony or Colony Complex	Start date	End date	Observation days	Total hours
Point Reyes Headlands	6/13/2020	8/18/2020	53	225
Devil's Slide Rock & Mainland	5/21/2020	8/19/2020	74	314
San Pedro Rock	5/31/2020	6/29/2020	5	2
Castle-Hurricane Colony Complex	5/28/2020	7/31/2020	40	139

Table 2. Total observed watercraft, aircraft, land-based sources, and resulting disturbances to seabirds (Common Murres, Brandt's Cormorants, Western Gulls, and Brown Pelicans) at Point Reyes Headlands, 2020. UAS are uncrewed aerial systems (i.e., drones). Disturbances indicate events that included alert, displaced, and flushed birds. Detection and disturbance rates are reported as numbers per observation hour.

Disturbance Source	Plane	Helicopter	UAS	Aircraft Total	Watercraft	Total
Total # of Detections	10	2	1	12	62	**75**
Detections/Hour	0.045	0.009	0.004	0.053	0.276	**0.334**
# of Agitation Events	0	0	0	0	0	**0**
# of Displacement Events	0	0	0	0	0	**0**
# of Flushing Events	0	0	0	0	2	**2**
Total Disturbed/Hour	0.000	0.000	0.000	0.000	0.009	**0.009**
Total Flushed or Displaced/Hour	0.000	0.000	0.000	0.000	0.009	**0.009**

Table 3. Total observed watercraft, aircraft, land-based sources, and resulting disturbances to seabirds (Common Murres, Brandt's Cormorants, Western Gulls, and Brown Pelicans) at Devil's Slide Rock & Mainland, 2020. UAS are uncrewed aerial systems (i.e., drones). Disturbances indicate events that included alert, displaced, and flushed birds. Detection and disturbance rates are reported as numbers per observation hour.

Disturbance Source	Plane	Helicopter	UAS	Aircraft Total	Watercraft	Land-based Noise	Total
Total # of Detections	49	13	2	62	88	4	**156**
Detections/Hour	0.160	0.043	0.007	0.203	0.286	0.013	**0.508**
# of Agitation Events	10	5	0	15	3	3	**21**
# of Displacement Events	0	0	0	0	0	0	**0**
# of Flushing Events	2	4	0	6	1	0	**7**
Total Disturbed/Hour	0.039	0.029	0.000	0.069	0.013	0.013	**0.094**
Total Flushed or Displaced/Hour	0.007	0.013	0.000	0.020	0.003	0.003	**0.026**

Table 4. Total observed watercraft, aircraft, land-based sources, and resulting disturbances to seabirds (Common Murres, Brandt's Cormorants, Western Gulls, and Brown Pelicans) at Castle-Hurricane Colony Complex, 2020. UAS are uncrewed aerial systems (i.e., drones). Disturbances indicate events that included alert, displaced, and flushed birds. Detection and disturbance rates are reported as numbers per observation hour.

Disturbance Source	Plane	Helicopter	UAS	Aircraft Total	Watercraft	Total
Total # of Detections	1	1	0	2	6	**8**
Detections/Hour	0.007	0.007	0.000	0.014	0.043	**0.058**
# of Agitation Events	1	0	0	1	0	**1**
# of Displacement Events	0	0	0	0	0	**0**
# of Flushing Events	0	0	0	0	0	**0**
Total Disturbed/Hour	0.007	0.000	0.000	0.007	0.000	**0.007**
Total Flushed or Displaced/Hour	0.000	0.000	0.000	0.000	0.000	**0.000**

Table 5. Common Murre breeding phenology and reproductive success at Point Reyes Lighthouse, 2020. Means (range; n) are reported. We calculated mean hatch date using first eggs only (i.e., does not include replacement clutches). Hatching success represents the number of eggs hatched per egg laid (includes both first and replacement clutches). Fledging success represents the number of chicks fledged per egg hatched (includes both first and replacement clutches). Data that were not reported owing to COVID-19 delays are marked with a "*". See Results section for details.

Plot	Number of Sites Monitored	Number of Egg Laying Sites	Mean Lay Date	Number of Eggs Laid	Mean Hatch Date	Hatching Success	Mean Fledge Date	Fledging Success	Chicks Fledged per Pair
PRH-03-B Edge	82	*	*	*	*	*	16 July (July 7 – Aug 7; 42)	96% (44)	*
PRH-03-B Ledge	102	*	*	*	*	*	21 July (July 9 – Aug 14; 57)	91% (63)	*
Plots Combined	**190**	*	*	*	*	*	**19 July (July 7 – Aug 14; 99)**	**93% (107)**	*

Table 6. Common Murre breeding phenology and reproductive success at Devil's Slide Rock & Mainland, 2020. Plots A, B, and D are on Devil's Slide Rock, and DSRM-05-A is located on the mainland. Means (range; n) are reported. We calculated mean hatch date using first eggs only (i.e., does not include replacement clutches). Hatching success represents the number of eggs hatched per egg laid (includes both first and replacement clutches). Fledging success represents the number of chicks fledged per egg hatched (includes both first and replacement clutches). Data that were not reported owing to COVID-19 delays are marked with a "*". See Results section for details.

Plot	Number of Sites Monitored	Number of Egg Laying Sites	Mean Lay Date	Number of Eggs Laid	Mean Hatch Date	Hatching Success	Mean Fledge Date	Fledging Success	Chicks Fledged per Pair
DSRM-01-Plot A	109	94	4 June (May 25 – June 28; 66)	94	4 July (June 26 – July 22; 69)	92% (88)	27 July (July 22 – Aug 2; 70)	88% (80)	0.75 (93)
DSRM-01-Plot B	87	78	31 May (May 19 – June 12; 51)	78	2 July (June 20 – July 11; 50)	96% (75)	27 July (July 19 – Aug 5; 62)	90% (70)	0.83 (76)
DSRM-01-Plot D	26	19	5 June (May 27 – June 14; 9)	19	7 July (June 28 – July 15; 8)	77% (17)	29 July (July 29 – Aug 2; 6)	69% (13)	0.47 (19)
DSR Plots Combined	**222**	**191**	**3 June (May 19 – June 28; 126)**	**191**	**3 July (June 20 – July 22; 127)**	**92% (180)**	**27 July (July 19 – Aug 5; 138)**	**87% (163)**	**0.76 (188)**
DSRM-05-A	88	79	2 June (May 21 – June 29; 46)	81	5 July (June 21 – July 31; 45)	80% (76)	29 July (July 16 – Aug 15; 53	87% (61)	0.65 (81)
DSRM-05-B	12	5	17 June (June 8 – July 2; 3)	5	12 July (July 10 – July 15; 2)	67% (3)	5 August (Aug 5 – Aug 5; 2)	100% (2)	0.40 (5)
DSM Plots Combined	**100**	**84**	**3 June (May 21 – July 2; 49)**	**86**	**6 July (June 21 – July 31; 47)**	**80% (79)**	**29 July (July 16 – Aug 15; 55)**	**87% (63)**	**0.64 (86)**

Table 7. Common Murre breeding phenology and reproductive success at Castle Rocks and Mainland, 2020. Means (range; n) are reported. We calculated mean hatch date using first eggs only (i.e., does not include replacement clutches). Hatching success represents the number of eggs hatched per egg laid (includes both first and replacement clutches). Fledging success represents the number of chicks fledged per egg hatched (includes both first and replacement clutches). Data that were not reported owing to COVID-19 delays are marked with a "*". See Results section for details.

Plot	Number of Sites Monitored	Number of Egg Laying Sites	Mean Lay Date	Number of Eggs Laid	Mean Hatch Date	Hatching Success	Mean Fledge Date	Fledging Success	Chicks Fledged per Pair
CRM-04	91	*	*	*	*	*	9 July (July 4 – July 15)	82% (49)	*

Table 8. High counts of nests and breeding birds from land-based surveys for Brandt's Cormorants, Pelagic Cormorants, Western Gulls, and Black Oystercatchers, 2020. Counts for Brandt's Cormorants, Pelagic Cormorants, Western Gulls, and Black Oystercatchers are the sum of high season nest counts. Pigeon Guillemot counts reported are for bird (not nest) peak counts only and as Land/Water counts. A dash indicates no survey was conducted.

Colony	Brandt's Cormorant	Pelagic Cormorant	Western Gull	Black Oystercatcher	Pigeon Guillemot
Point Reyes Headlands	256	10	33	1	33[1]
Bird Island	0	0	9	-	-
Devil's Slide Rock & Mainland	197	15	6	0	79
Bench Mark-227X	132	0	6	0	14
Castle Rocks & Mainland	42	10	6	1	5
Hurricane Point Rocks	2	0	5	1	14

[1] Survey area includes only the area around the lighthouse, not the entire headlands. See Methods for more detail.

Table 9. Brandt's Cormorant breeding phenology and reproductive success from monitored areas at Point Reyes Headlands, 2020. Means are reported (range; n). Clutch initiation date includes first clutches only. Breeding success includes replacement clutches. Breeding success per nest represents the proportion of egg-laying nests that fledged at least one chick. Data that were not reported due to COVID-19 delays are marked with a "*". See Results section for details.

Colony or Subcolony	Number Breeding Sites	Clutch Initiation Date	Clutch Size	Breeding Success	Number Chicks Fledged/Pair	Breeding Success/ Nest	Fledging Success
Arch Rock (PRH-11-D)	14	*	3.10	100% (3)	3.00 (3-3; 2)	1.00 (2)	100% (3)
Cone Shoulder (PRH-13-CS)	5	*	2.00	67% (12)	2.00 (0-4; 4)	0.75 (4)	83% (5)
Cone Upper (PRH-13-CU)	50	*	2.78	69% (88)	2.04 (0-3; 49)	0.98 (49)	80% (109)
West Cone (PRH-13-WC)	3	*	3.00	50% (6)	1.67 (1-2; 3)	1.00 (3)	58% (5)
Area B Mainland (PRH-14-E)	2	*	2.00	100% (2)	2.00 (2-2; 2)	1.00 (2)	100 % (2)
Point Reyes Total	**74**	*	**2.83**	**69% (111)**	**2.05 (0-4; 60)**	**0.97 (60)**	**81% (124)**

Table 10. Brandt's Cormorant breeding phenology and reproductive success from monitored areas at Devil's Slide Rock & Mainland, 2020. Means are reported (range; n). Clutch initiation date includes first clutches only. Breeding success includes replacement clutches. Breeding success per nest represents the proportion of egg-laying nests that fledged at least one chick. Data that were not reported due to COVID-19 delays are marked with a "*". See Results section for details.

Colony or Subcolony	Number Breeding Sites	Clutch Initiation Date	Clutch Size	Breeding Success	Number of Chicks Fledged/Pair	Breeding Success/ Nest	Fledging Success
DSRM-05-A-Roost	5	*	*	80% (12)	2 (0-3; 5)	0.80 (5)	100% (10)
DSRM-05-A-Upper	9	*	3.00	89% (22)	2.11 (0-3; 9)	0.89 (9)	100% (19)
DSRM-05-A-Lower	84	*	2.79	57% (234)	1.56 (0-3; 84)	0.77 (84)	85% (153)
DSRM-05-B	50	*	2.73	60% (131)	1.60 (0-4; 50)	0.78 (50)	89% (88)
DSRM Combined	**148**	*	**2.77**	**61% (399)**	**1.62 (0-4; 148)**	**0.78 (148)**	**88% (270)**

Table 11. Brandt's Cormorant breeding phenology and reproductive success from monitored areas at Castle Rocks & Mainland, 2020. Means are reported (range; n). Clutch initiation date includes first clutches only. Breeding success includes replacement clutches. Breeding success per nest represents the proportion of egg-laying nests that fledged at least one chick. Data that were not reported due to COVID-19 delays are marked with a "*". See Results section for details.

Colony or Subcolony	Number Breeding Sites	Clutch Initiation Date	Clutch Size	Breeding Success	Number of Chicks Fledged/Pair	Breeding Success/ Nest	Fledging Success
CRM-03A	17	*	*	68% (42)	1.76 (0-3; 17)	0.82 (17)	85% (36)
CRM-03-B	21	*	*	45% (44)	1.10 (0-3; 20)	0.55 (20)	79% (28)
Castle Rocks & Mainland Total	**38**	*	*	**56% (86)**	**1.41 (0-3; 37)**	**0.68 (37)**	**82% (64)**

Table 12. Productivity of Pelagic Cormorants and Western Gulls at Devil's Slide Rock & Mainland (DSRM) and Castle Rocks and Mainland (CRM), 2020. Means (range; n) or (n) are reported. Breeding success per nest represents the proportion of egg-laying nests that fledged at least one chick.

Species	Pelagic Cormorant (DSRM)	Western Gull (DSRM)	Pelagic Cormorant (CRM)
Number Breeding Sites	11	6	8
Number Chicks Fledged	5	2	17
Number of Chicks Fledged/Pair (Productivity)	0.50 (0-2; 10)	0.40 (0-1; 5)	2.12 (0-3; 8)
Breeding Success/Nest	0.30 (10)	0.40 (5)	0.88 (8)

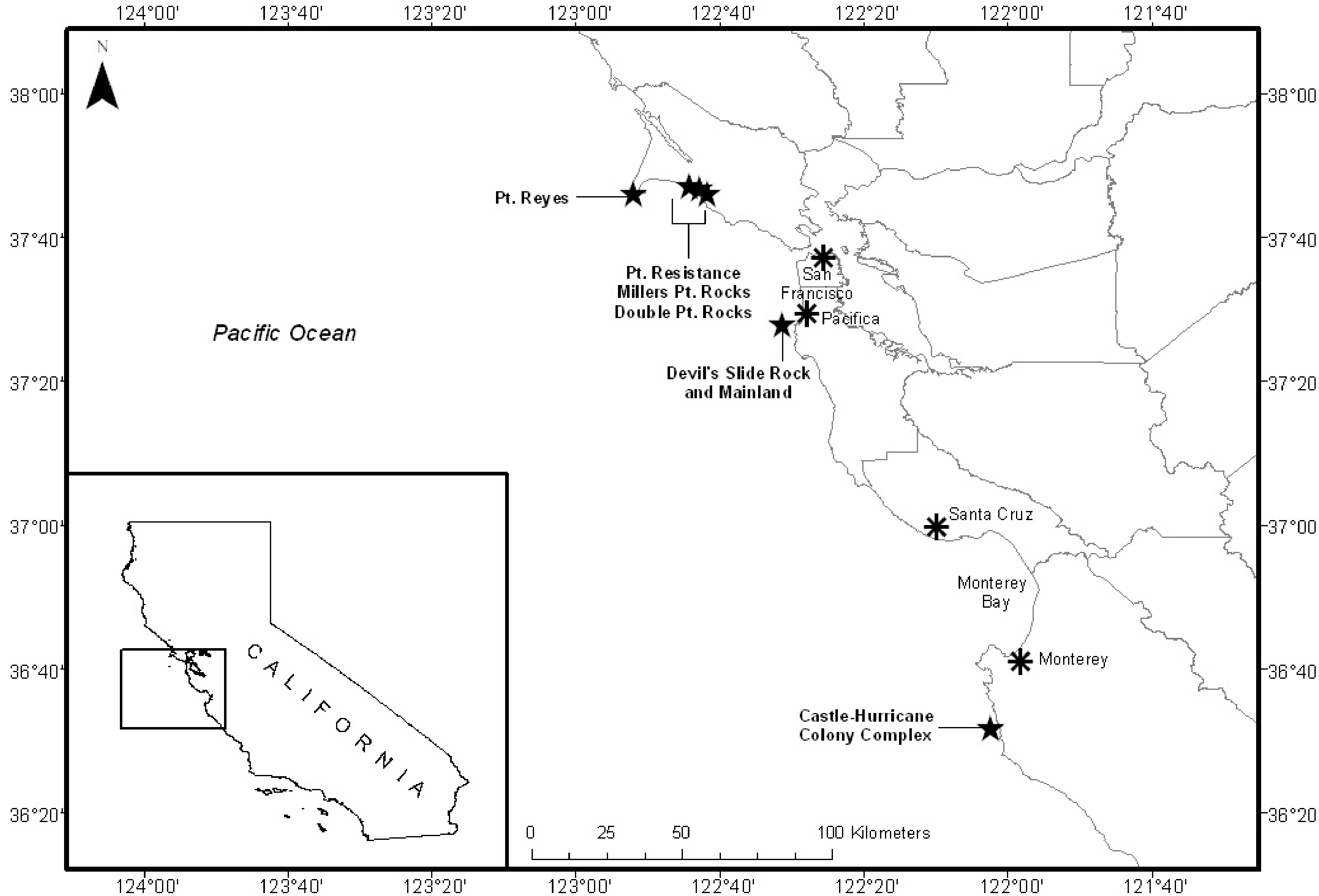


Figure 1. Study area, showing locations of study colonies or colony complexes along the Central California coast where we monitored seabird disturbance, attendance, and reproductive success. Pt. Resistance, Miller's Pt., and Double Pt. were not monitored in 2020.

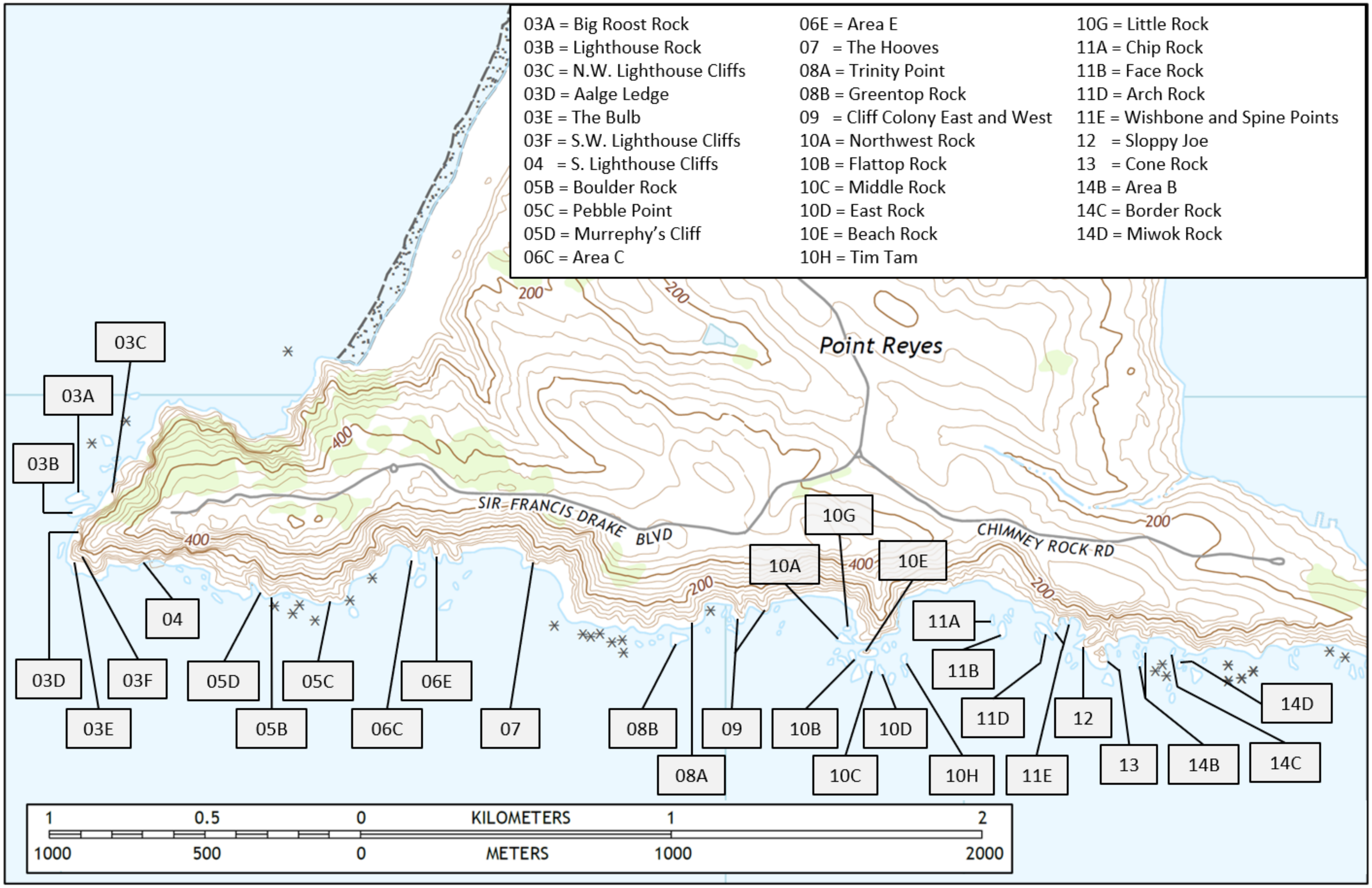


Figure 2. Point Reyes Headlands, including subcolonies 03A through 14D.

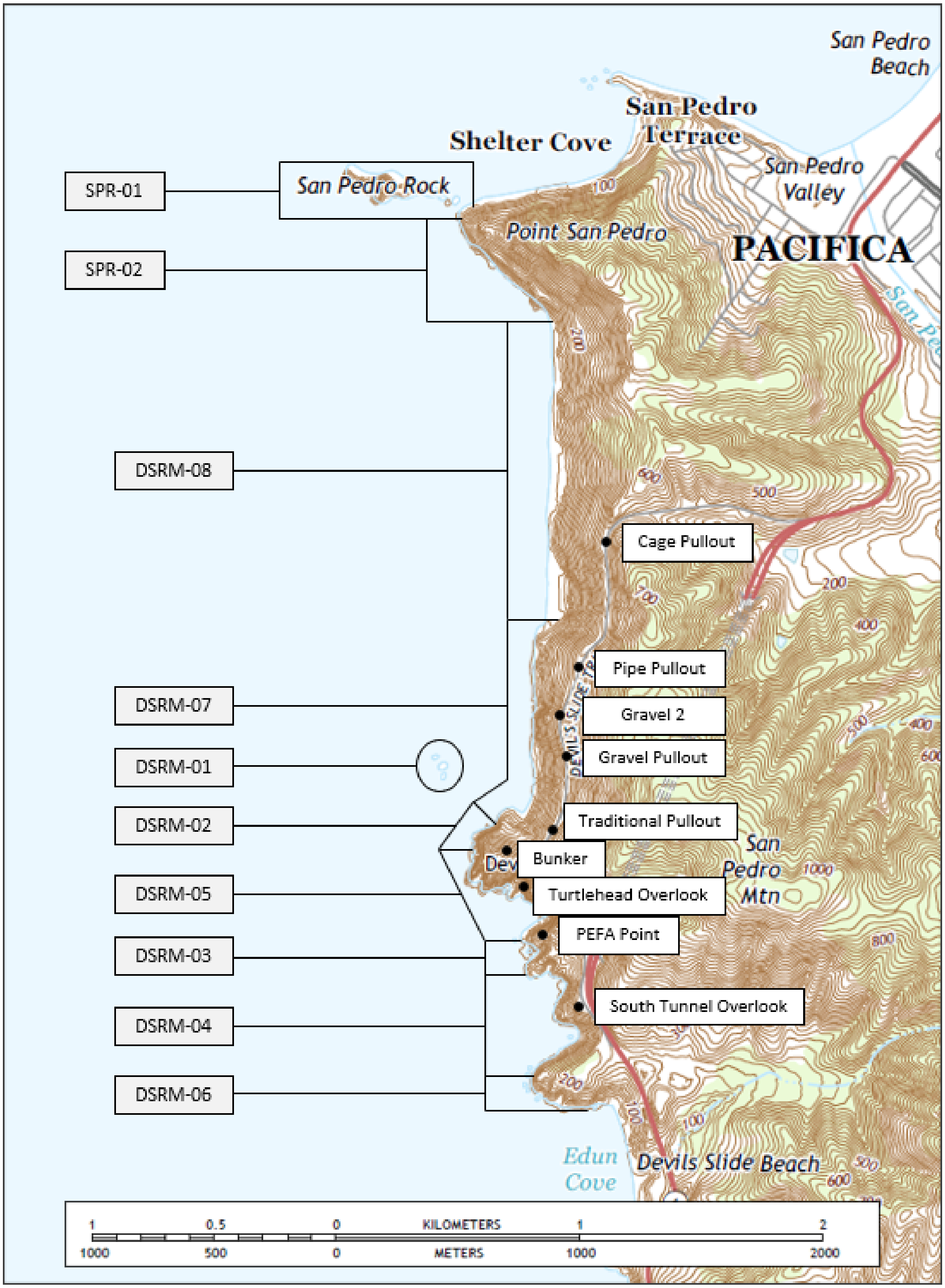


Figure 3. Devil's Slide Colony Complex, including San Pedro Rock and the colonies and subcolonies of Devil's Slide Rock & Mainland.

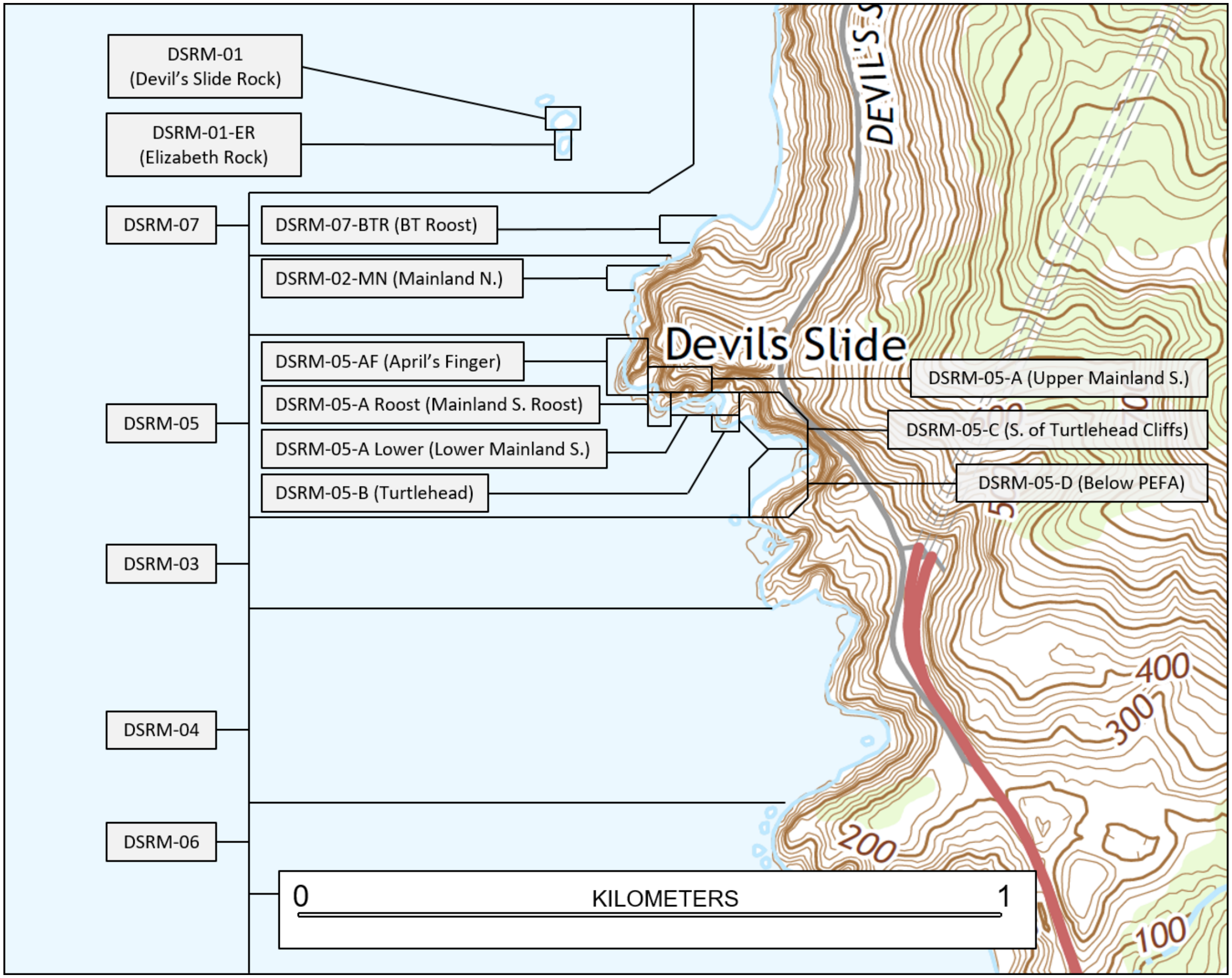


Figure 4. Detailed view of Devil's Slide Rock & Mainland (DSRM) subcolonies.

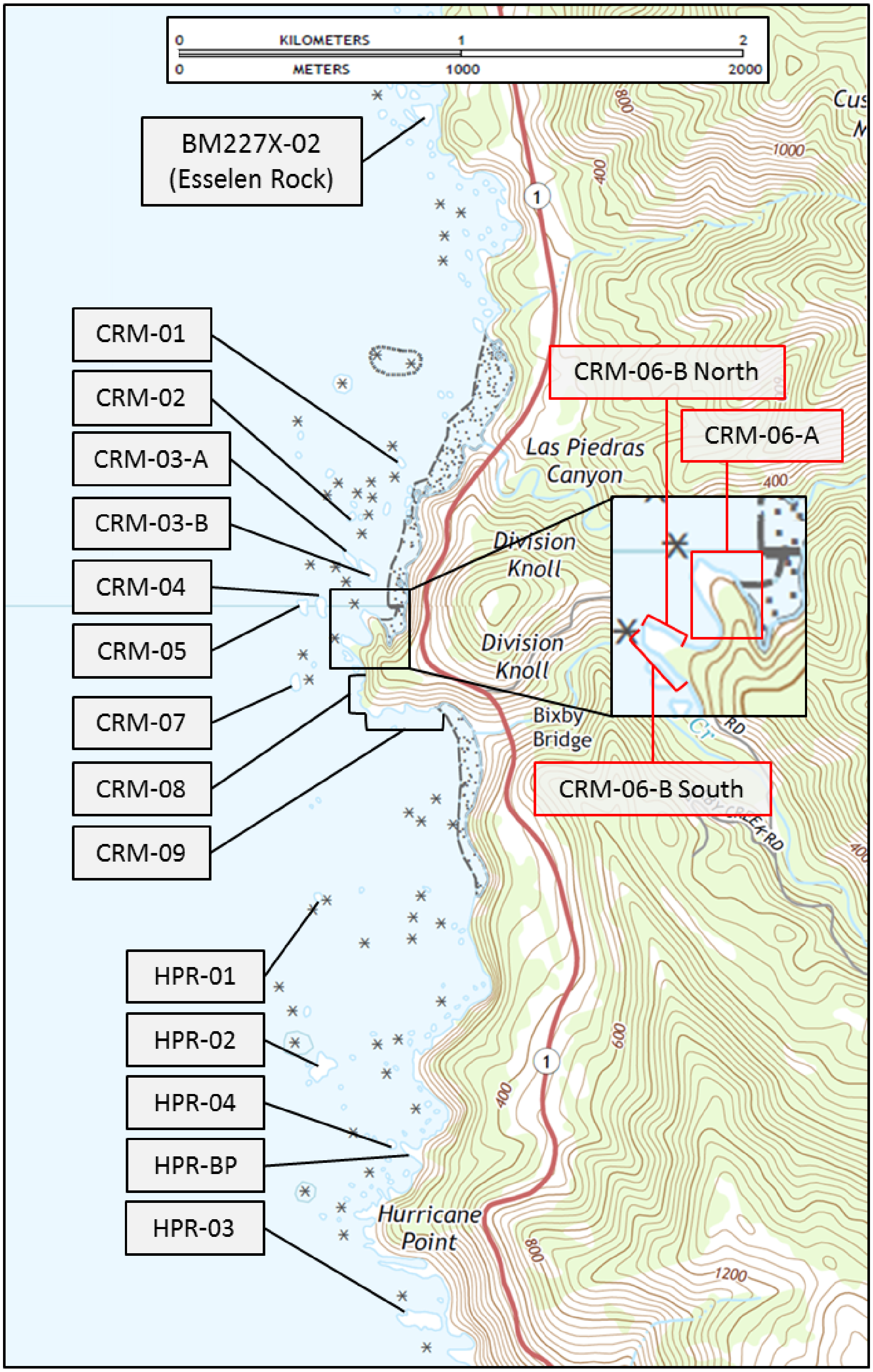


Figure 5. Castle-Hurricane Colony Complex, including Bench Mark-227X (BM227X), Castle Rocks and Mainland (CRM), and Hurricane Point Rocks (Hurricane) colonies and subcolonies.

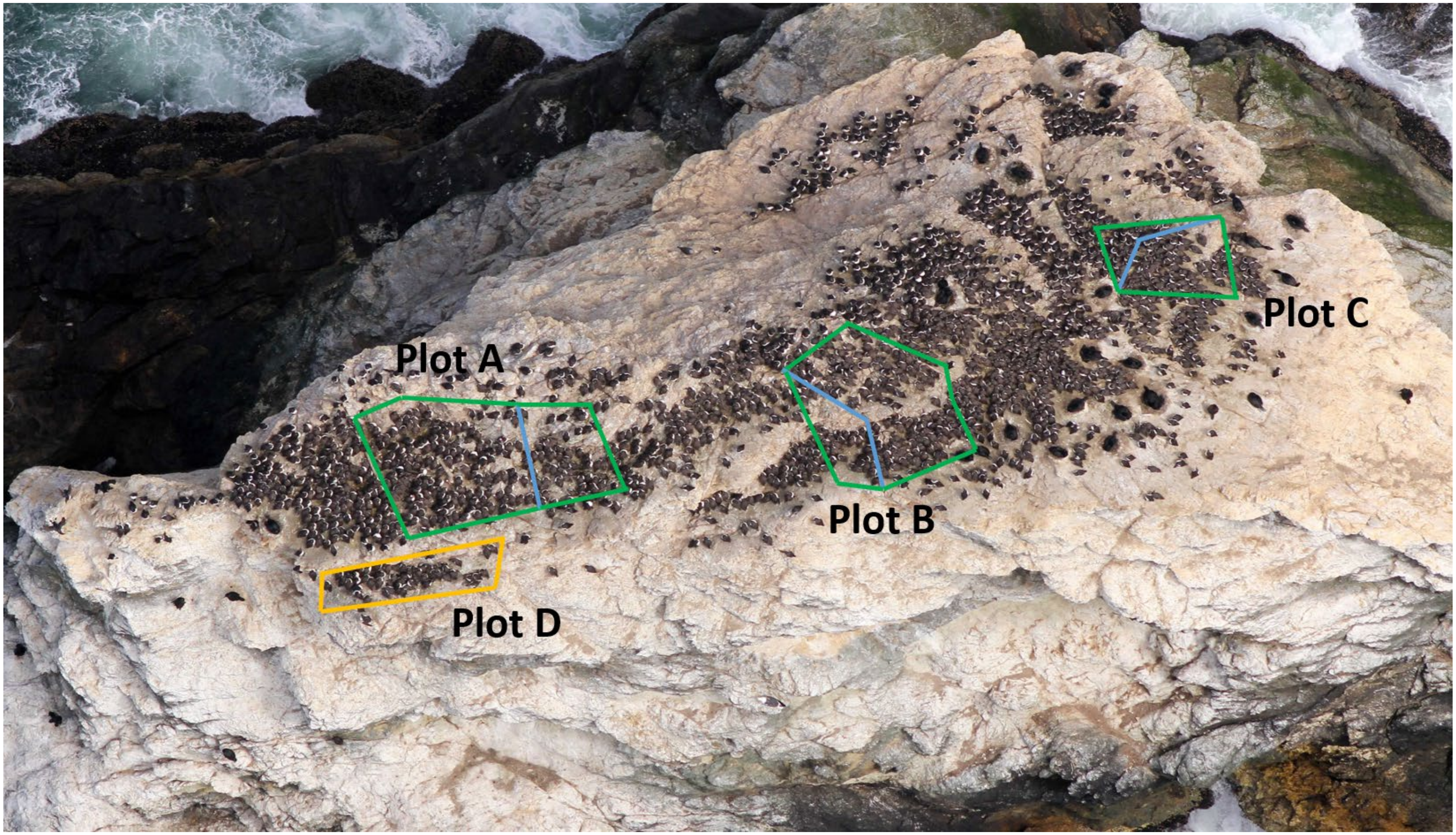


Figure 6. Aerial view (from the south) of Common Murre plot boundaries used on Devil's Slide Rock from 2006-2020. Green polygons show plot boundaries for the 2006 season, blue boundaries show adjustments made to Plots A, B, and C for 2007 and subsequent seasons (productivity was followed in remaining larger sections only). Plot C was no longer followed beginning in 2014, and Plot D was added for the 2015 and subsequent seasons.

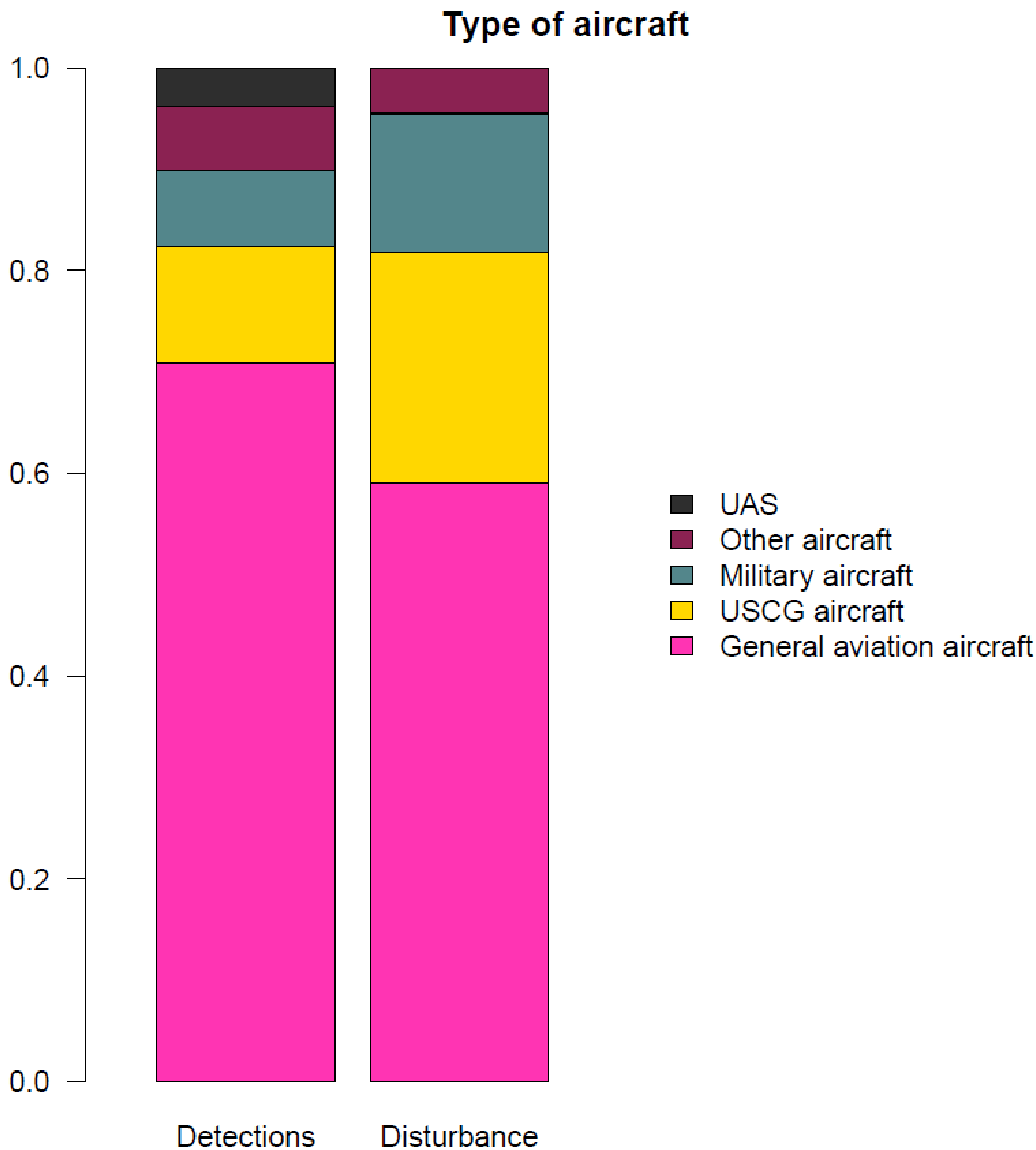


Figure 7. Aircraft detections (n = 79) and disturbances (n = 22) at Point Reyes Headlands, Devil's Slide Rock & Mainland, and Castle-Hurricane Colony Complex combined in 2020, categorized by type. "UAS" indicates an uncrewed aerial system (i.e., drone).

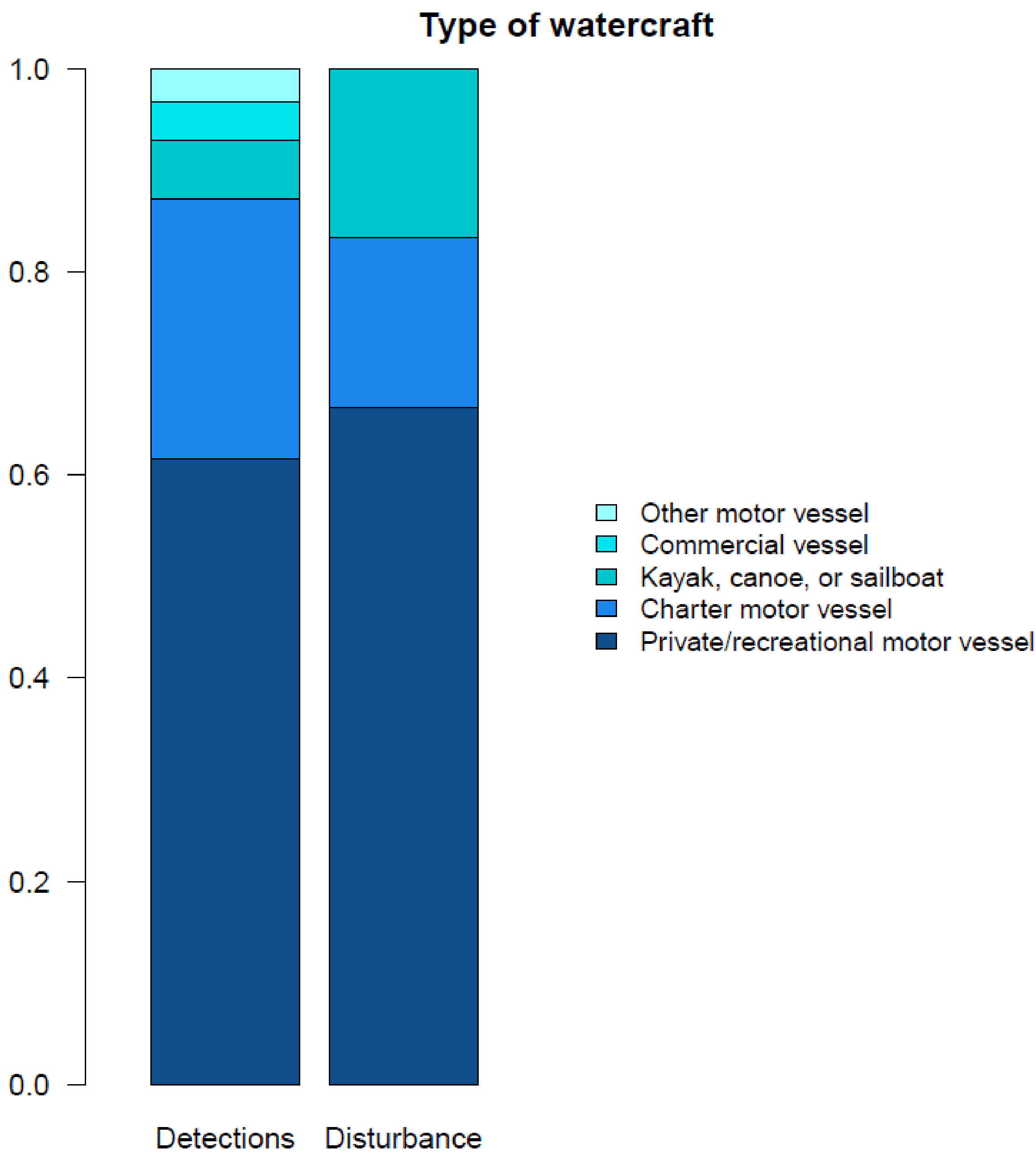


Figure 8. Watercraft detections (n = 156) and disturbances (n = 6) at Point Reyes Headlands, Devil's Slide Rock & Mainland, and Castle-Hurricane Colony Complex combined in 2020, categorized by type.

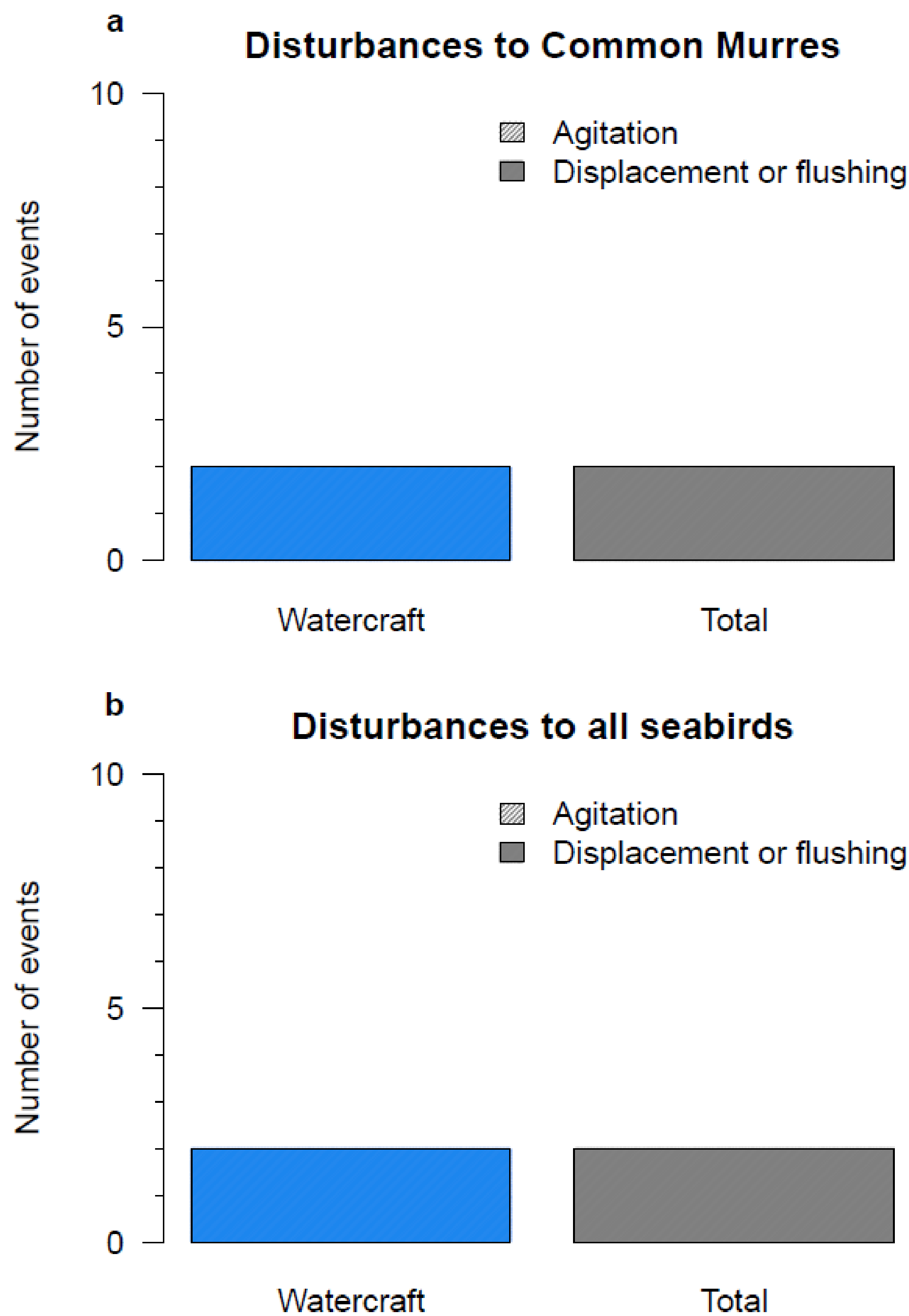


Figure 9. Number of disturbance events from anthropogenic sources to (a) Common Murres and (b) total seabirds disturbed (agitated, displaced and/or flushed) at Point Reyes Headlands, 2020. Both disturbance events were caused by watercraft.

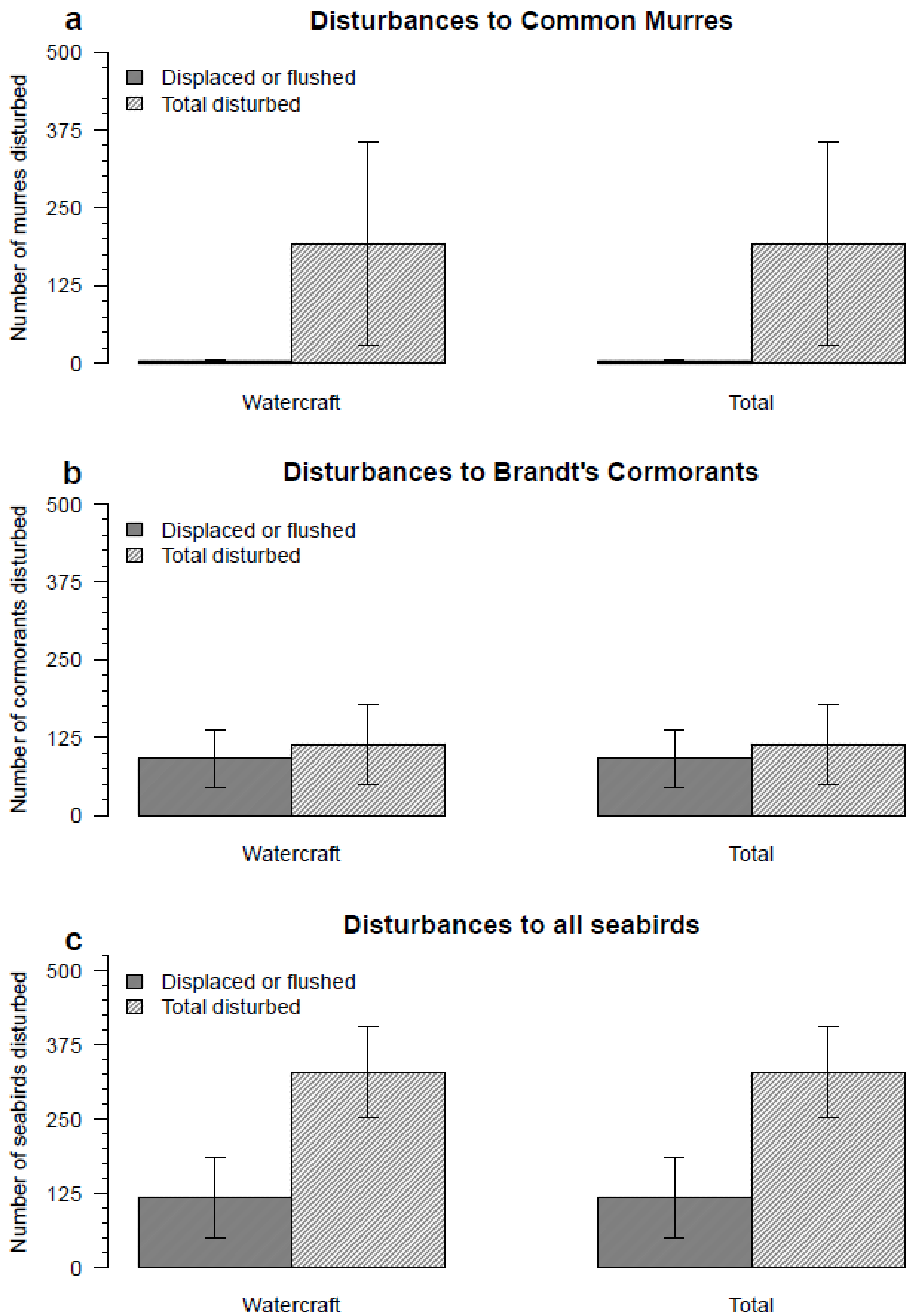


Figure 10. Mean number of (a) Common Murres, (b) Brandt's Cormorants, and (c) total seabirds disturbed (agitated, displaced and/or flushed) by anthropogenic sources at Point Reyes Headlands, 2020. Error bars indicate ranges.

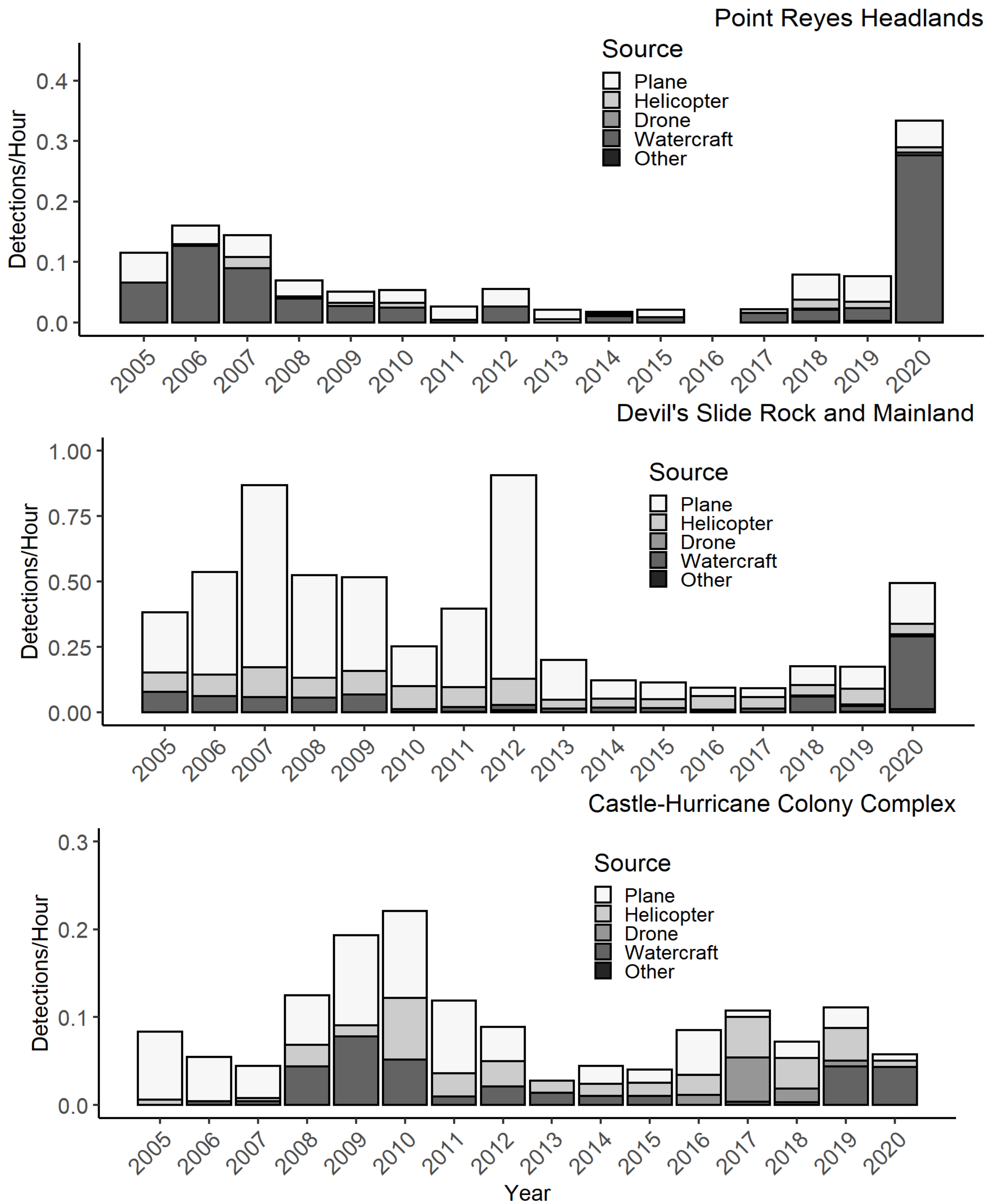


Figure 11. Detection rates (number of detections per observation hour) of watercraft, helicopters, planes, drones, and other anthropogenic sources at Point Reyes Headlands, Devil's Slide Rock & Mainland, and Castle-Hurricane Colony Complex, 2005-2020. Note different scales between graphs. Point Reyes Headlands was not monitored in 2016.

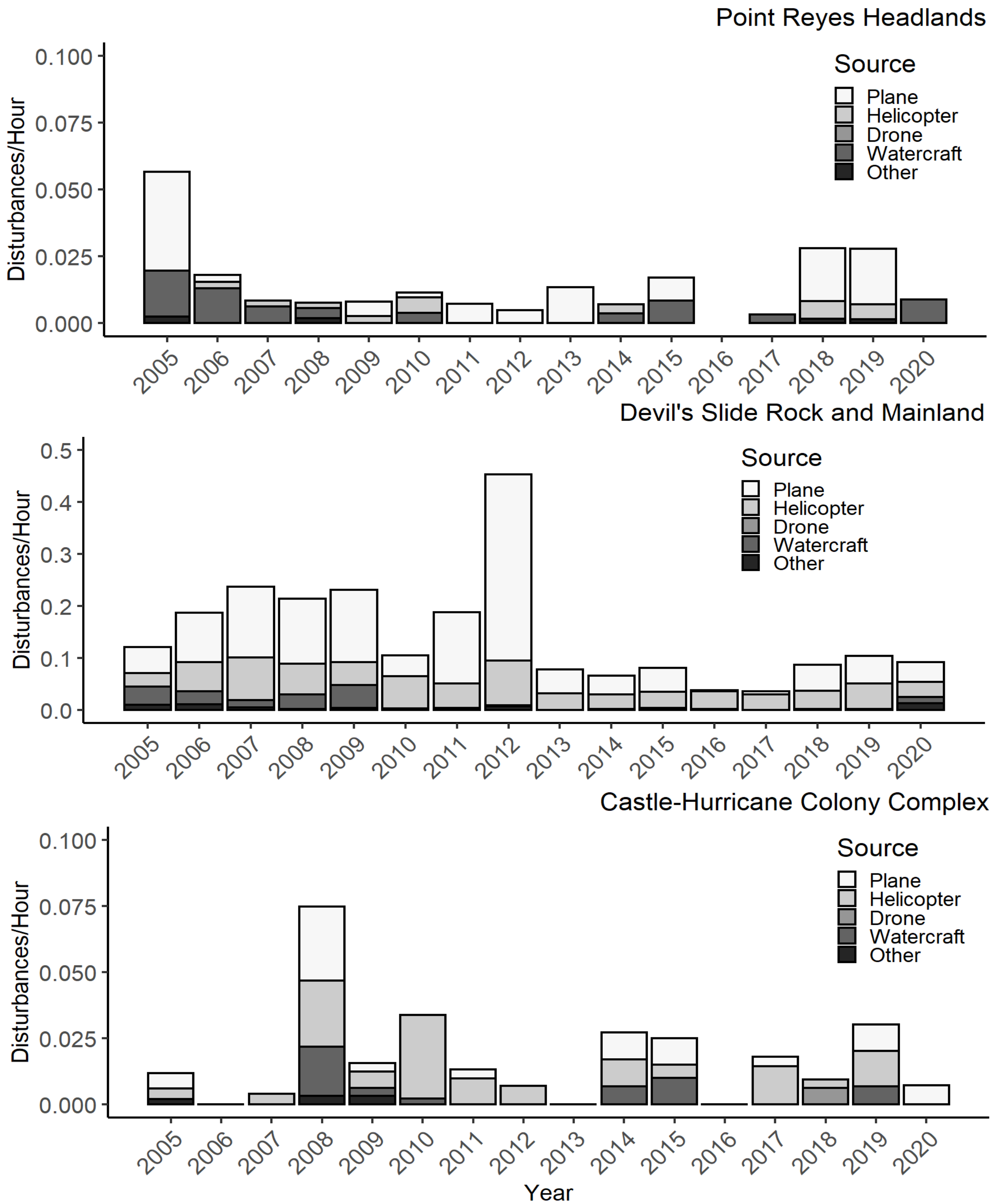


Figure 12. Disturbance rates (number of disturbances per observation hour) of watercraft, helicopters, planes, drones, and other anthropogenic sources at Point Reyes Headlands, Devil's Slide Rock & Mainland, and Castle-Hurricane Colony Complex, 2005-2020. Note different scales between graphs. Point Reyes Headlands was not monitored in 2016.

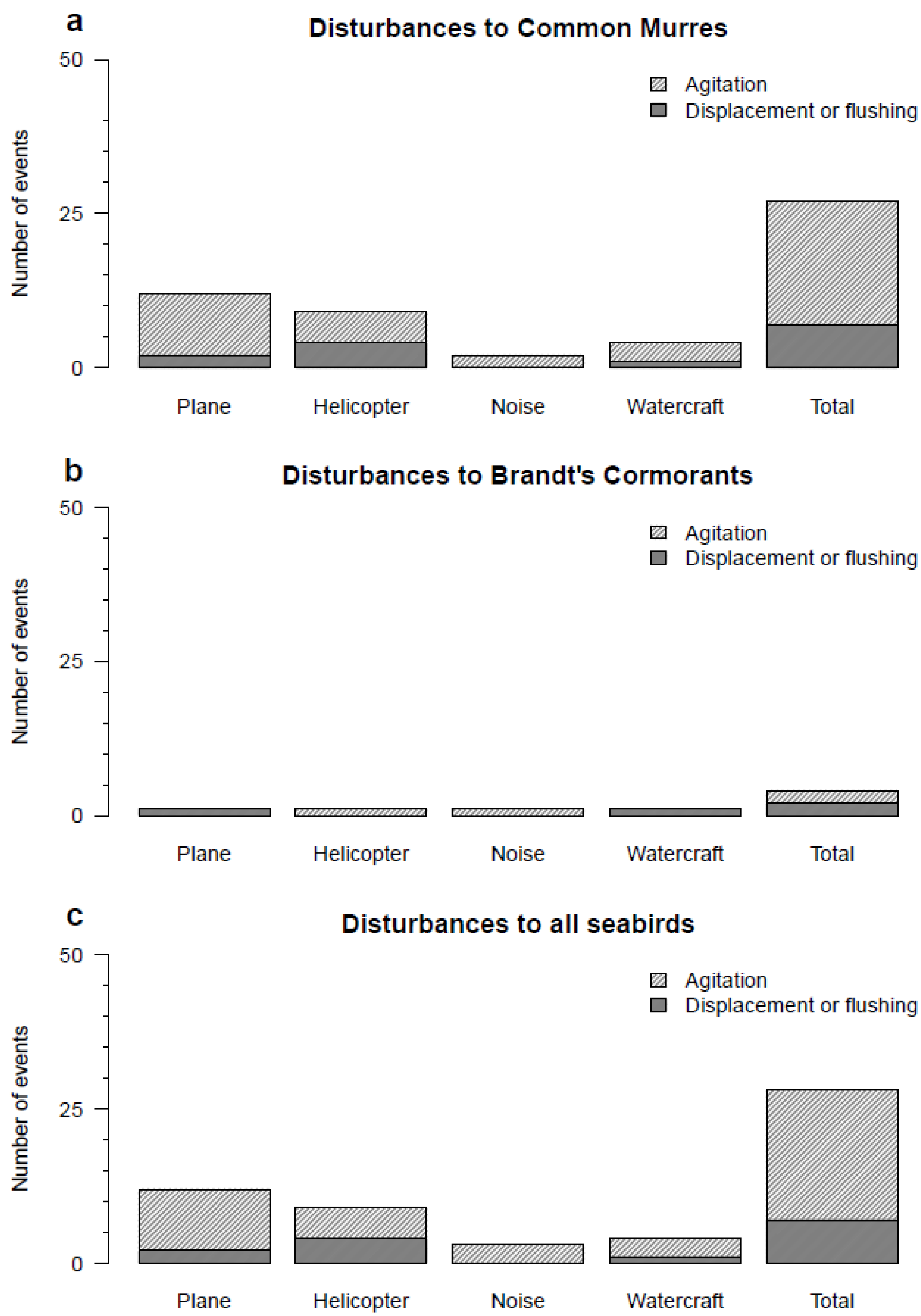


Figure 13. Number of disturbance events from anthropogenic sources of (a) Common Murres and (b) total seabirds disturbed (agitated, displaced and/or flushed) at Devil's Slide Rock & Mainland, 2020.

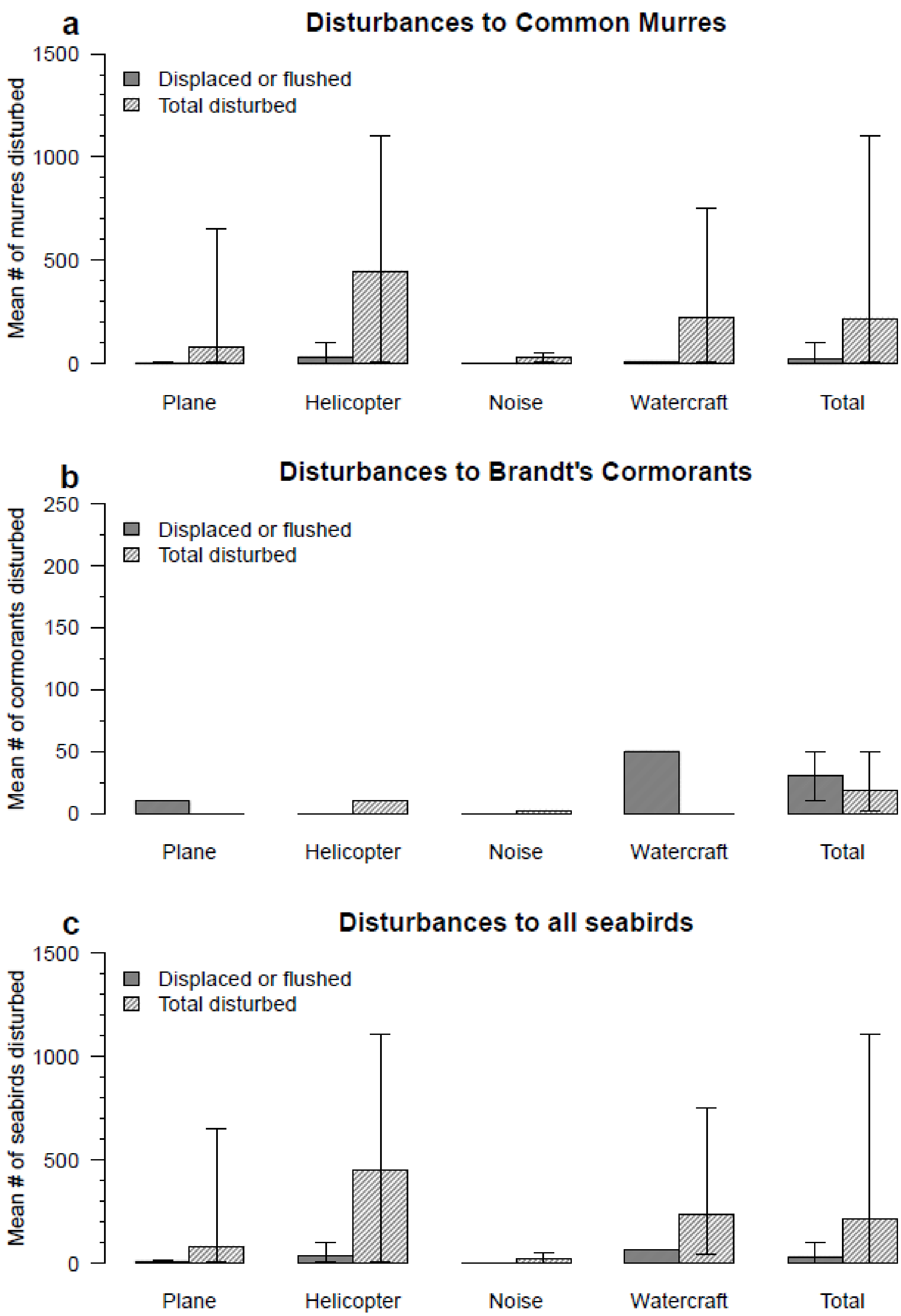


Figure 14. Mean number of (a) Common Murres, (b) Brandt's Cormorants, and (c) total seabirds disturbed (agitated, displaced and/or flushed) by anthropogenic sources at Devil's Slide Rock & Mainland, 2020. Error bars indicate ranges.

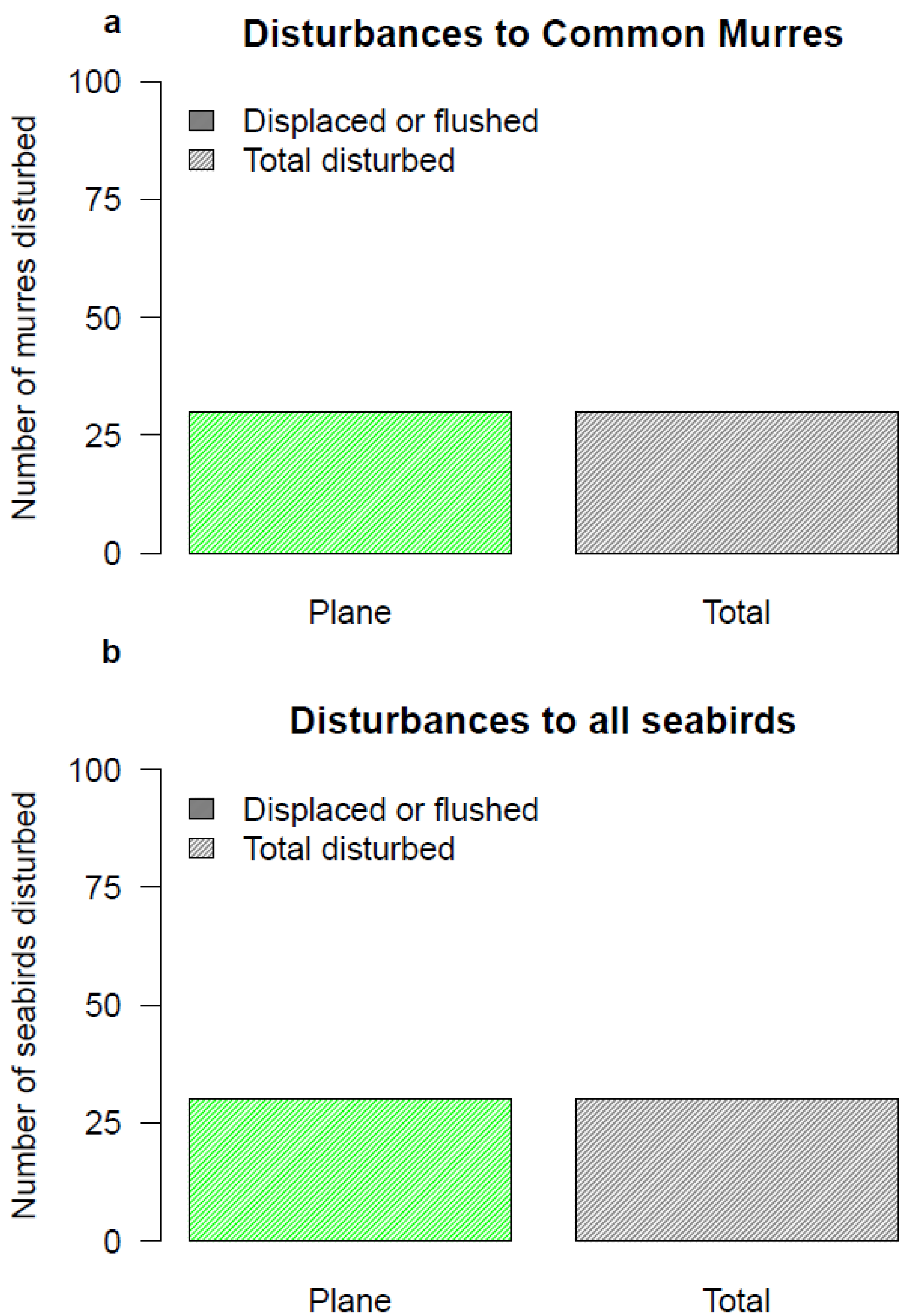


Figure 15. Mean number of (a) Common Murres and (b) total seabirds disturbed (agitated, displaced and/or flushed) by anthropogenic sources at Castle-Hurricane Colony Complex, 2020. Only one disturbance event was observed, which caused only agitation.

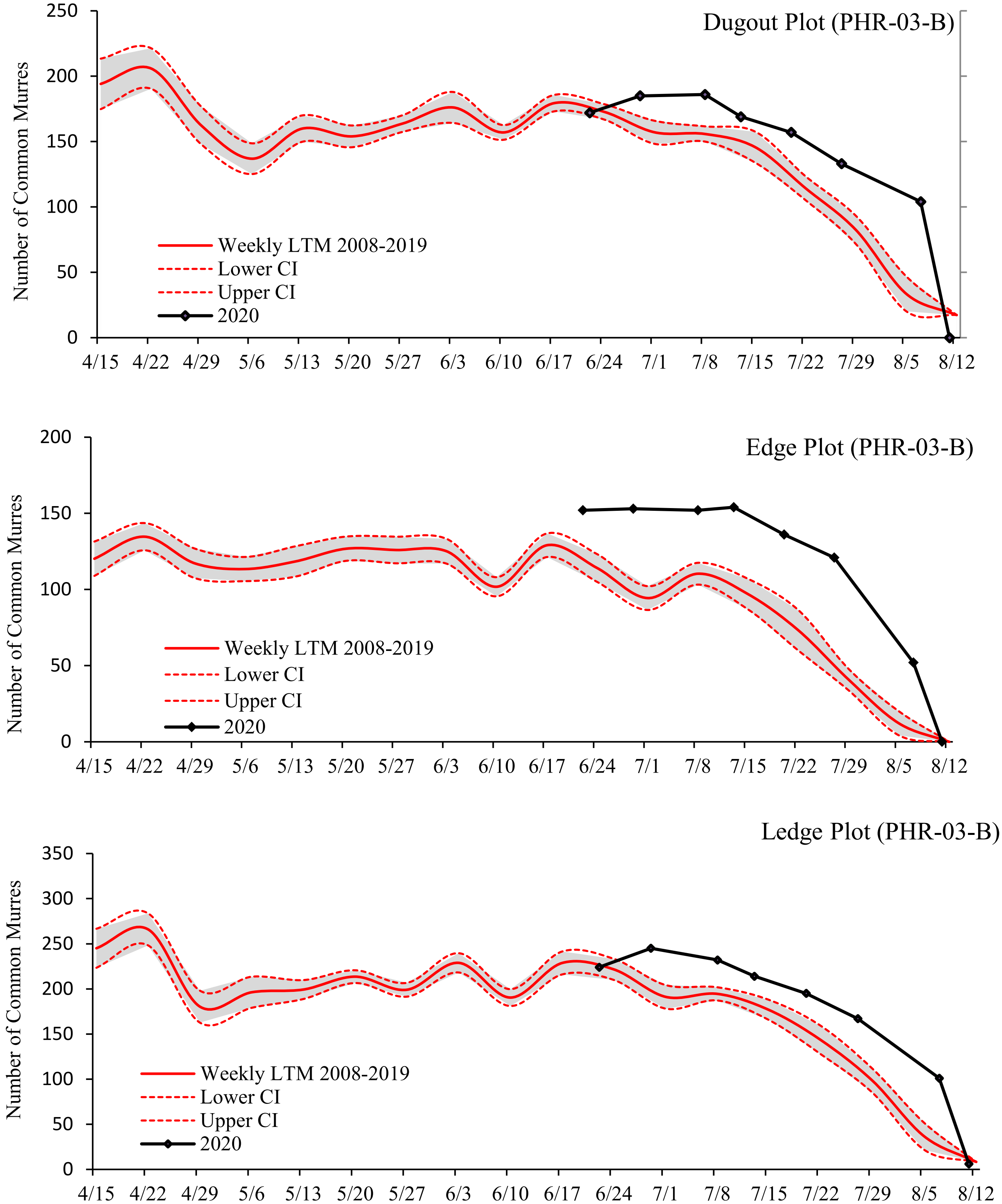
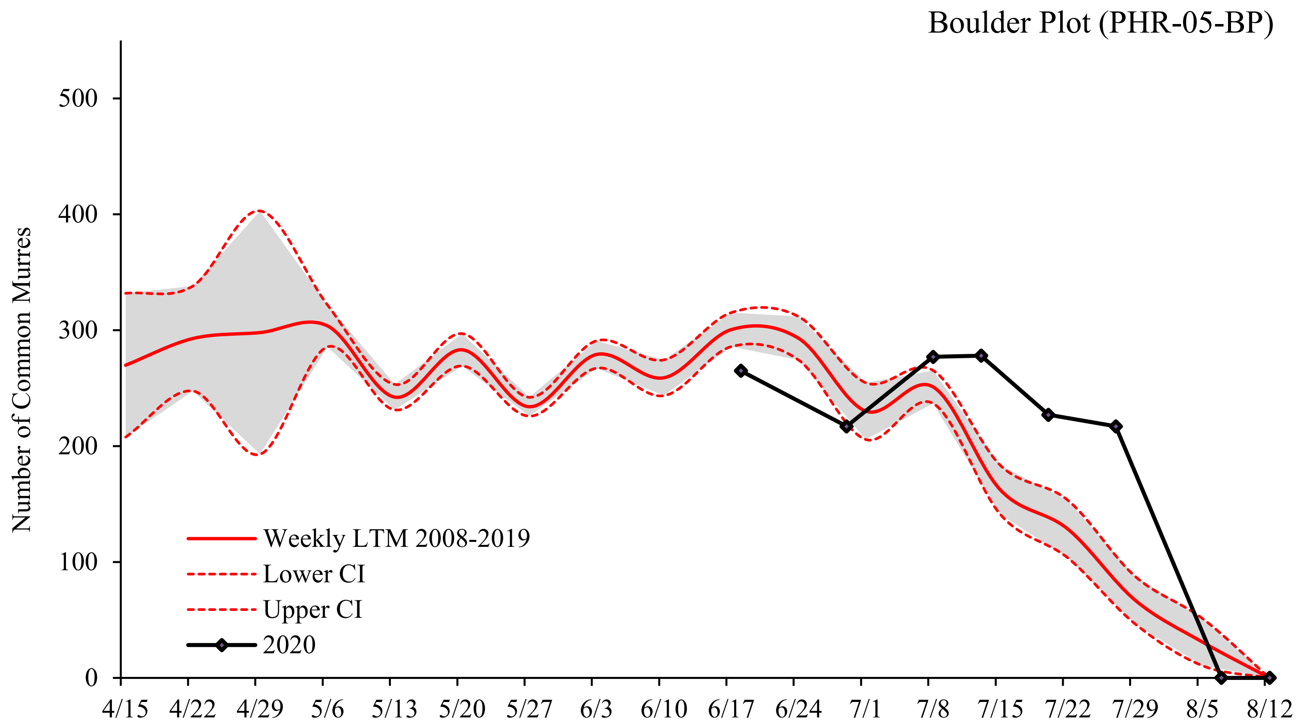


Figure 16. Seasonal attendance of Common Murres at Point Reyes Headlands Lighthouse Rock plots (PRH-03-B; three plots) in 2020 compared to long-term mean (LTM, 2008-2019).



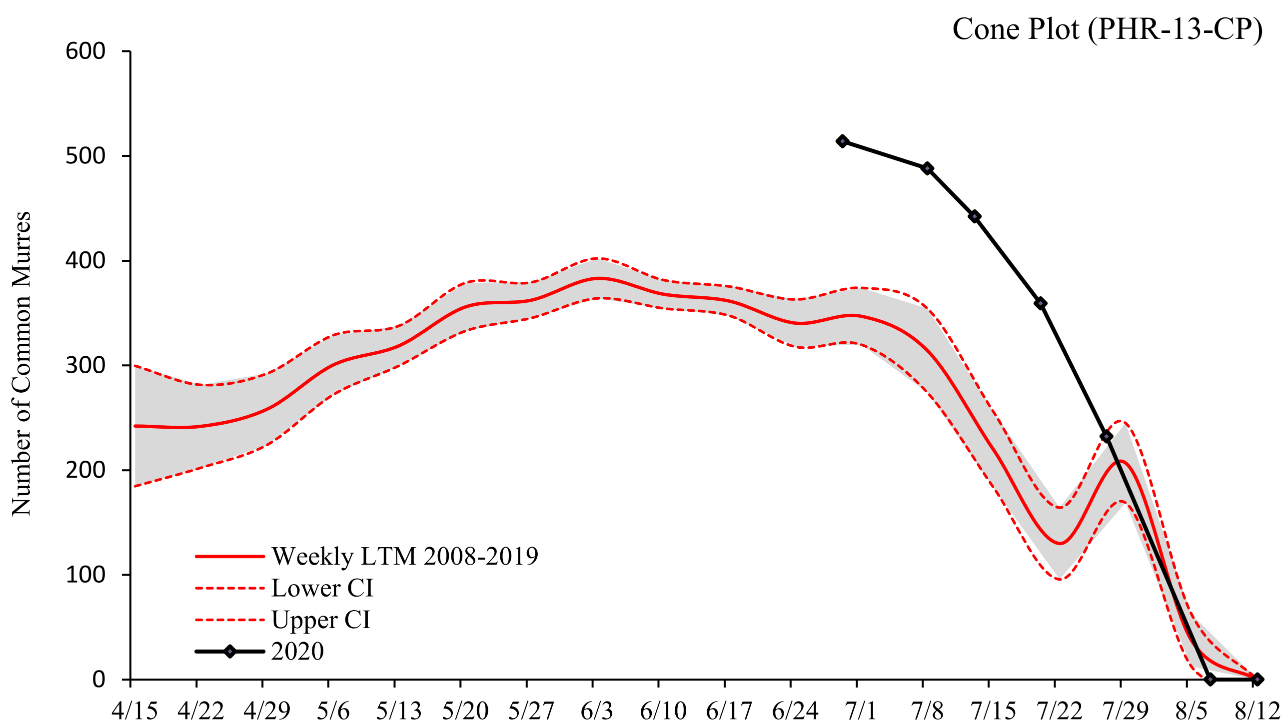


Figure 17. Seasonal attendance of Common Murres at Point Reyes Headlands plots on Boulder and Cone Rocks (subcolonies: PRH-05-BP and PRH-13-CP) in 2020 compared to the long-term mean (LTM, 2008-2019).

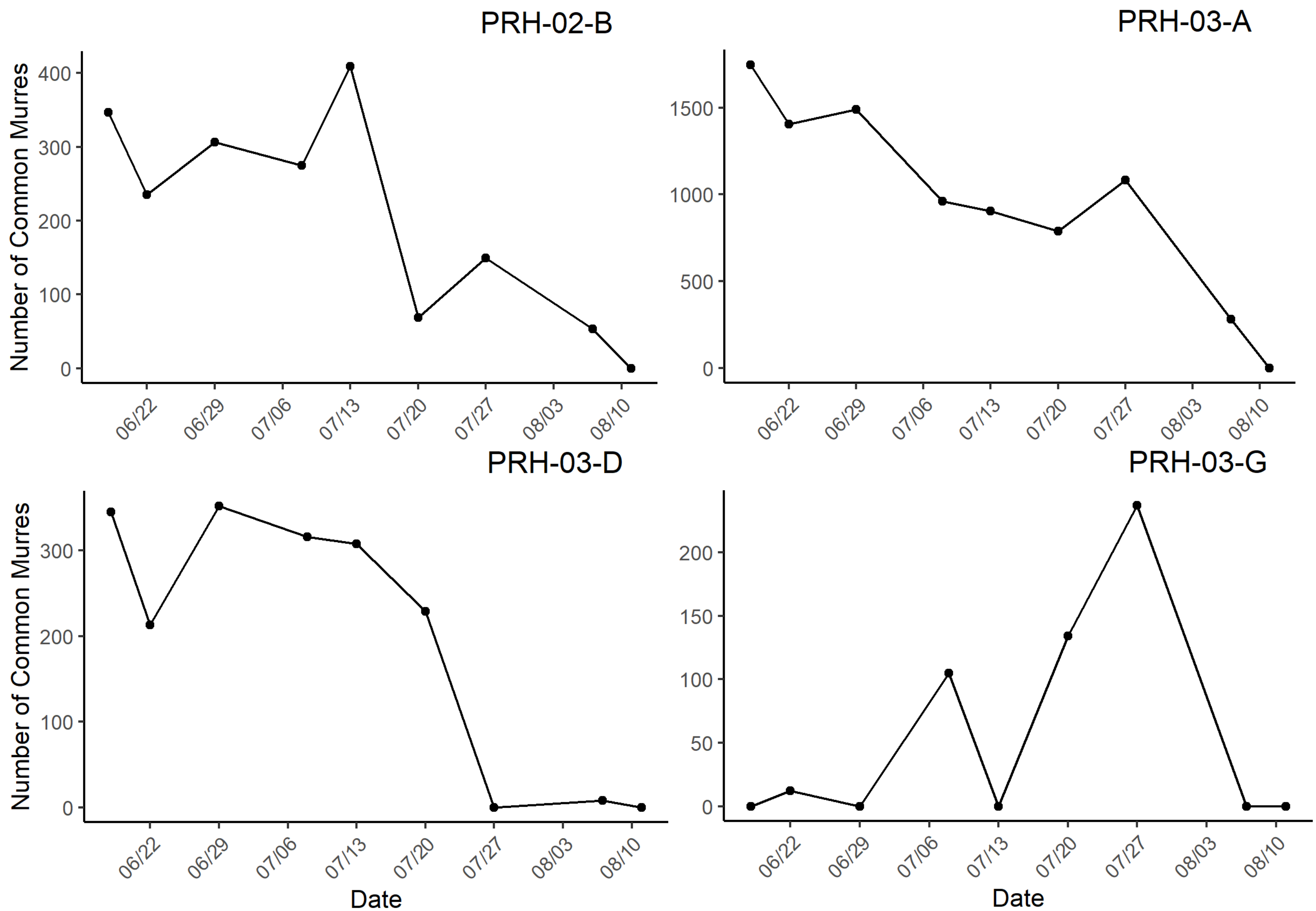


Figure 18. Seasonal attendance of Common Murres at Point Reyes Headlands (subcolonies: PRH-02-B (Rock 2), PRH-03-A (Big Roost Rock), PRH-03-D (Aalgae Ledge), and PRH-03-G (Levin's Rock)) from 18 June to 11 August, 2020.

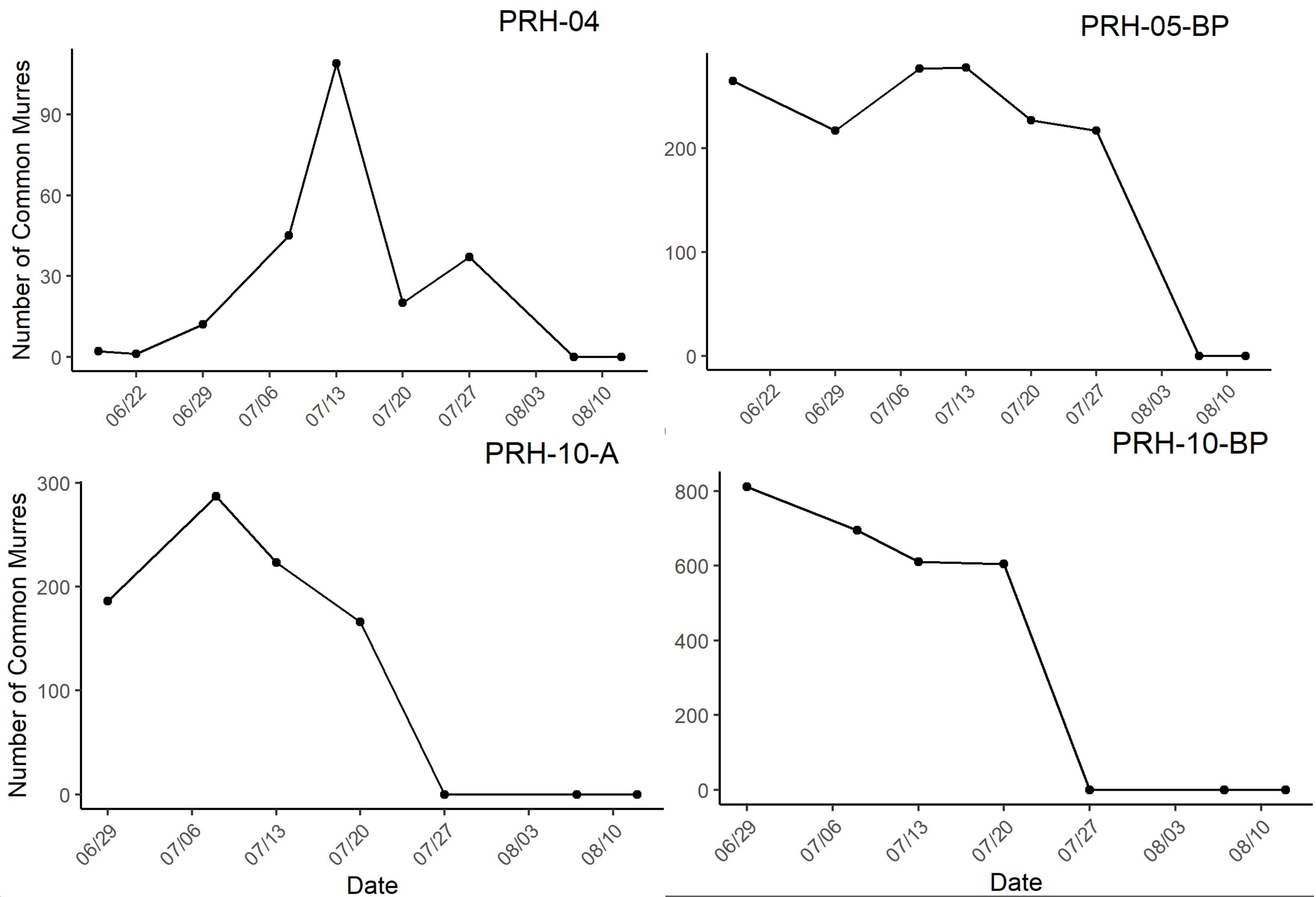


Figure 19. Seasonal attendance of Common Murres at Point Reyes Headlands (subcolonies: PRH-04 (S. Lighthouse Cliffs), PRH-05-BP (Boulder Rock Plot), PRH-10-A (Northwest Rock), and PRH-10-BP (Flattop Rock Plot)) from 18 June to 12 August, 2020.

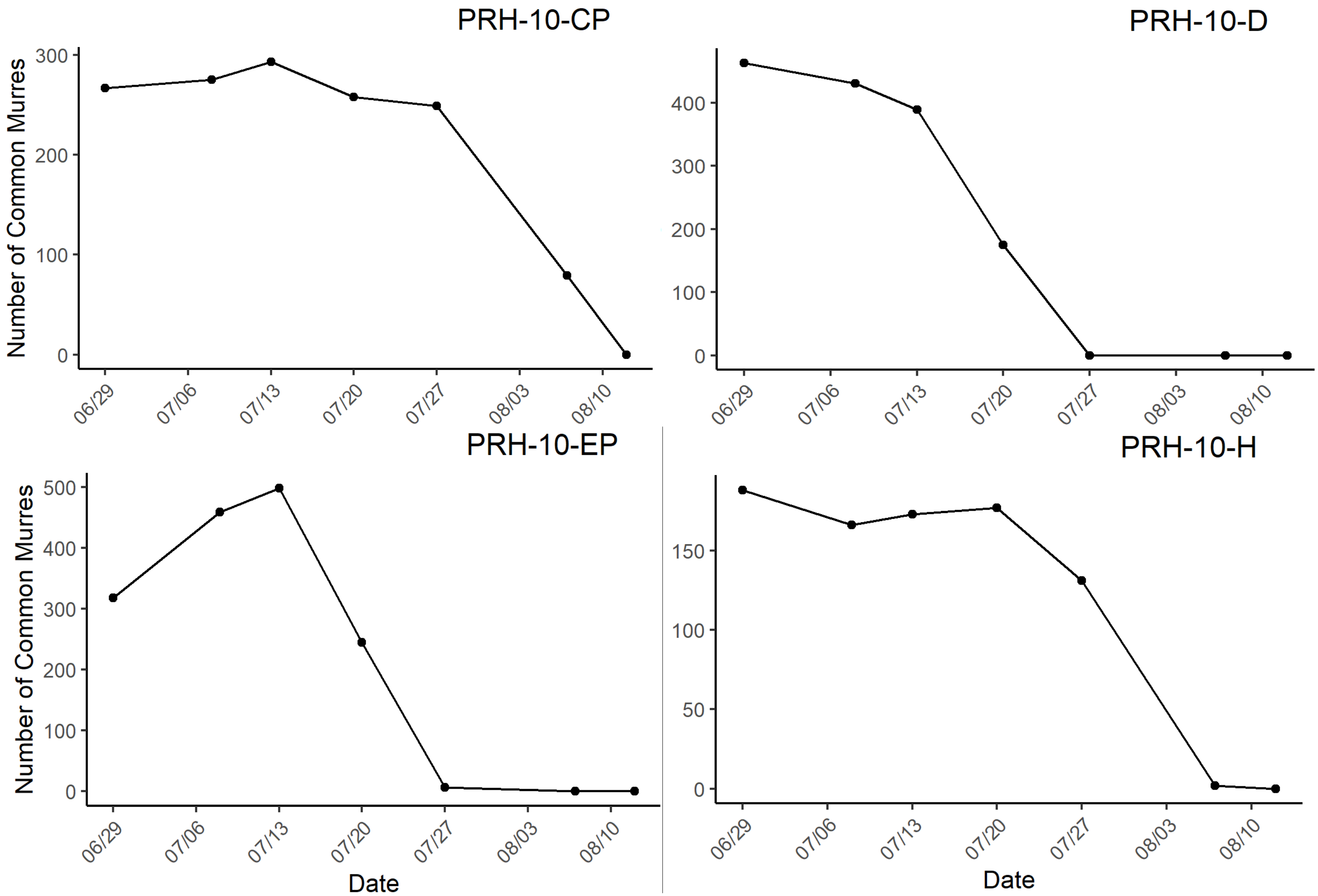


Figure 20. Seasonal attendance of Common Murres at Point Reyes Headlands (subcolonies: PRH-10-CP (Middle Rock Plot), PRH-10-D (East Rock), PRH-10-EP (Beach Rock Plot), and PRH-10-H (Tim Tam Rock)) from 29 June to 12 August, 2020.

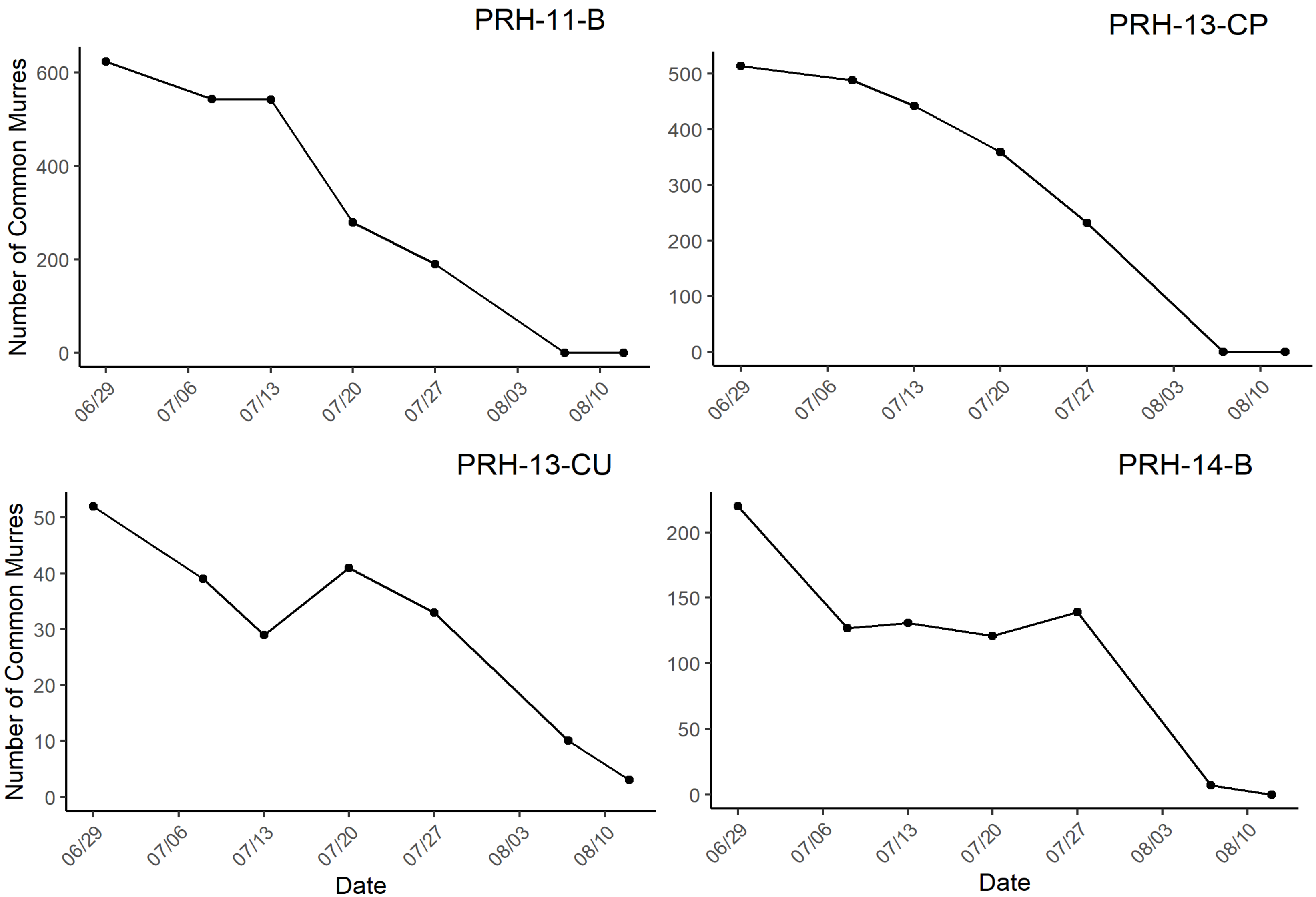
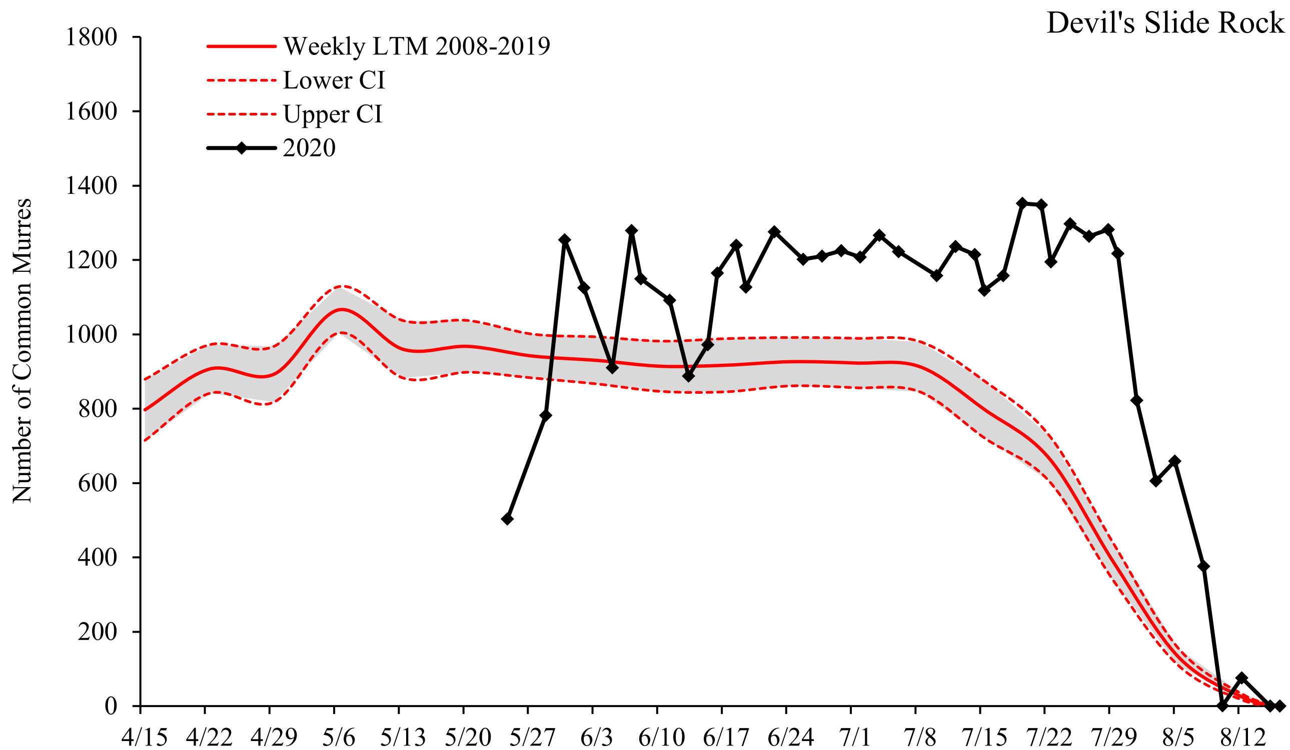


Figure 21. Seasonal attendance of Common Murres at Point Reyes Headlands (subcolonies: PRH-11-B (Face Rock), PRH-13-CP (Cone Plot), PRH-13-CU (Cone Upper) and PRH-14-B (Area B)) from 29 June to 12 August, 2020.



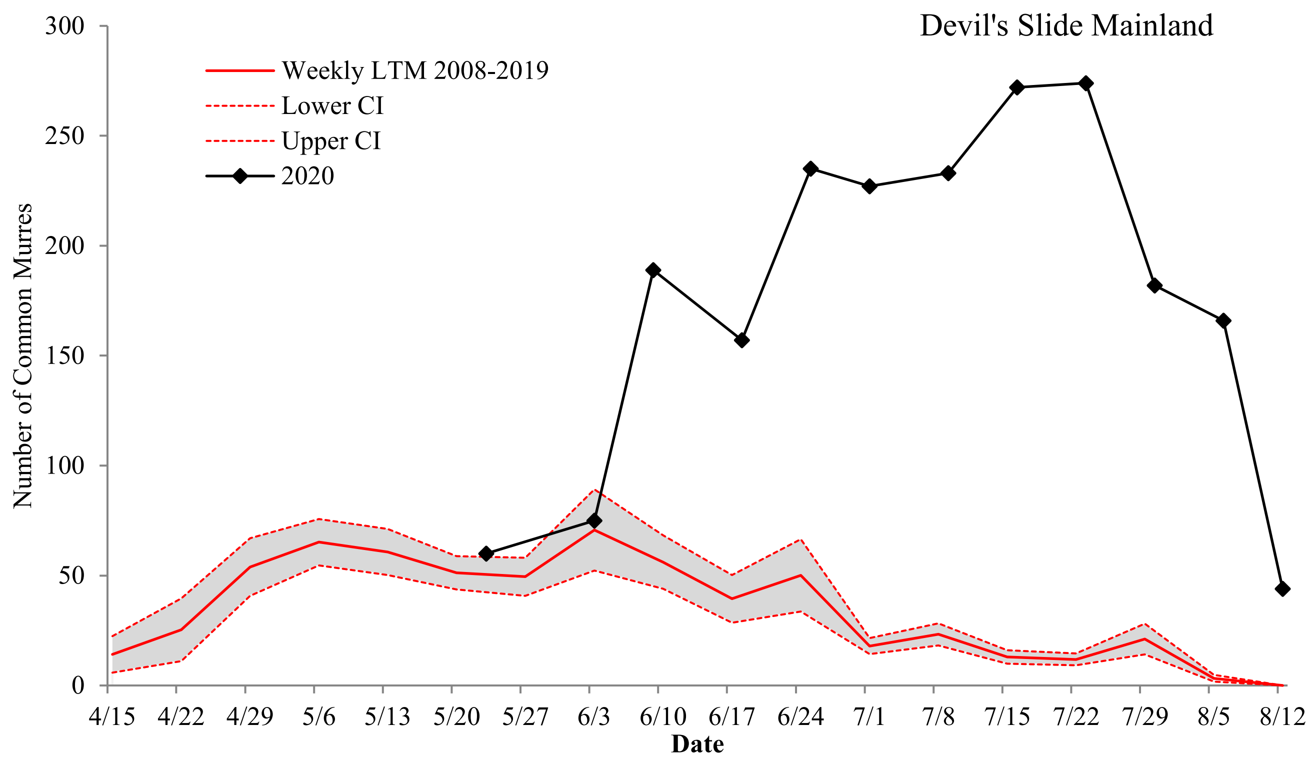


Figure 22. Seasonal attendance of Common Murres at Devil's Slide Rock (DSRM-01) and all Devil's Slide Mainland (DSM) subcolonies in 2020 compared to long-term mean (LTM, 2008-2019).

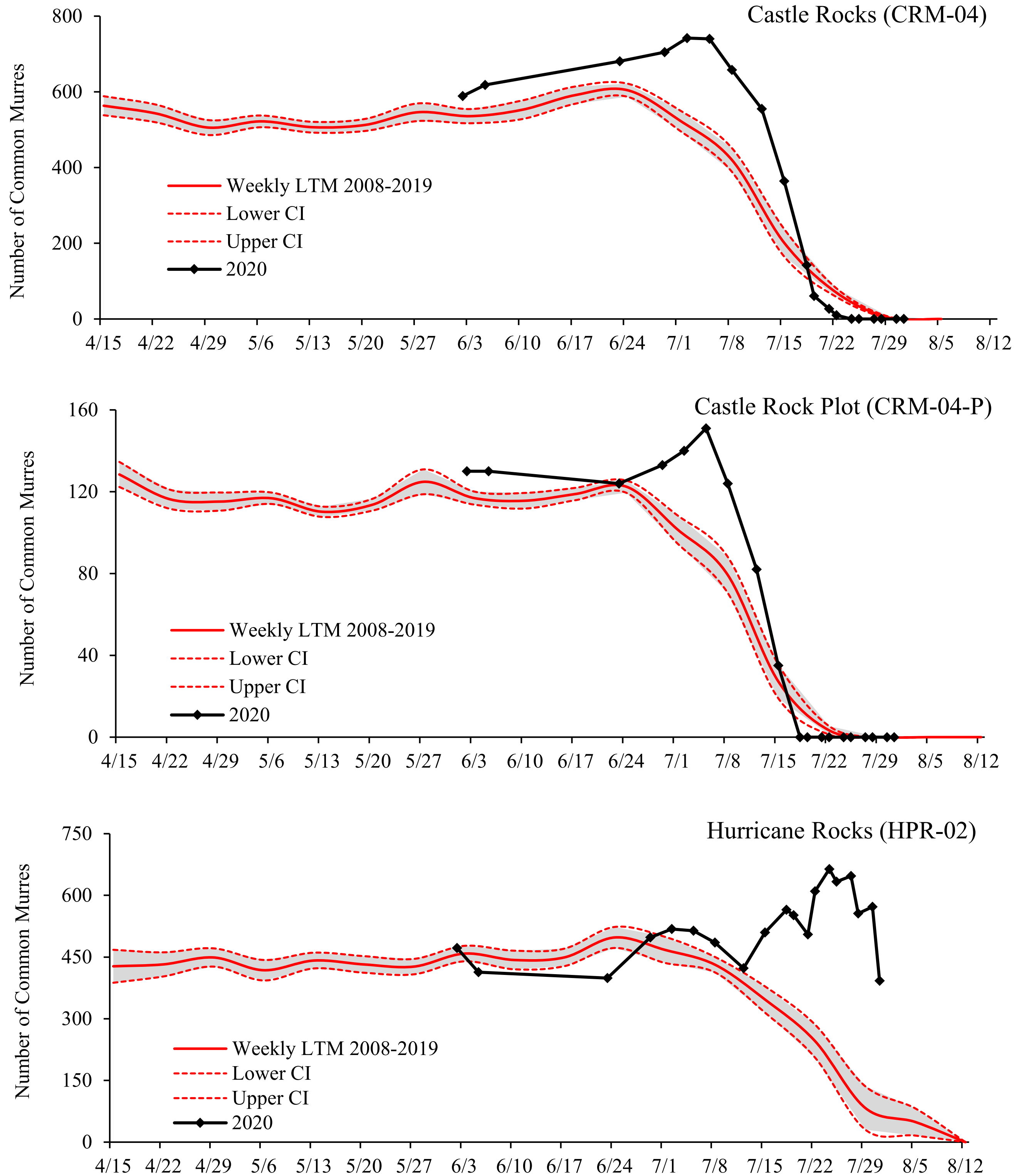


Figure 23. Seasonal attendance of Common Murres at Castle Rocks (CRM-04), Castle Rock plot (CRM-04-P), and Hurricane Rocks colony (HPR-02) in 2020 compared to the long-term mean (LTM, 2008-2019).

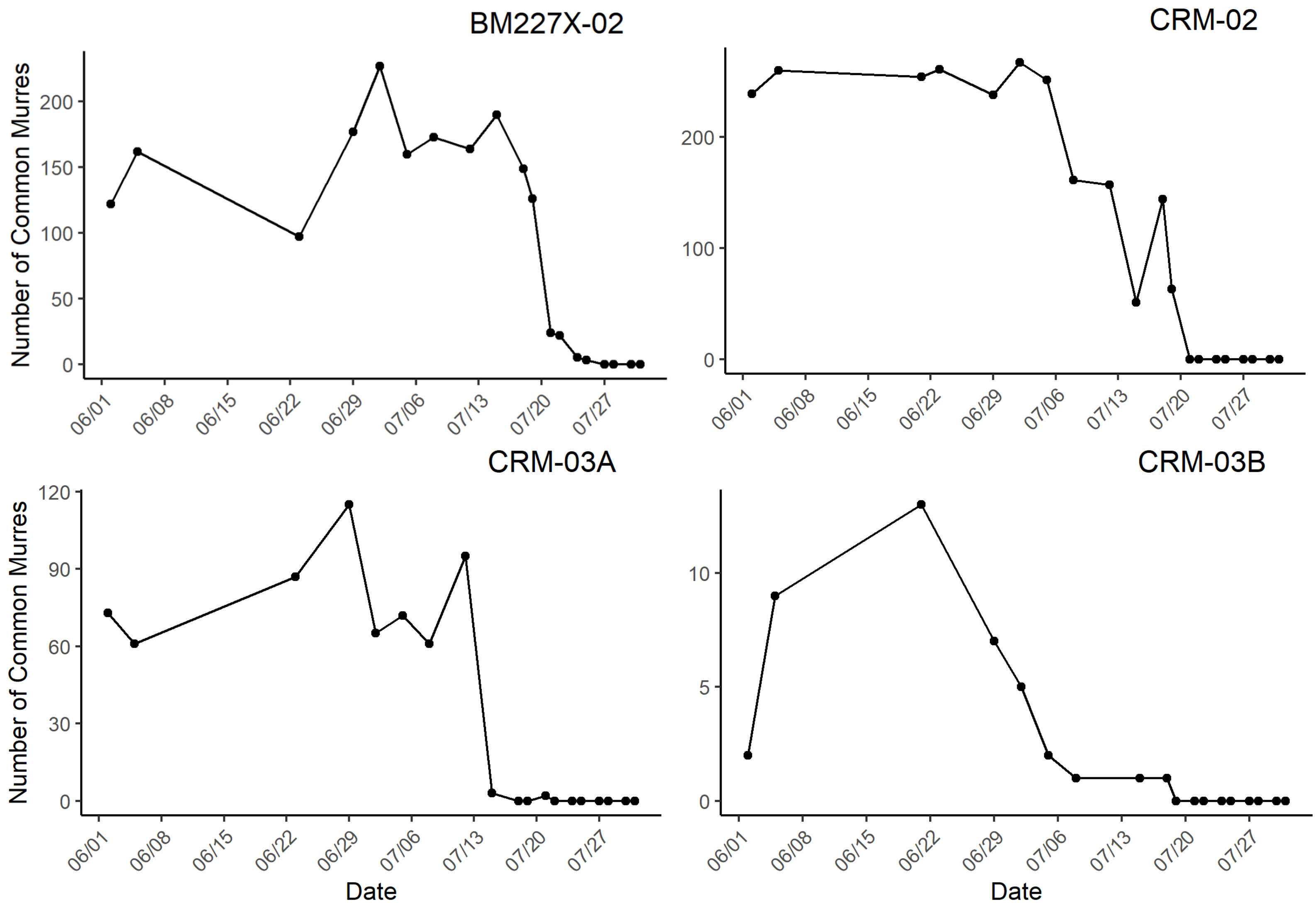


Figure 24. Seasonal attendance of Common Murres at Castle-Hurricane Colony Complex (subcolonies: BM227X-02, CRM-02, CRM-03-A, and CRM-03-B) from 2 June to 31 July, 2020.

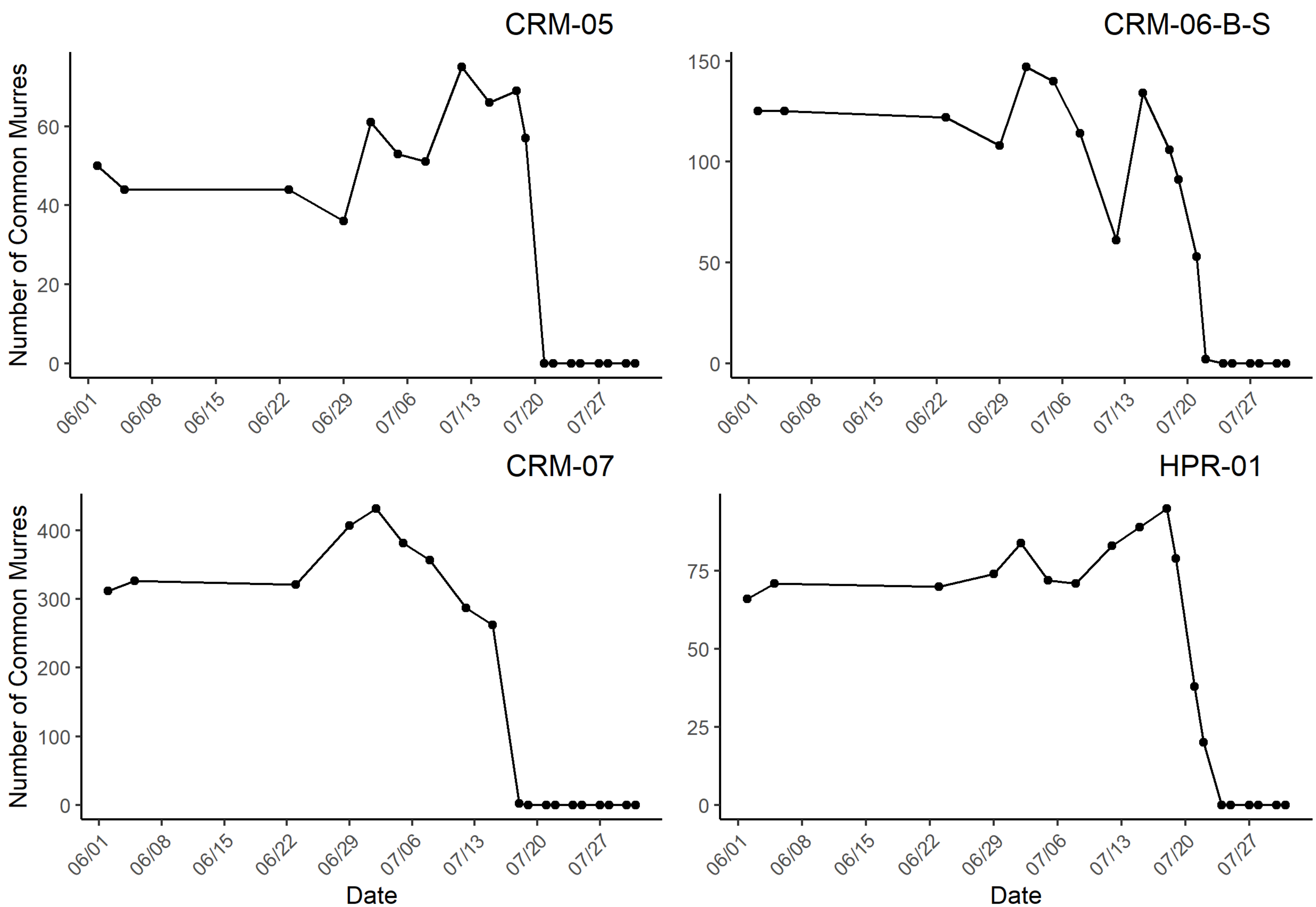


Figure 25. Seasonal attendance of Common Murres at Castle-Hurricane Colony Complex (subcolonies: CRM-05, CRM-06-B-S, CRM-07, and HPR-01) from 2 June to 31 July, 2020.

Figure 26. Productivity (chicks fledged per pair) of Common Murres at Point Reyes Headlands, Devil's Slide Rock, and Castle Rock-04 from 1996-2020. The solid horizontal line indicates the long-term weighted mean (1996-2019), and the dashed lines represent the 95% confidence interval. Data were incomplete at Point Reyes and Castle Rock owing to the later start to monitoring.

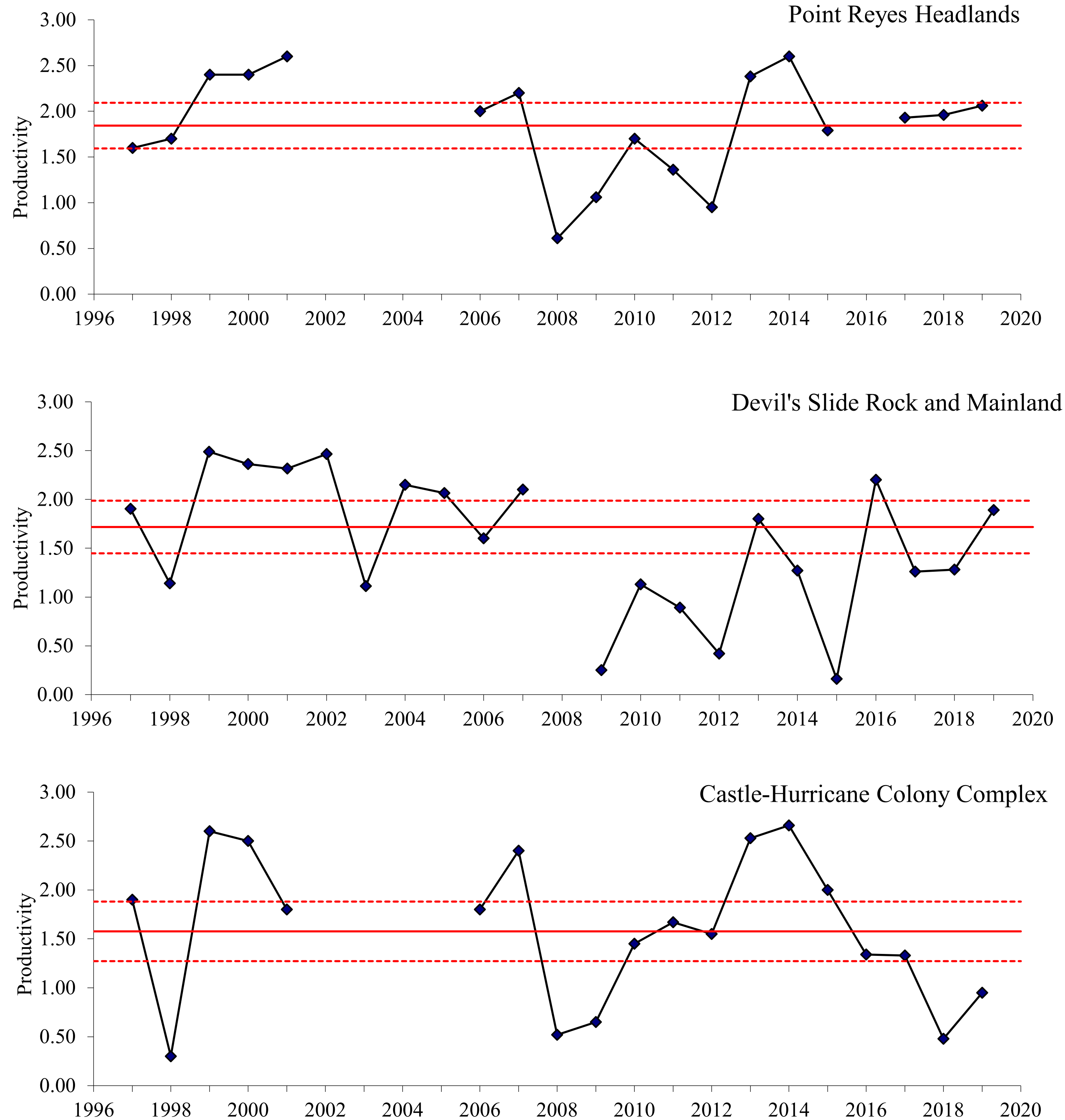
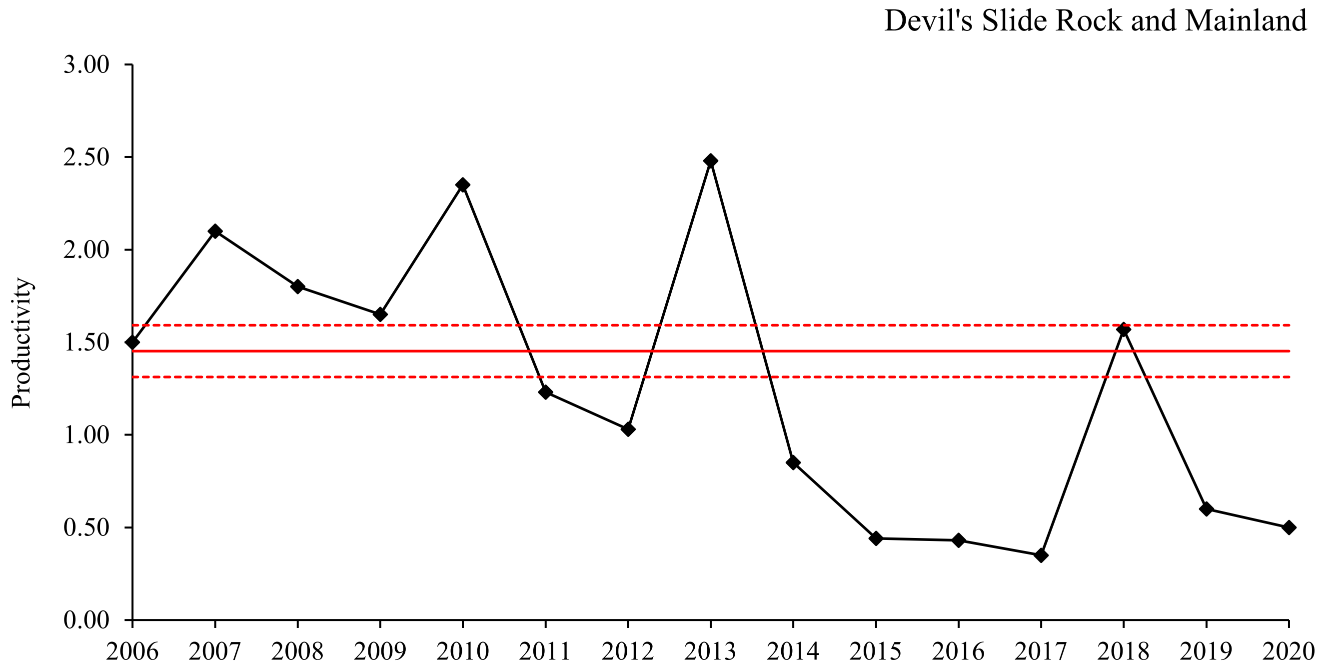


Figure 27. Productivity (chicks fledged per pair) of Brandt's Cormorants at Point Reyes Headlands, Devil's Slide Rock & Mainland, and Castle-Hurricane Colony Complex from 1997-2020. The solid horizontal line indicates the long-term weighted mean (1996-2019), and the dashed lines represent the 95% confidence interval. Data were incomplete at all sites owing to the delayed start.



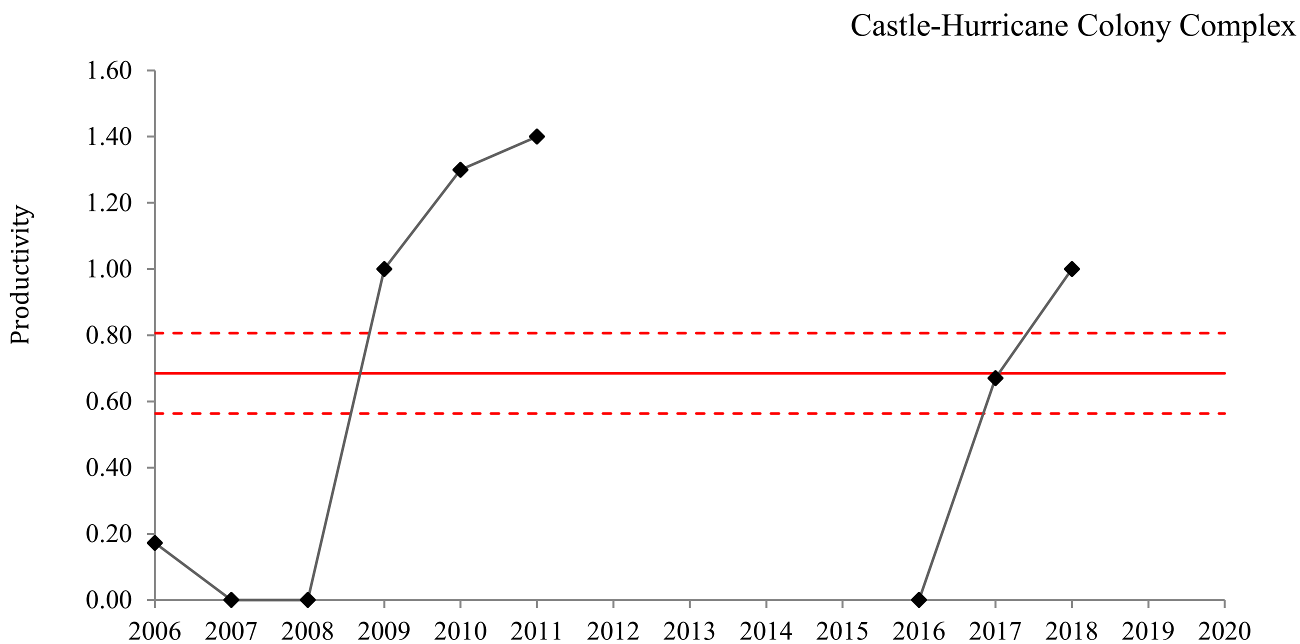


Figure 28. Productivity (chicks fledged per pair) of Pelagic Cormorants at Devil's Slide Rock & Mainland and Castle-Hurricane Colony Complex from 2006-2020. The solid horizontal line indicates the long-term weighted mean (2006-2019), and the dashed lines represent the 95% confidence interval. At Castle-Hurricane, no cormorants were monitored in 2019, and data are incomplete in 2020 owing to the late start to monitoring.

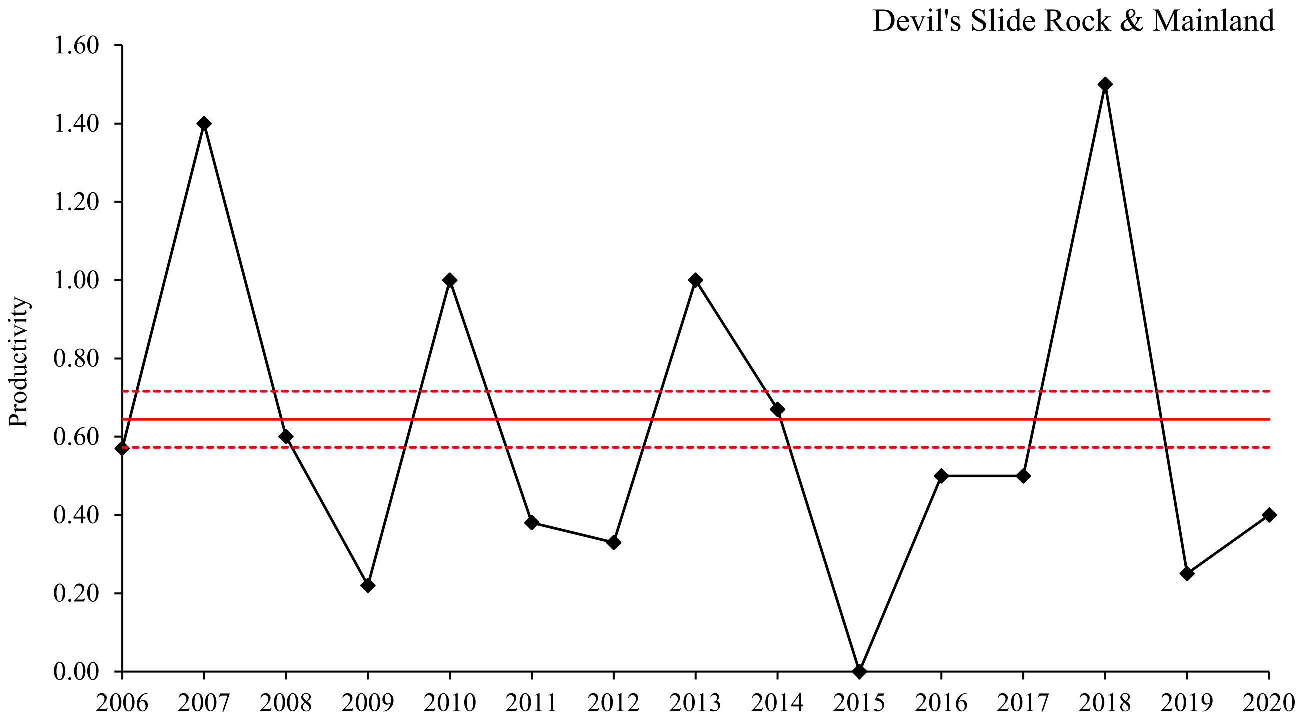


Figure 29. Productivity (chicks fledged per pair) of Western Gulls at Devil's Slide Rock & Mainland, 2006-2020. The solid horizontal line indicates the long-term weighted mean (2006-2019), and the dashed lines represent the 95% confidence interval.

Appendix 1. Number of aircraft overflights and land-based sources observed (detections and disturbances), categorized by affiliation, at Point Reyes Headlands, Devil's Slide Rock & Mainland, and Castle-Hurricane Colony Complex, 2020. UAS indicates an uncrewed aerial system (i.e., drone).

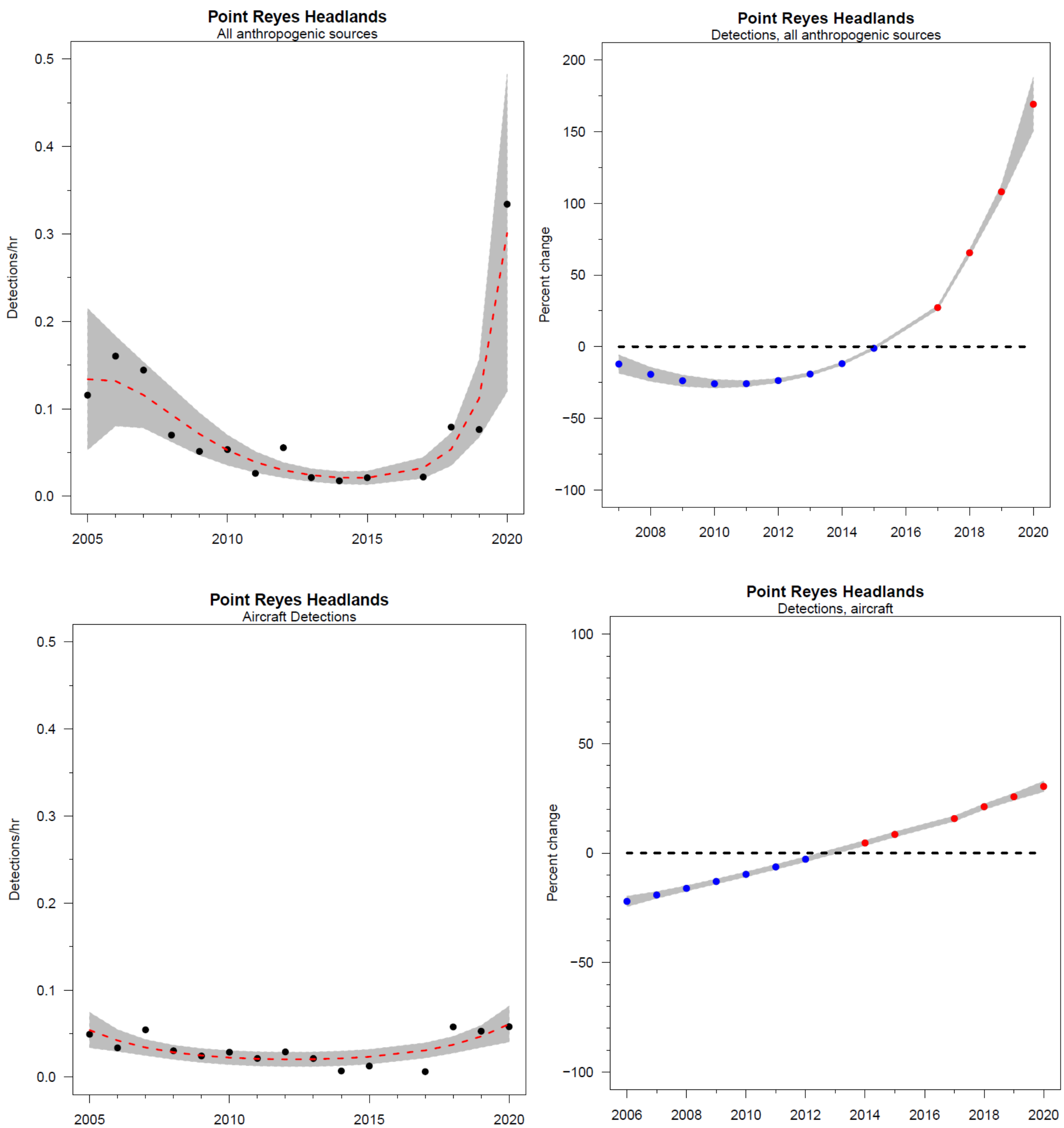
a) Detections

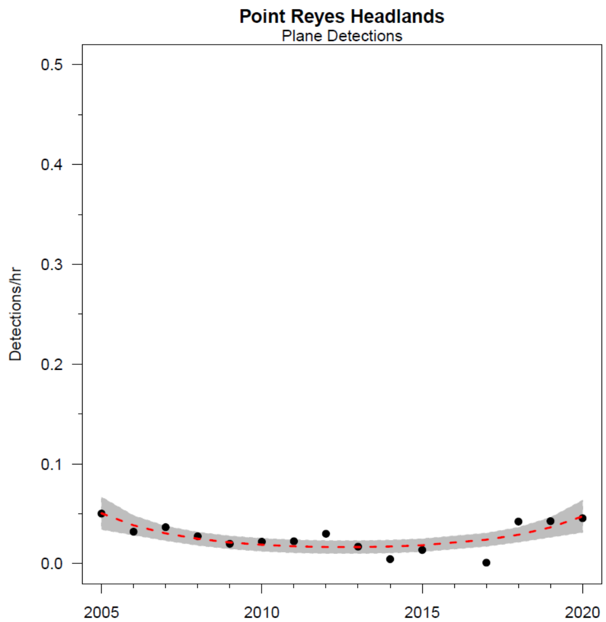
Affiliation	Helicopter	Plane	UAS	Humans on Foot	Loud Noises	Motor Vehicle Noise	Total
Charter	1						1
Commercial		1					1
Law Enforcement	1				1		2
Media	1						1
Military	1	5					6
Private/recreational	4	52	3	1			60
Unknown	1				1	1	3
USCG	7	2					9
Total	**16**	**60**	**3**	**1**	**2**	**1**	**83**

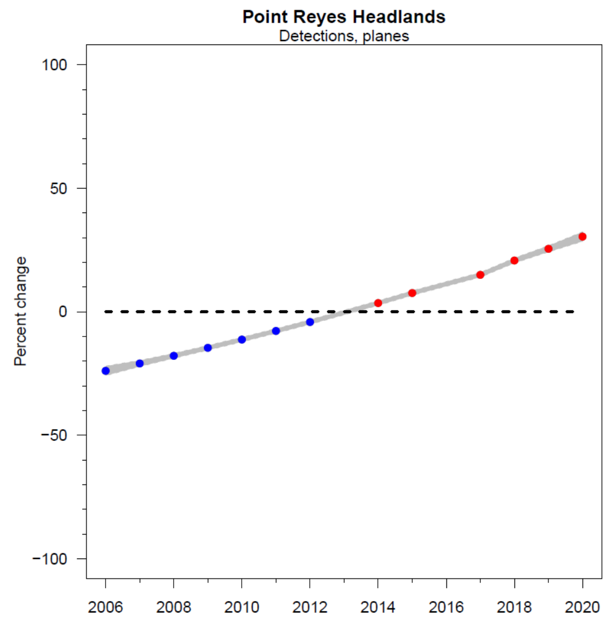
b) Disturbance events

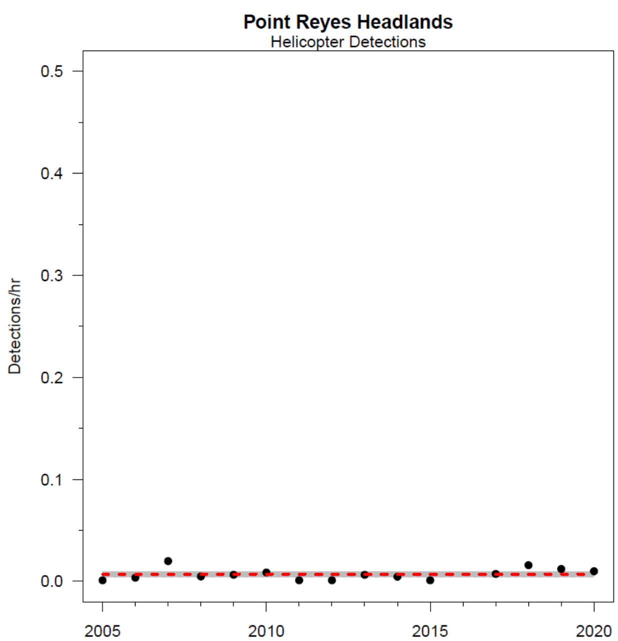
Affiliation	Helicopter	Plane	Humans on Foot	Loud Noises	Motor Vehicle Noise	Total
Commercial		1				1
Law Enforcement				1		1
Military	1	2				3
Private/Recreational	3	10	1			14
Unknown				1	1	2
USCG	5					5
Total	**9**	**13**	**1**	**2**	**1**	**26**

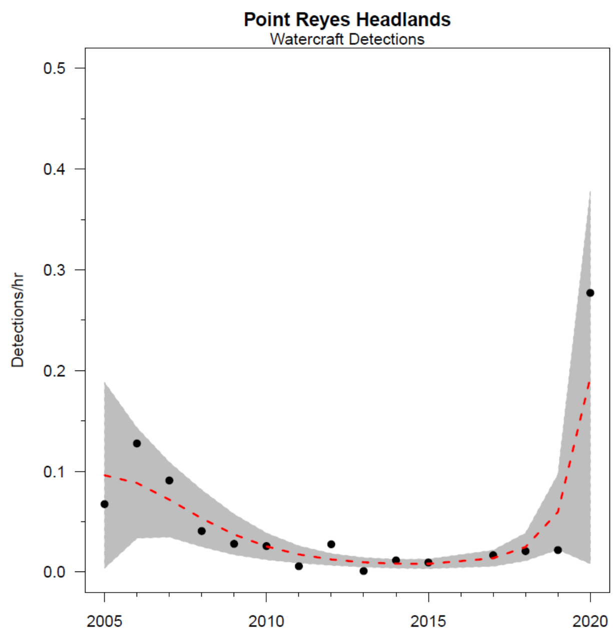
Appendix 2. Trends in anthropogenic detection rates, disturbance rates, and annual rates of change at Point Reyes Headlands, 2005-2020. The left column shows rates and their trendlines based on generalized linear models. The right column displays the percent annual change in detection or disturbance rates. Percent annual changes are shown only if the relationships are statistically significant, with 95% confidence intervals that do not bound 0. Red dots indicate increasing rates, whereas blue dots indicate decreasing rates. Missing dots are not statistically significant.

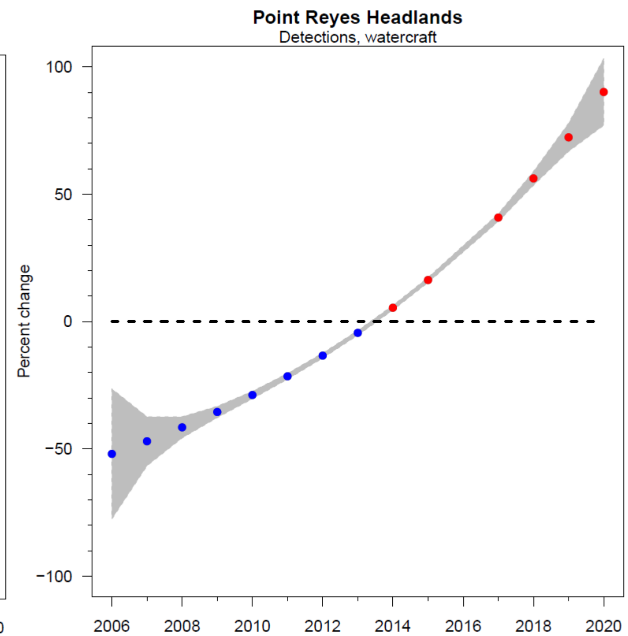


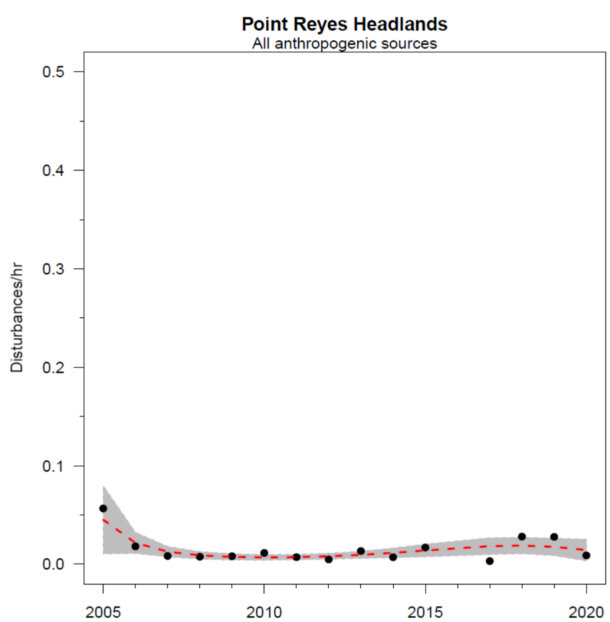

Point Reyes Headlands
Plane Detections
Detections/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

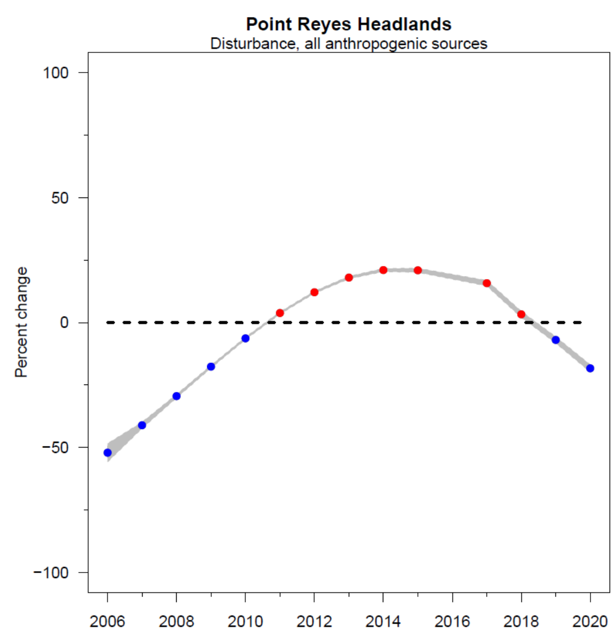

Point Reyes Headlands
Detections, planes
Percent change
100
50
0
−50
−100
2006
2008
2010
2012
2014
2016
2018
2020

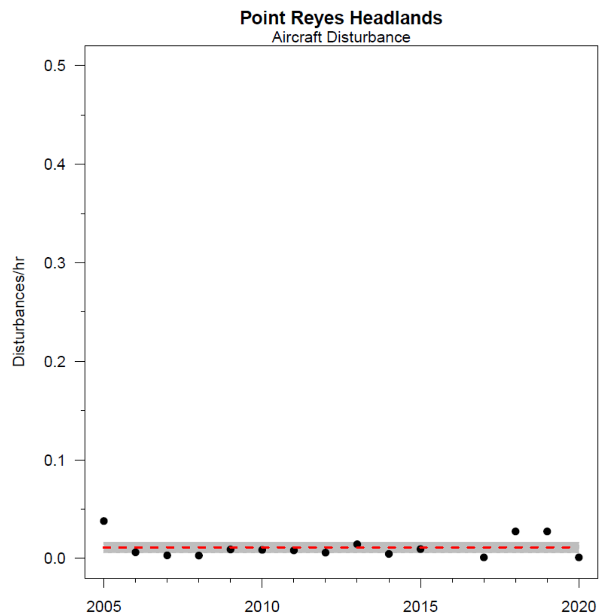

Point Reyes Headlands
Helicopter Detections
Detections/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

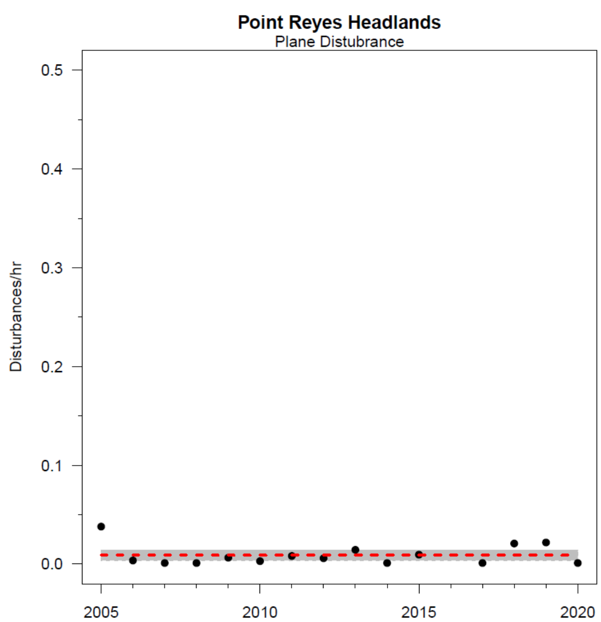

Point Reyes Headlands
Watercraft Detections
Detections/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

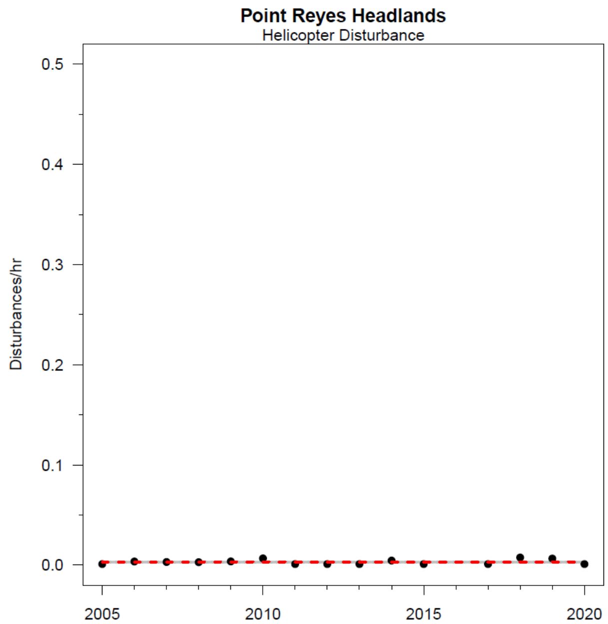

Point Reyes Headlands
Detections, watercraft
Percent change
100
50
0
−50
−100
2006
2008
2010
2012
2014
2016
2018
2020

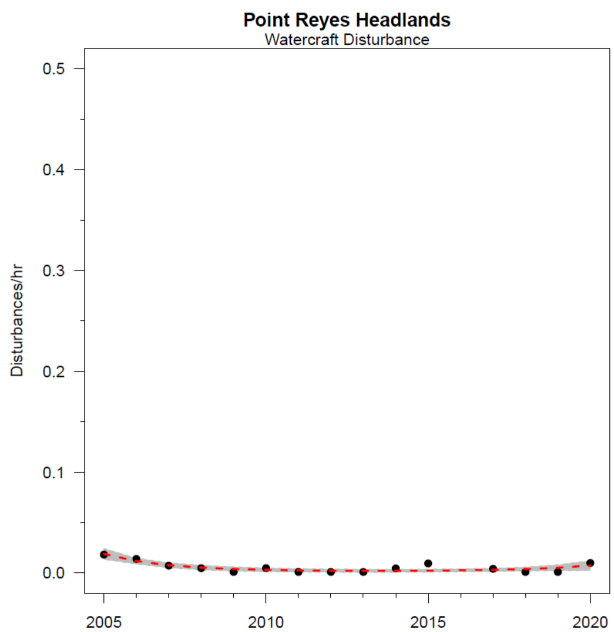

Point Reyes Headlands
All anthropogenic sources
Disturbances/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

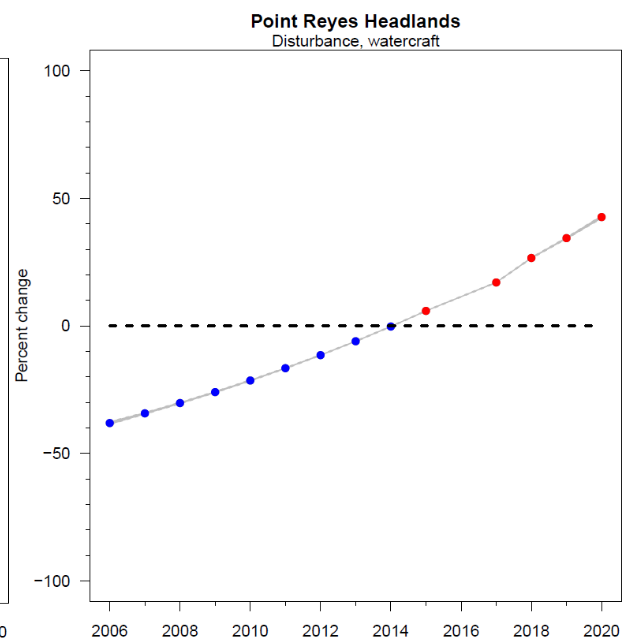

Point Reyes Headlands
Disturbance, all anthropogenic sources
Percent change
100
50
0
−50
−100
2006
2008
2010
2012
2014
2016
2018
2020


Point Reyes Headlands
Aircraft Disturbance
Disturbances/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

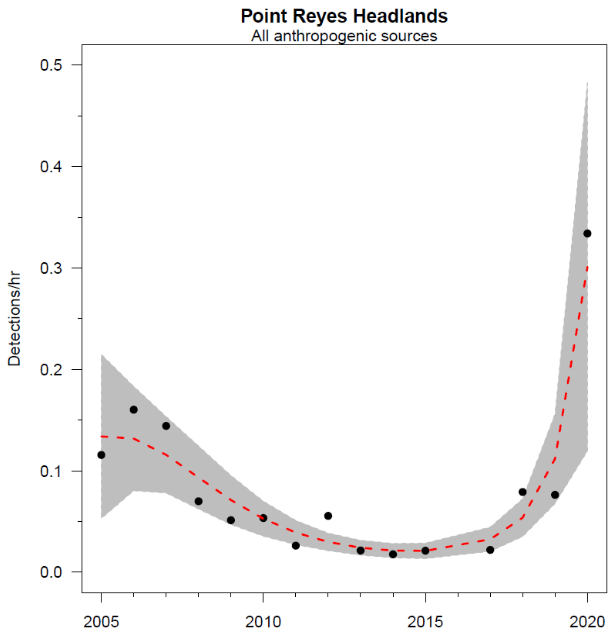

Point Reyes Headlands
Plane Distubrance
Disturbances/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

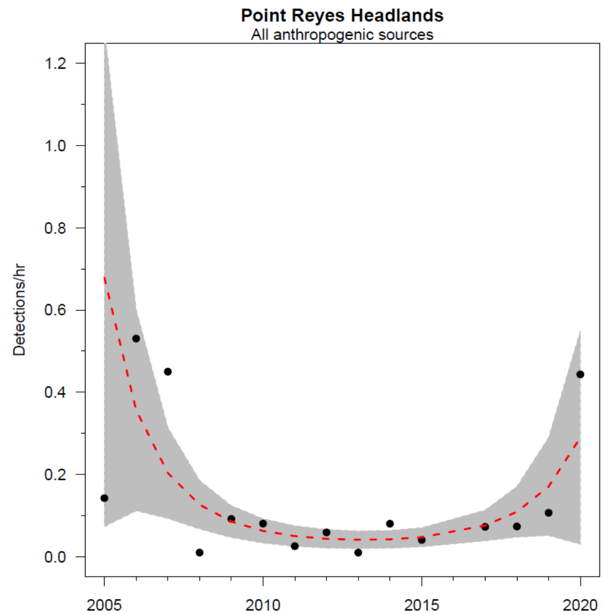

Point Reyes Headlands
Helicopter Disturbance
Disturbances/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

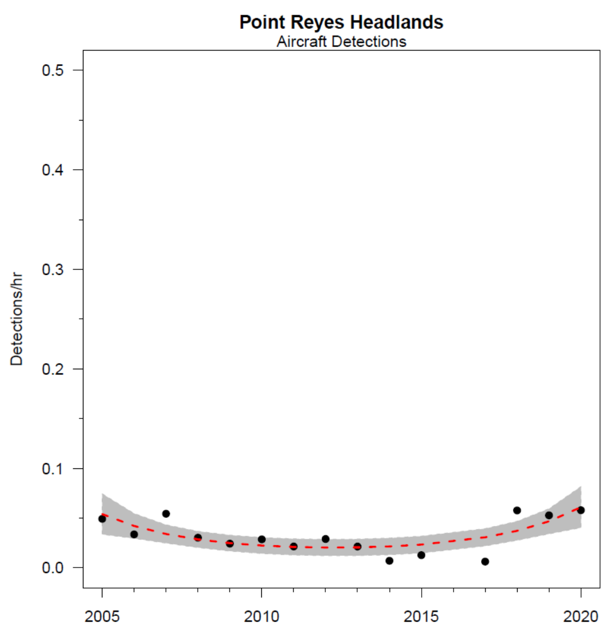

Point Reyes Headlands
Watercraft Disturbance
Disturbances/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

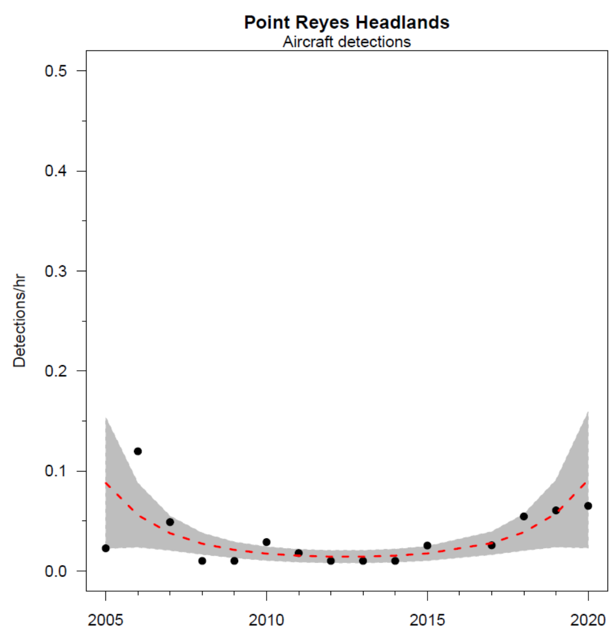

Point Reyes Headlands
Disturbance, watercraft
Percent change
100
50
0
−50
−100
2006
2008
2010
2012
2014
2016
2018
2020

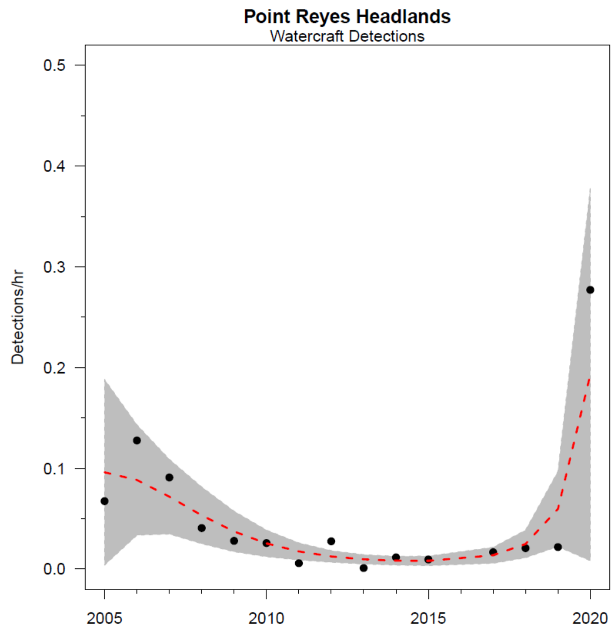
Appendix 3. Comparison of all long-term anthropogenic detection and disturbance rate data at Point Reyes Headlands, Devil's Slide Rock, and Castle-Hurricane Colony Complex, 2020. The left column shows detection and disturbance rates using all available rate data (and can be found in Appendices 2, 4-5, above and below). The right column shows detection and disturbance rates with time series directly comparable with the truncated 2020 season. At Devil's Slide, we used data from June-August in each year, while at Point Reyes and Castle-Hurricane, we used data from July-August. We record rates of all anthropogenic sources, all aircraft, or all watercraft for comparison.

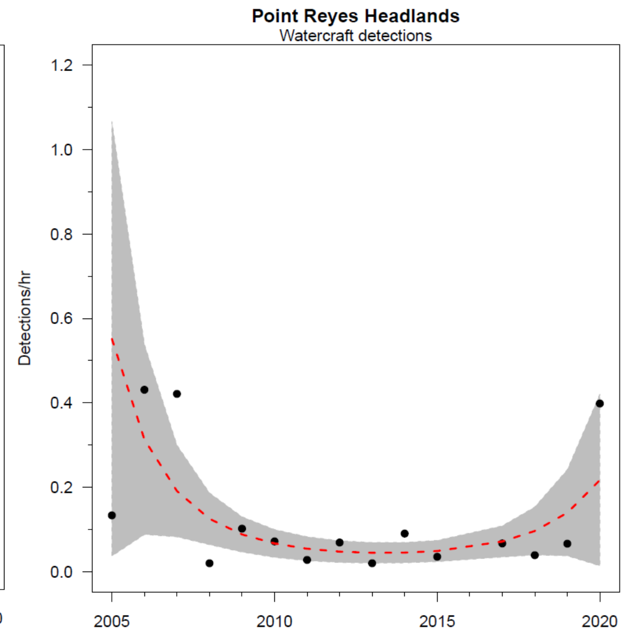


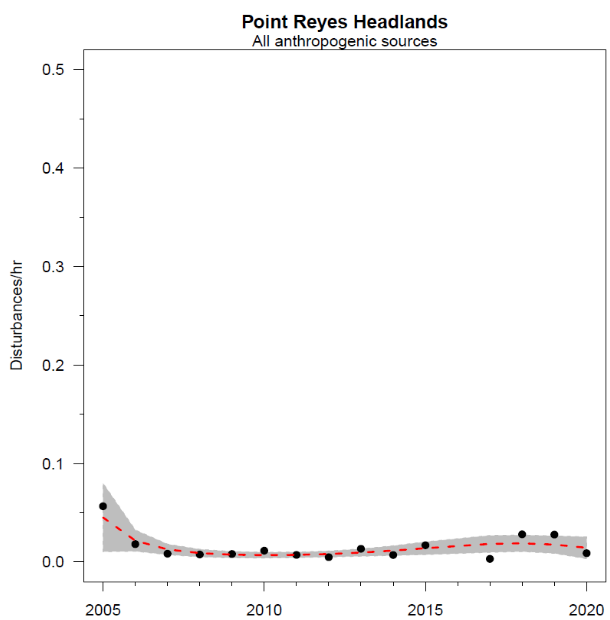


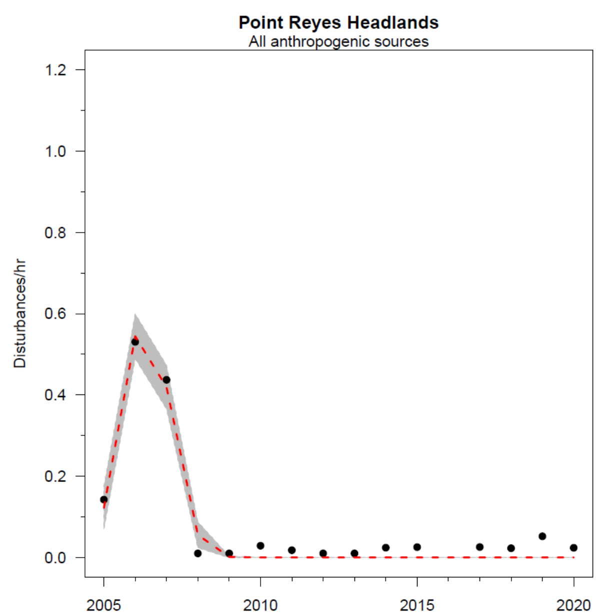


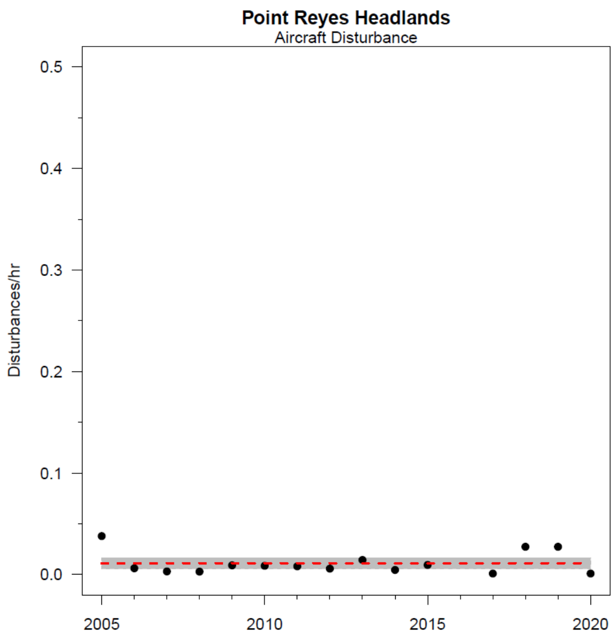


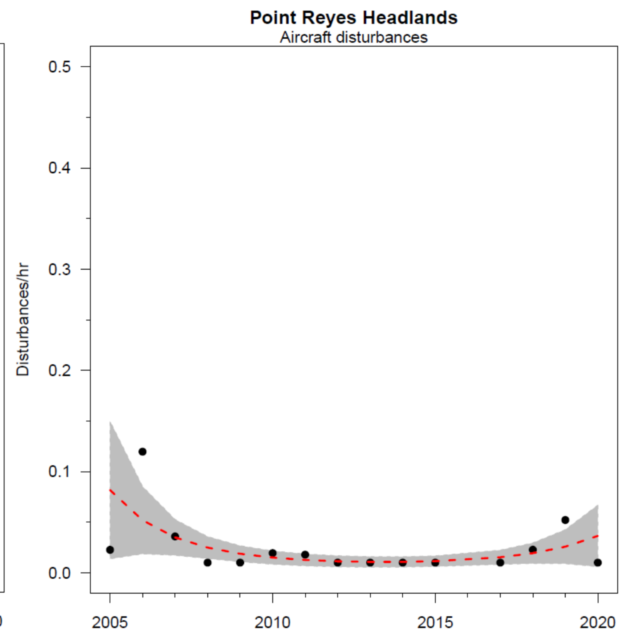

Point Reyes Headlands
Watercraft Detections
Detections/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

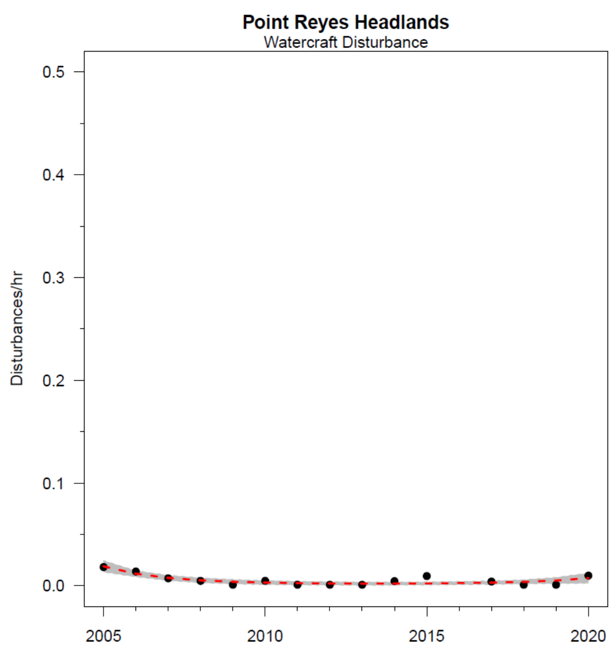

Point Reyes Headlands
Watercraft detections
Detections/hr
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2005
2010
2015
2020

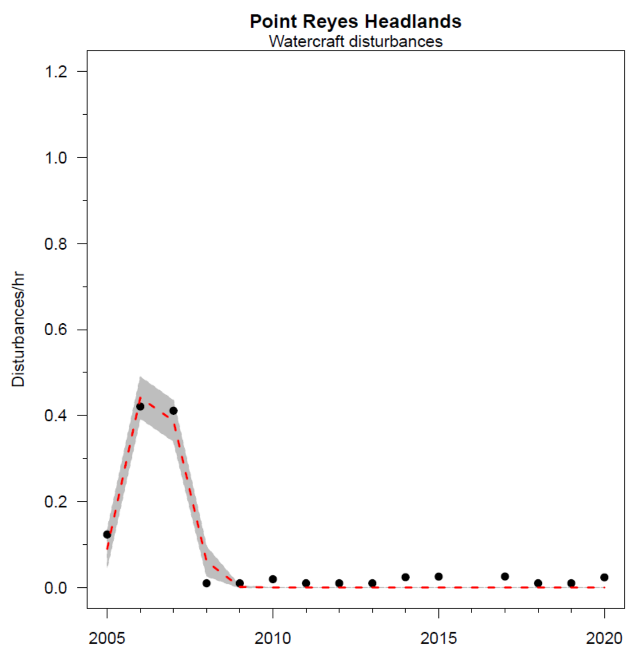

Point Reyes Headlands
All anthropogenic sources
Disturbances/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

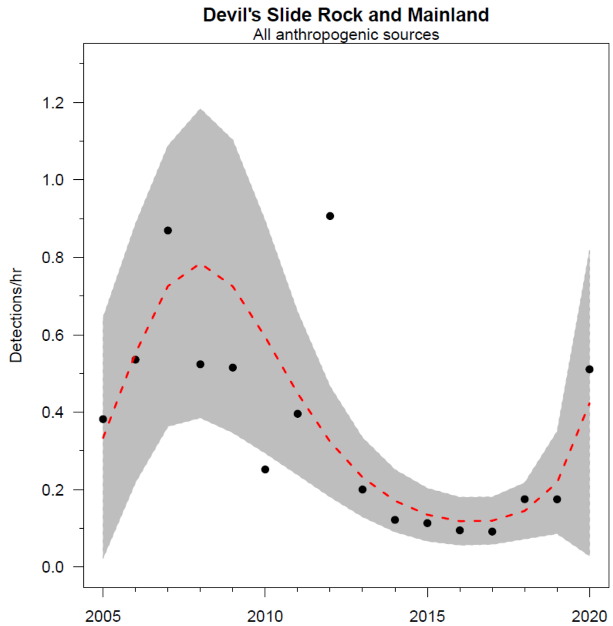

Point Reyes Headlands
All anthropogenic sources
Disturbances/hr
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2005
2010
2015
2020

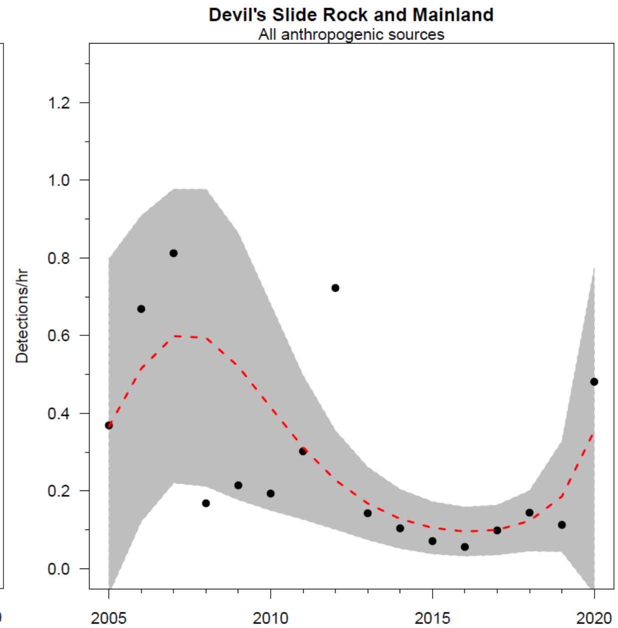

Point Reyes Headlands
Aircraft Disturbance
Disturbances/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

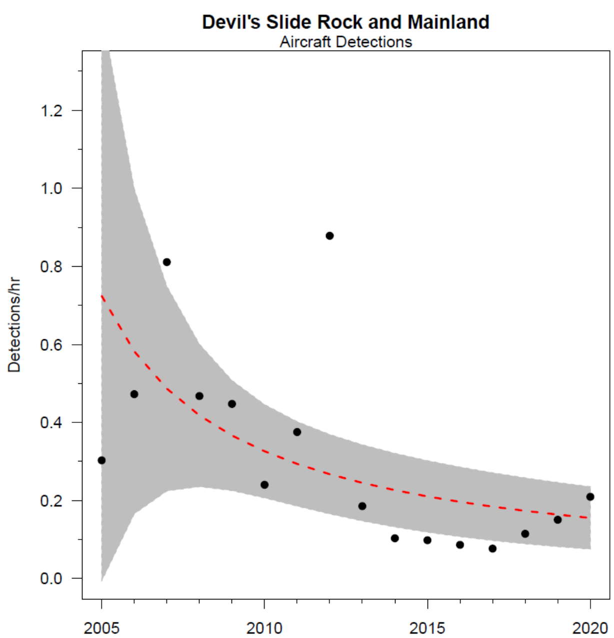

Point Reyes Headlands
Aircraft disturbances
Disturbances/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

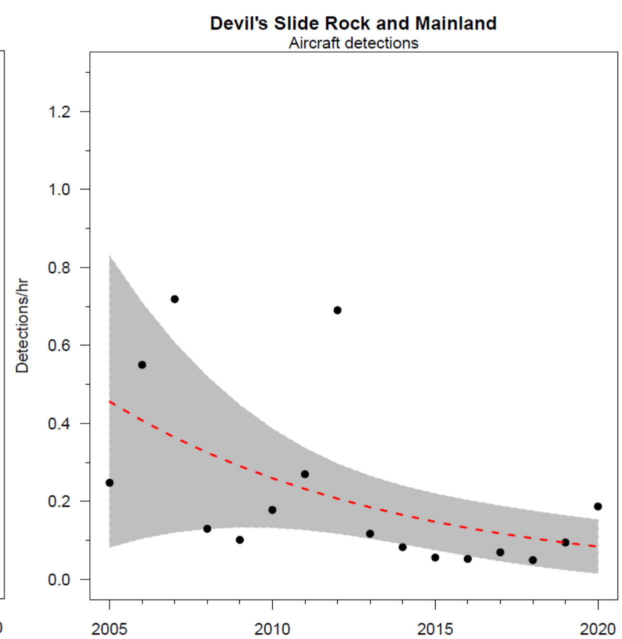

Point Reyes Headlands
Watercraft Disturbance
Disturbances/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

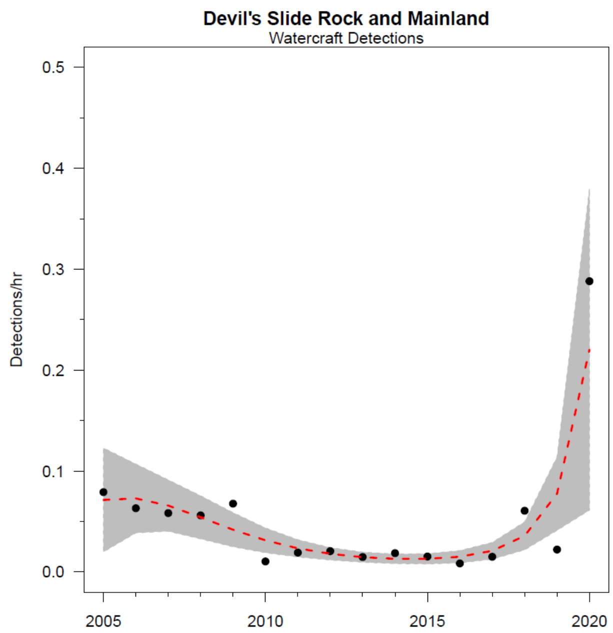

Point Reyes Headlands
Watercraft disturbances
Disturbances/hr
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2005
2010
2015
2020

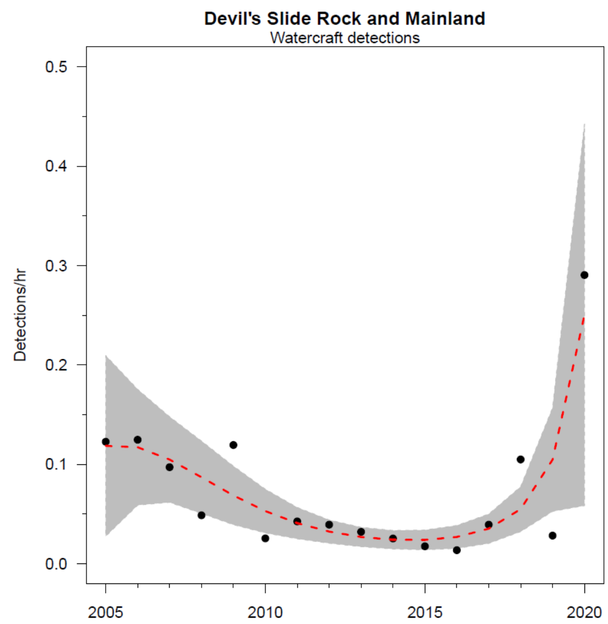

Devil's Slide Rock and Mainland
All anthropogenic sources
Detections/hr
0.0
0.2
0.4
0.6
0.8
1.0
1.2
2005
2010
2015
2020

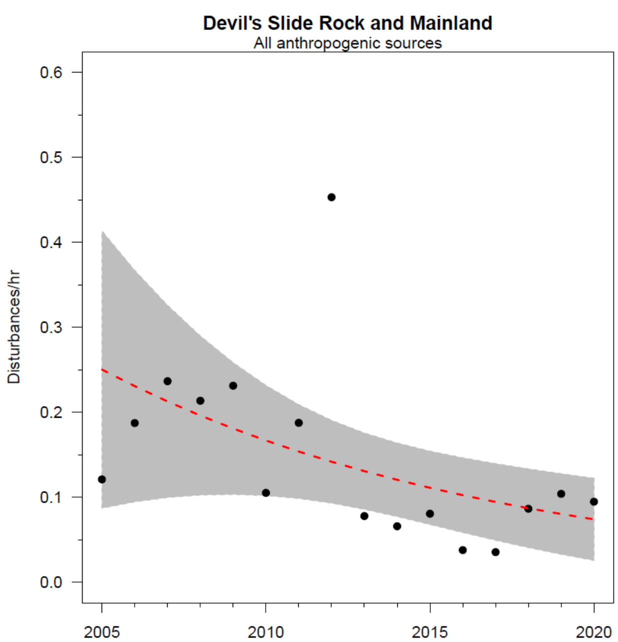

Devil's Slide Rock and Mainland
All anthropogenic sources
Detections/hr
0.0
0.2
0.4
0.6
0.8
1.0
1.2
2005
2010
2015
2020

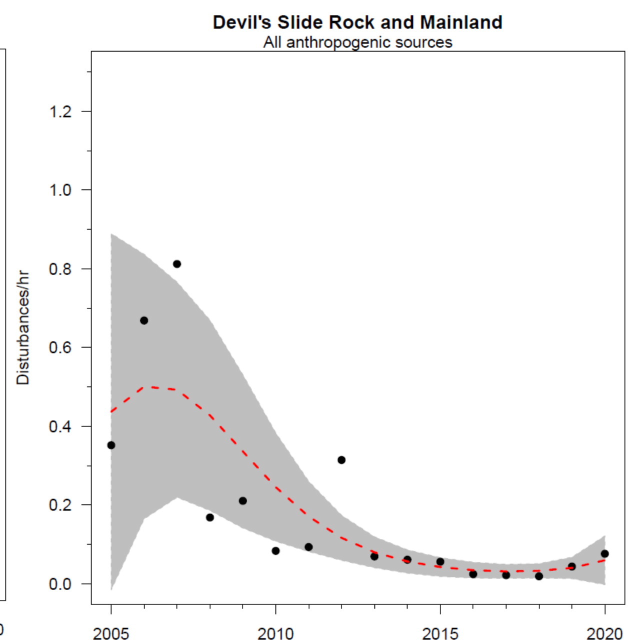

Devil's Slide Rock and Mainland
Aircraft Detections
Detections/hr
0.0
0.2
0.4
0.6
0.8
1.0
1.2
2005
2010
2015
2020

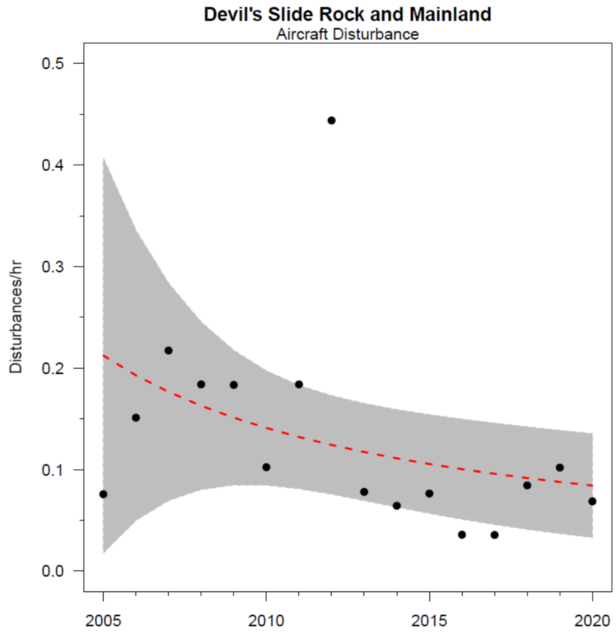

Devil's Slide Rock and Mainland
Aircraft detections
Detections/hr
0.0
0.2
0.4
0.6
0.8
1.0
1.2
2005
2010
2015
2020

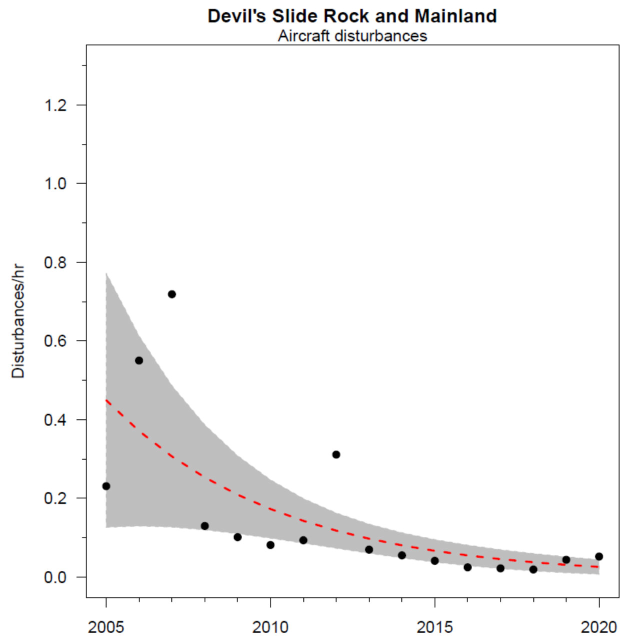

Devil's Slide Rock and Mainland
Watercraft Detections
Detections/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

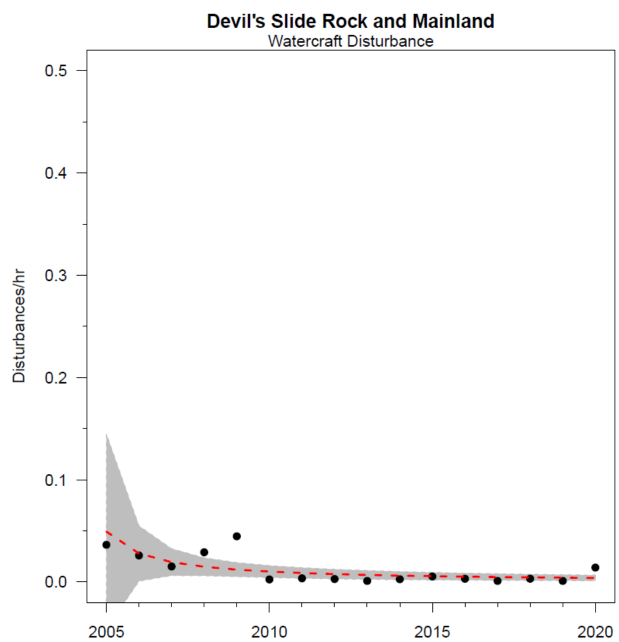

Devil's Slide Rock and Mainland
Watercraft detections
Detections/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

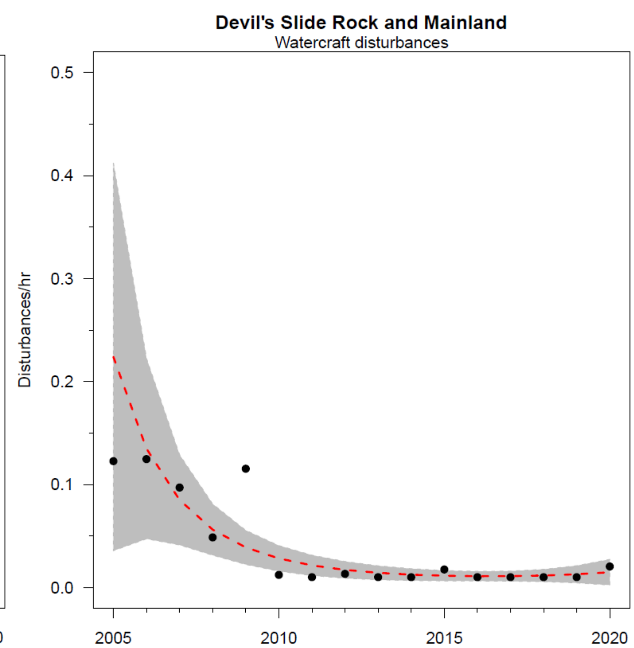

Devil's Slide Rock and Mainland
All anthropogenic sources
Disturbances/hr
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

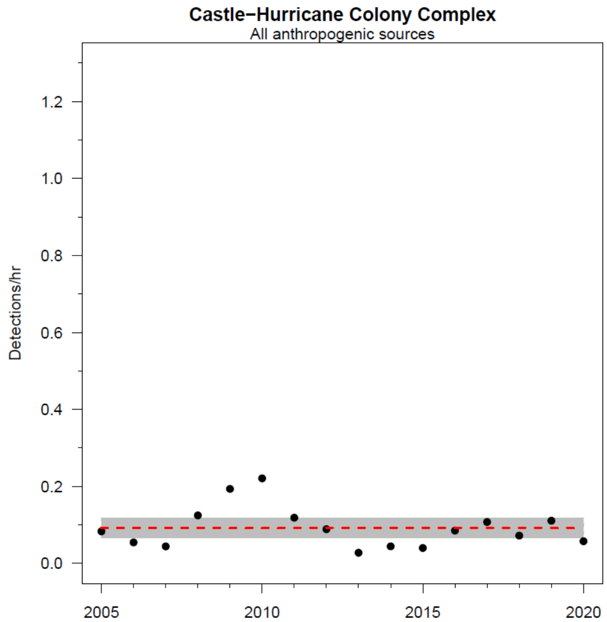

Devil's Slide Rock and Mainland
All anthropogenic sources
Disturbances/hr
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2005
2010
2015
2020

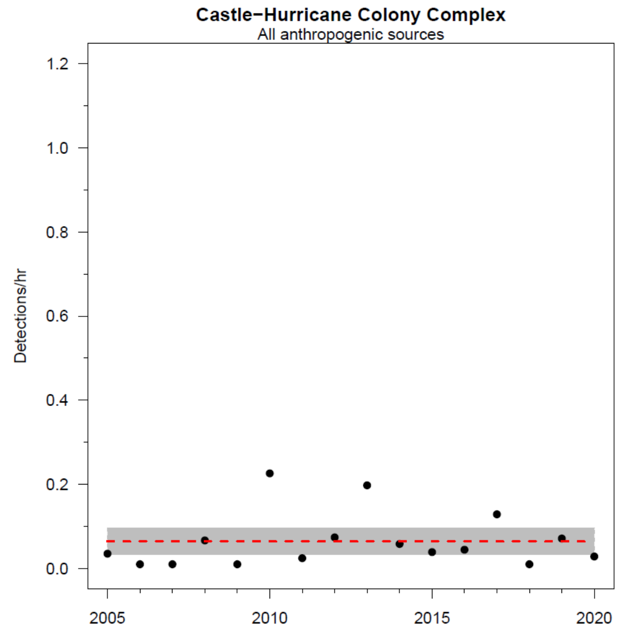

Devil's Slide Rock and Mainland
Aircraft Disturbance
Disturbances/hr
0.0
0.1
0.2
0.3
0.4
0.5
2005
2010
2015
2020

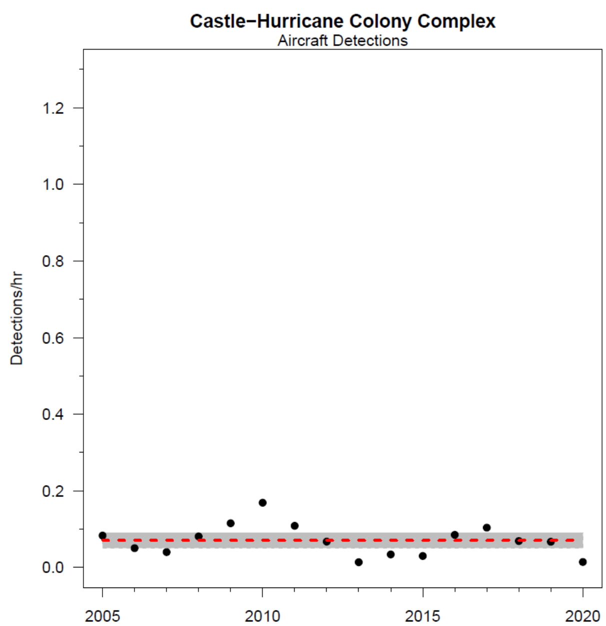

Devil's Slide Rock and Mainland
Aircraft disturbances
Disturbances/hr
0.0
0.2
0.4
0.6
0.8
1.0
1.2
2005
2010
2015
2020

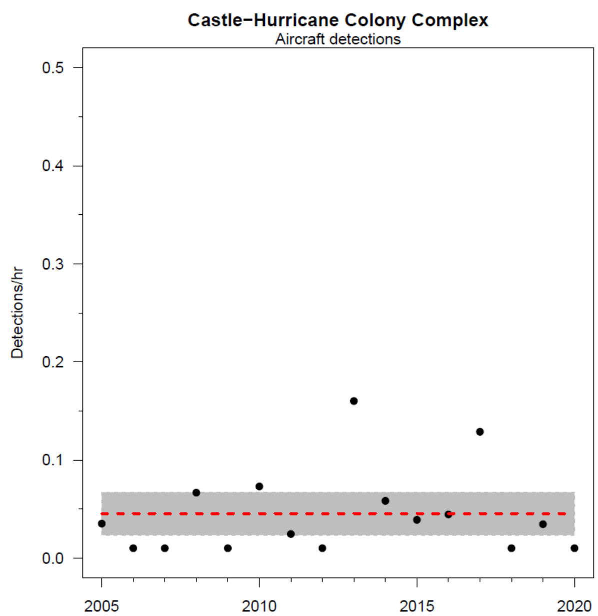

Devil's Slide Rock and Mainland
Watercraft Disturbance
Disturbances/hr
0.0
0.1
0.2
0.3
0.4
0.5
2005
2010
2015
2020

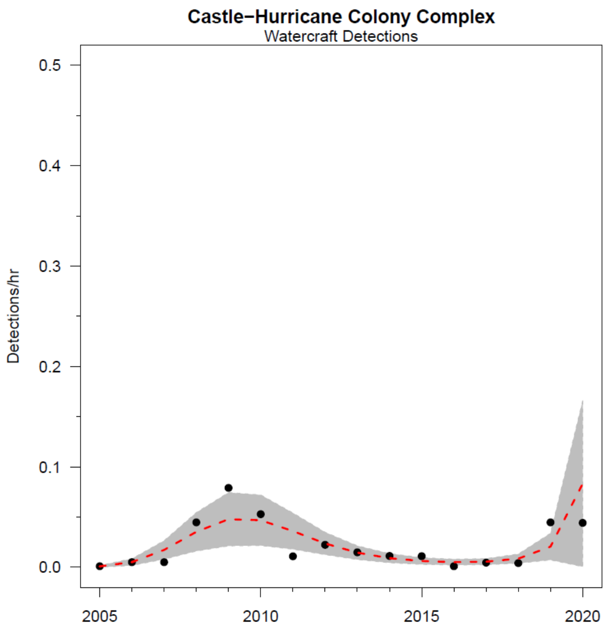

Devil's Slide Rock and Mainland
Watercraft disturbances
Disturbances/hr
0.0
0.1
0.2
0.3
0.4
0.5
2005
2010
2015
2020

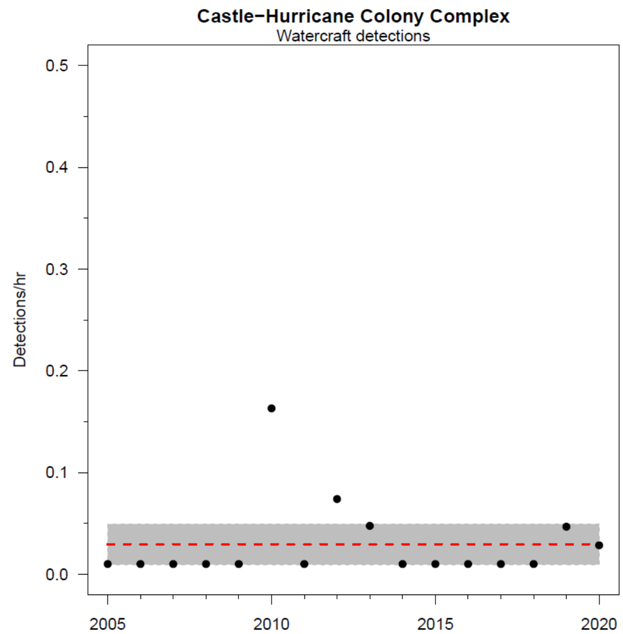

Castle−Hurricane Colony Complex
All anthropogenic sources
Detections/hr
0.0
0.2
0.4
0.6
0.8
1.0
1.2
2005
2010
2015
2020

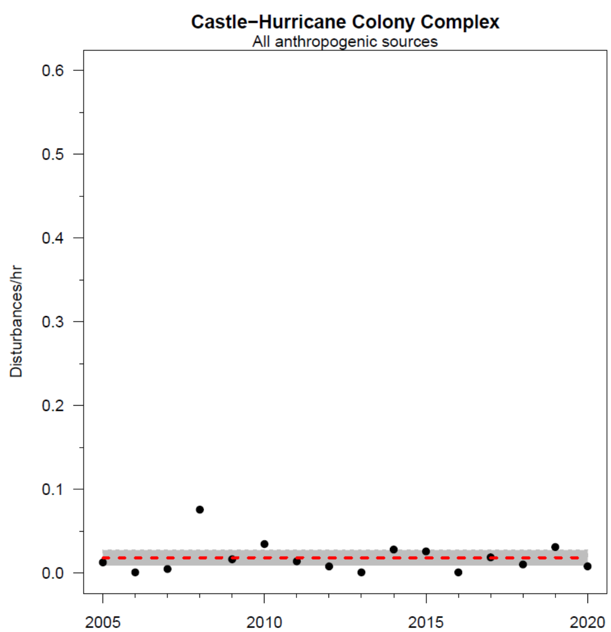

Castle−Hurricane Colony Complex
All anthropogenic sources
Detections/hr
0.0
0.2
0.4
0.6
0.8
1.0
1.2
2005
2010
2015
2020

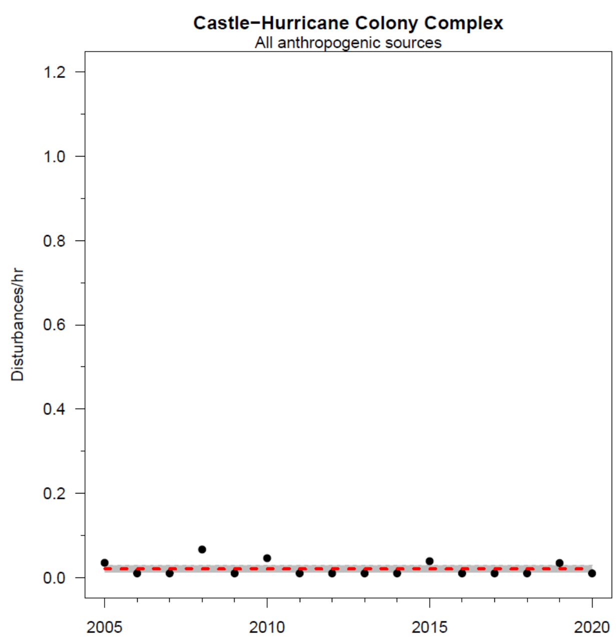

Castle−Hurricane Colony Complex
Aircraft Detections
Detections/hr
0.0
0.2
0.4
0.6
0.8
1.0
1.2
2005
2010
2015
2020

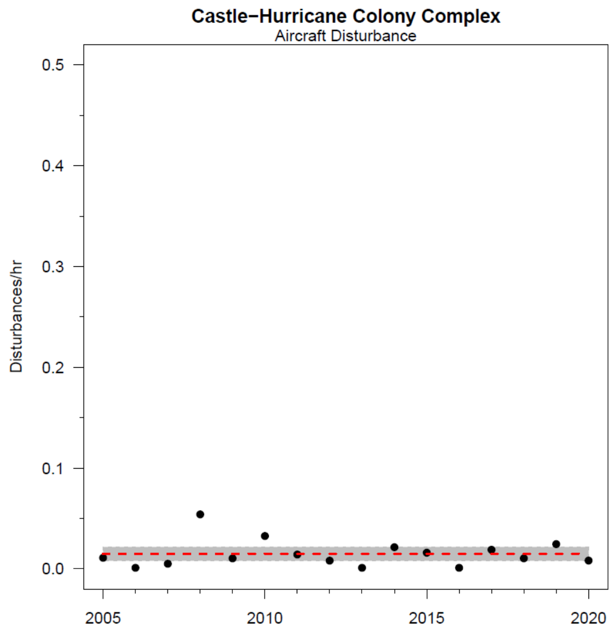

Castle−Hurricane Colony Complex
Aircraft detections
Detections/hr
0.0
0.1
0.2
0.3
0.4
0.5
2005
2010
2015
2020

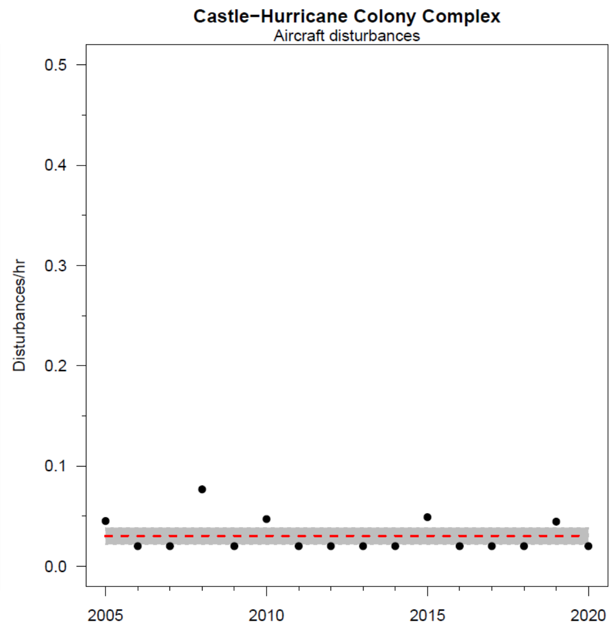

Castle−Hurricane Colony Complex
Watercraft Detections
Detections/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

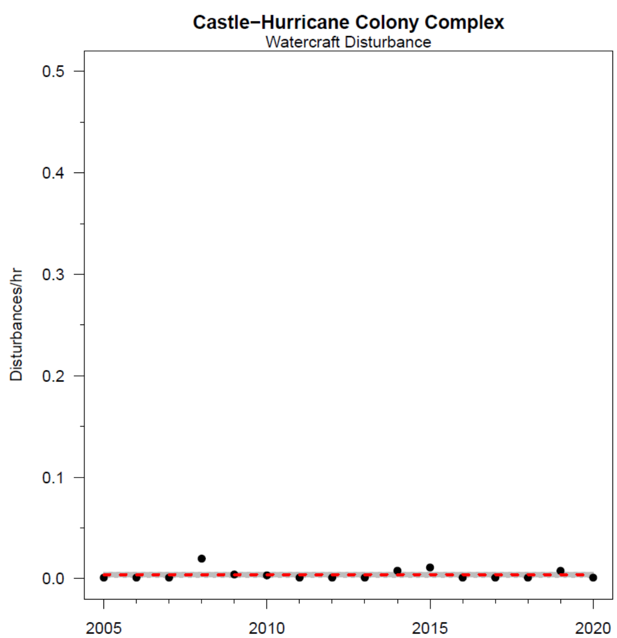

Castle−Hurricane Colony Complex
Watercraft detections
Detections/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

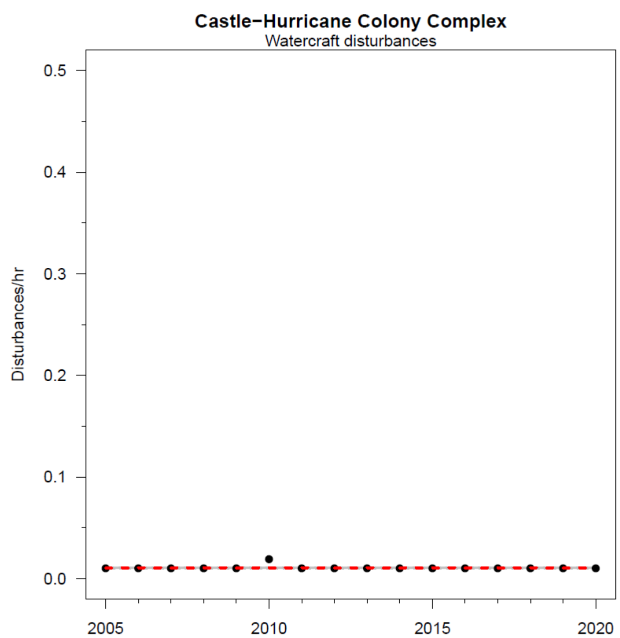

Castle−Hurricane Colony Complex
All anthropogenic sources
Disturbances/hr
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020


Castle−Hurricane Colony Complex
All anthropogenic sources
Disturbances/hr
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2005
2010
2015
2020

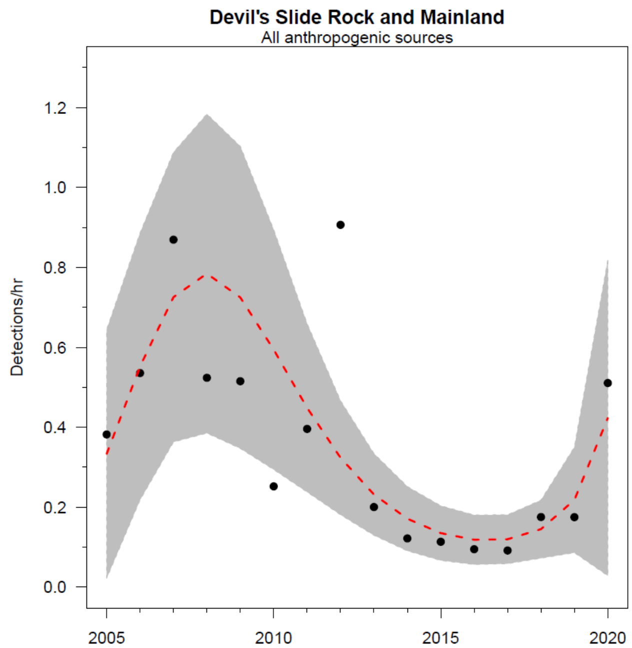

Castle−Hurricane Colony Complex
Aircraft Disturbance
Disturbances/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

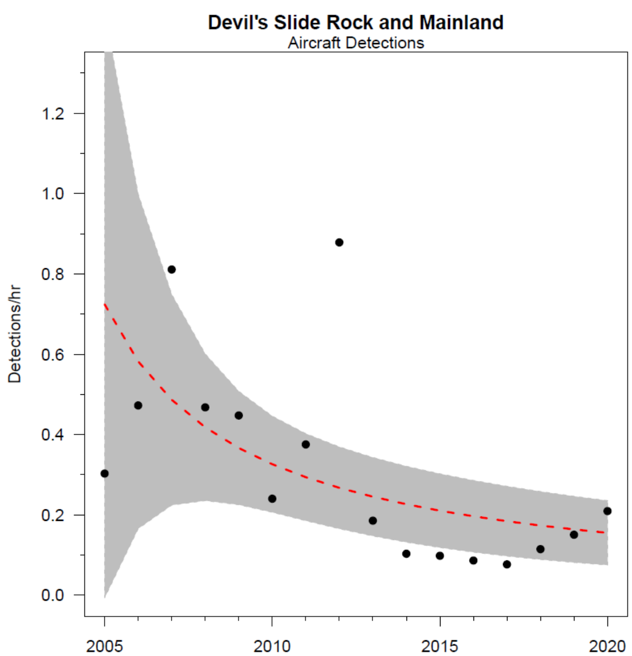

Castle−Hurricane Colony Complex
Aircraft disturbances
Disturbances/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

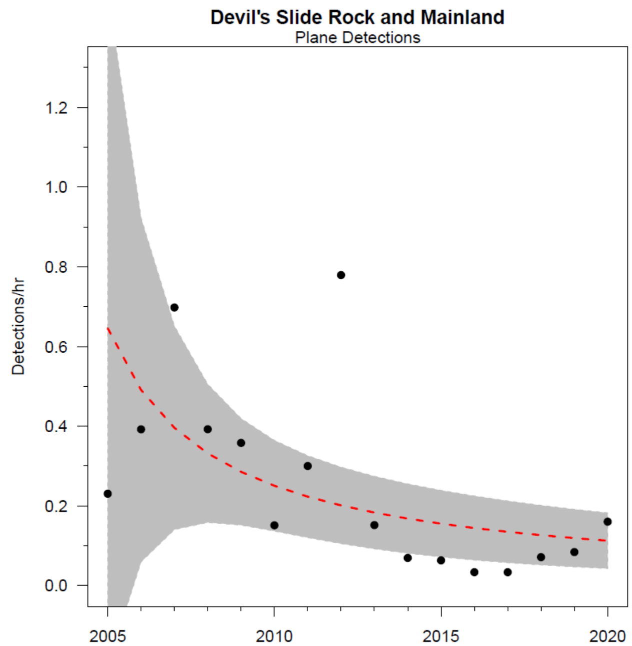

Castle−Hurricane Colony Complex
Watercraft Disturbance
Disturbances/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

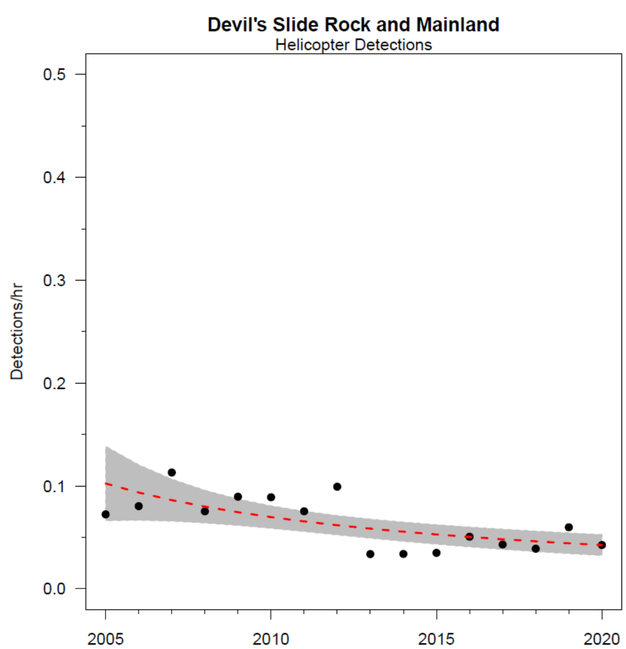

Castle−Hurricane Colony Complex
Watercraft disturbances
Disturbances/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

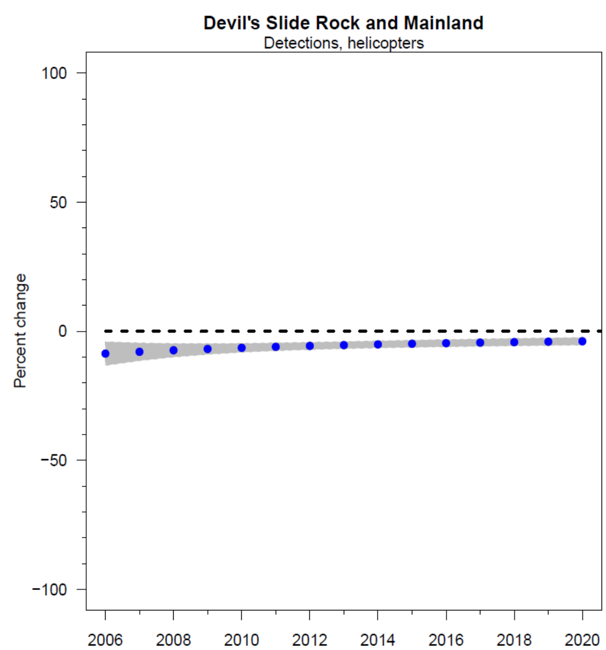
Appendix 4. Trends in anthropogenic detection rates, disturbance rates, and annual rates of change at Devil's Slide Rock & Mainland, 2005-2020. The left column shows rates and their trendlines based on generalized linear models. The right column displays the percent annual change in detection or disturbance rates. Percent annual changes are shown only if the relationships are statistically significant, with 95% confidence intervals that do not bound 0. Red dots indicate increasing rates, whereas blue dots indicate decreasing rates. Missing dots are not statistically significant.

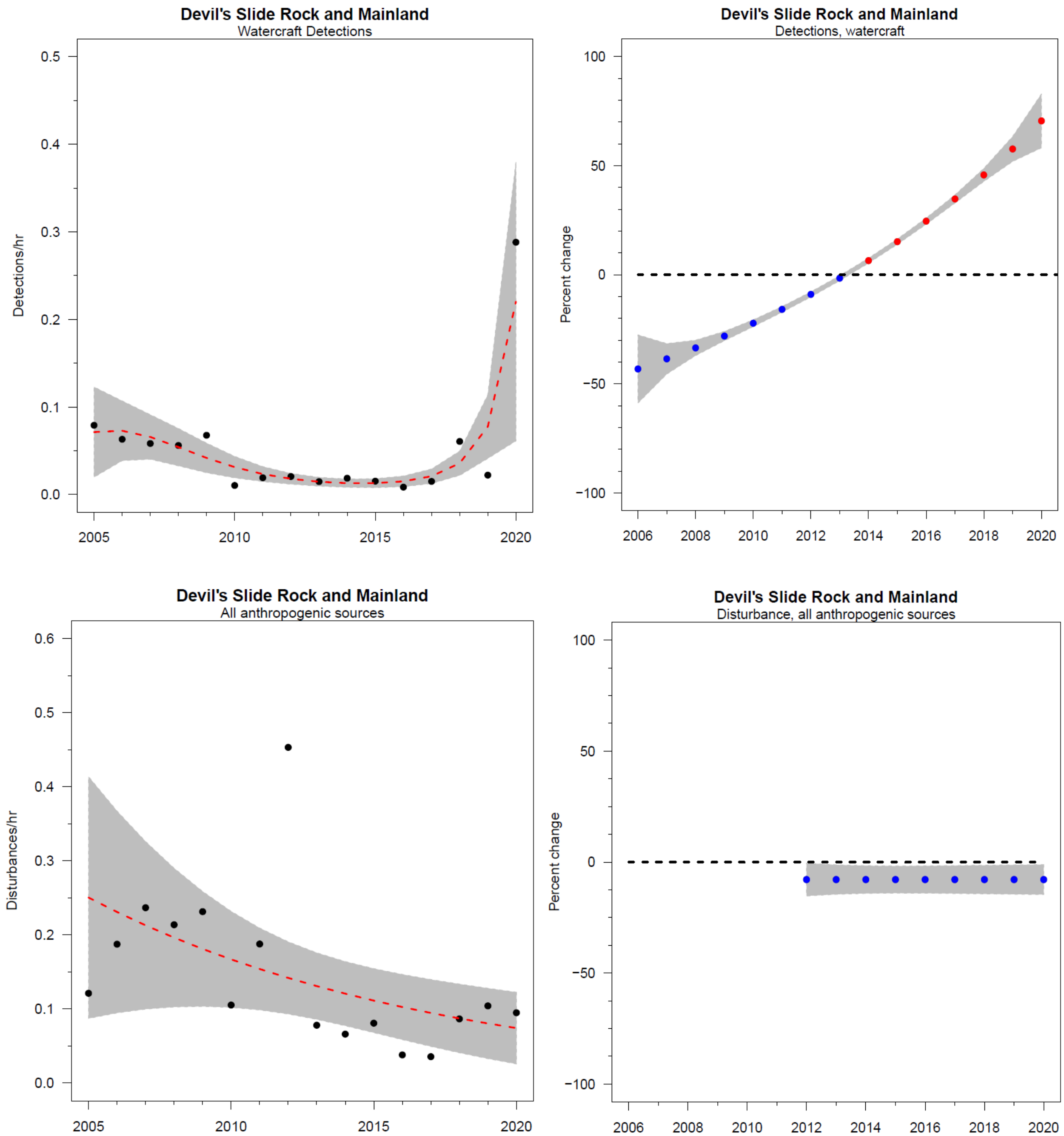




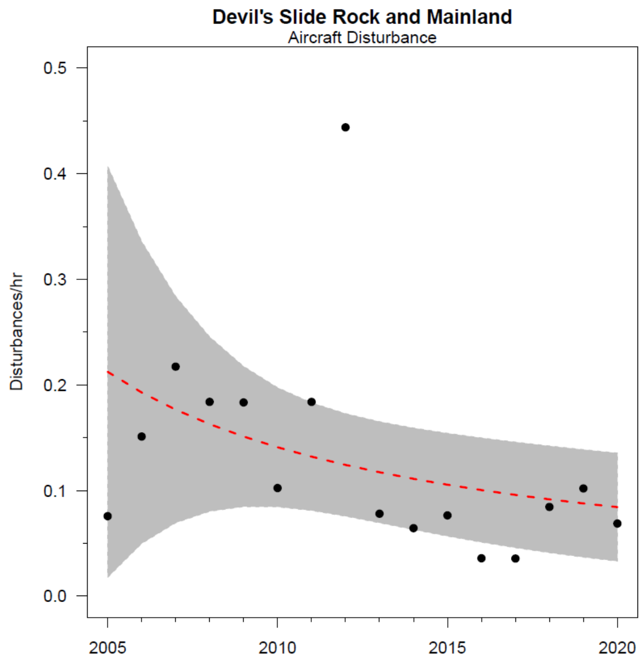

Devil's Slide Rock and Mainland
Plane Detections
Detections/hr
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2005
2010
2015
2020

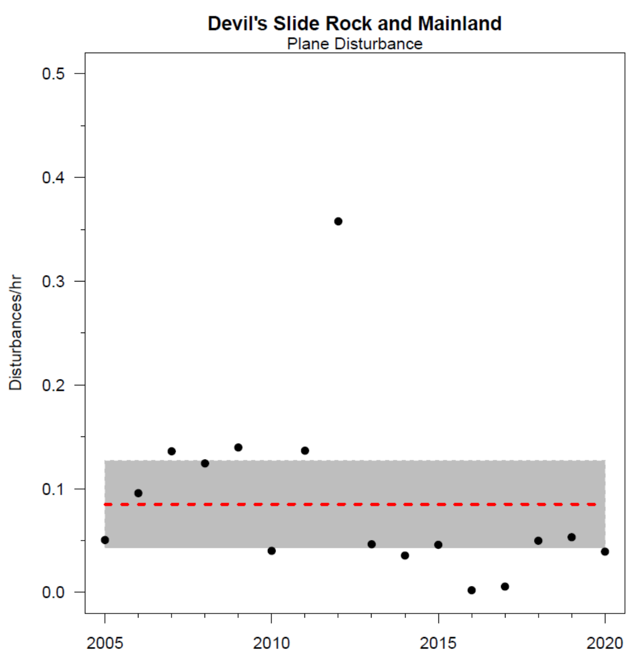

Devil's Slide Rock and Mainland
Helicopter Detections
Detections/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

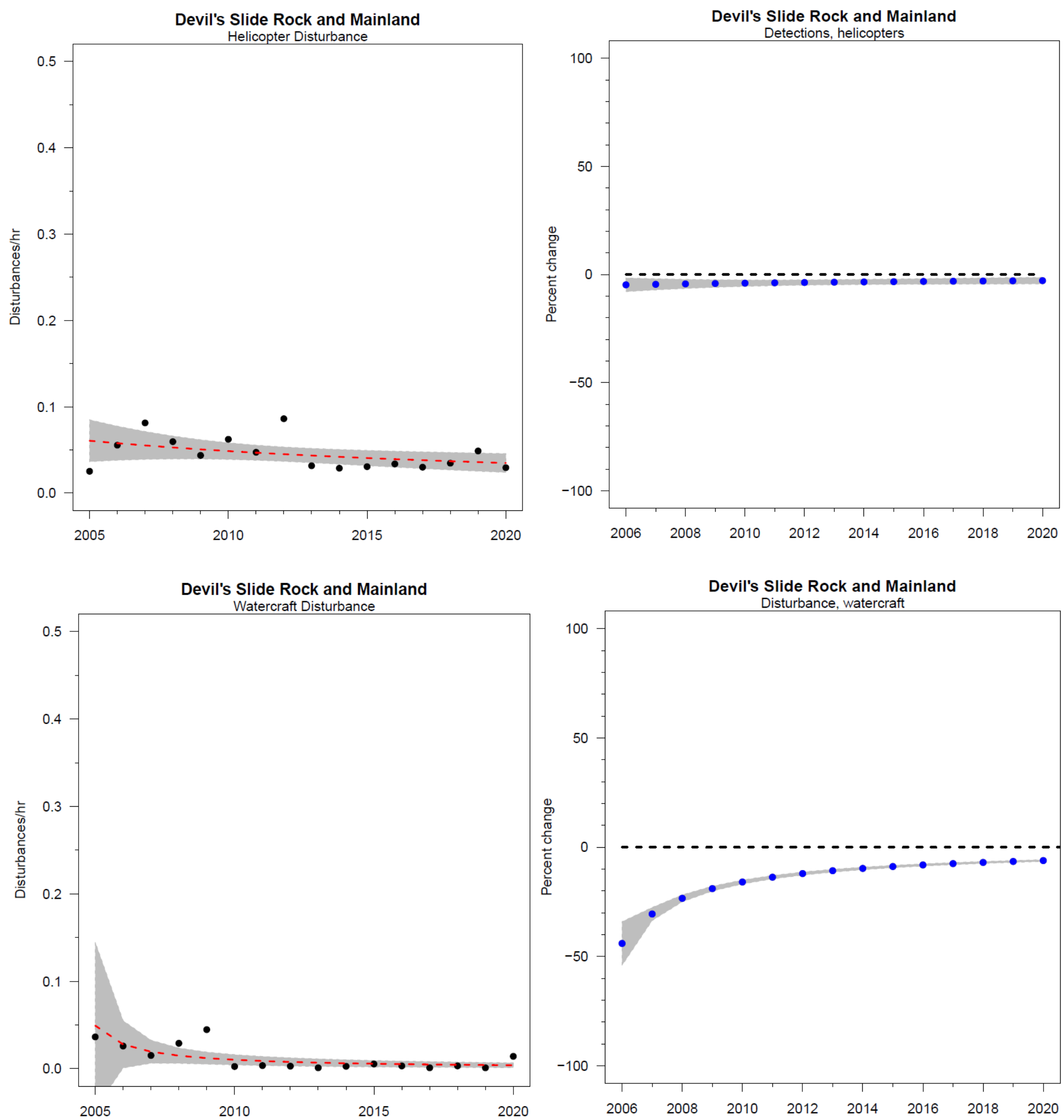

Devil's Slide Rock and Mainland
Detections, helicopters
Percent change
100
50
0
−50
−100
2006
2008
2010
2012
2014
2016
2018
2020



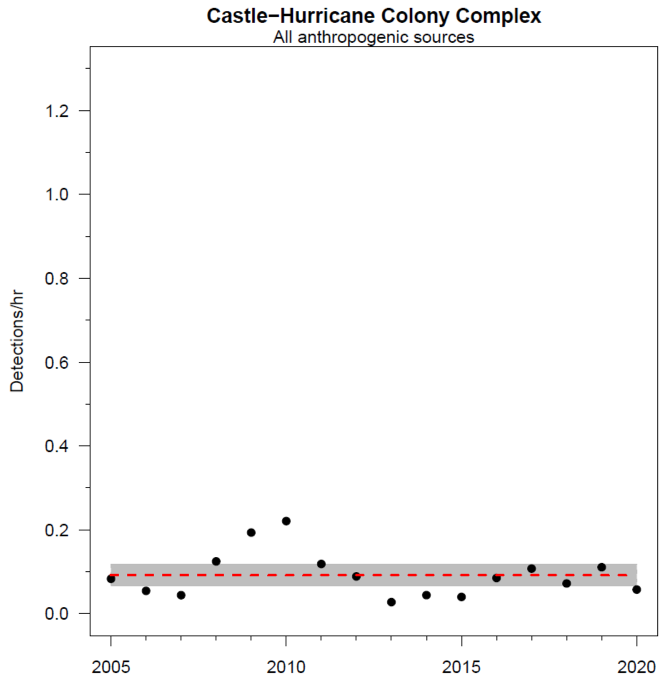
Devil's Slide Rock and Mainland
Watercraft Detections
Detections/hr
Devil's Slide Rock and Mainland
Detections, watercraft
Percent change
Devil's Slide Rock and Mainland
All anthropogenic sources
Disturbances/hr
Devil's Slide Rock and Mainland
Disturbance, all anthropogenic sources
Percent change

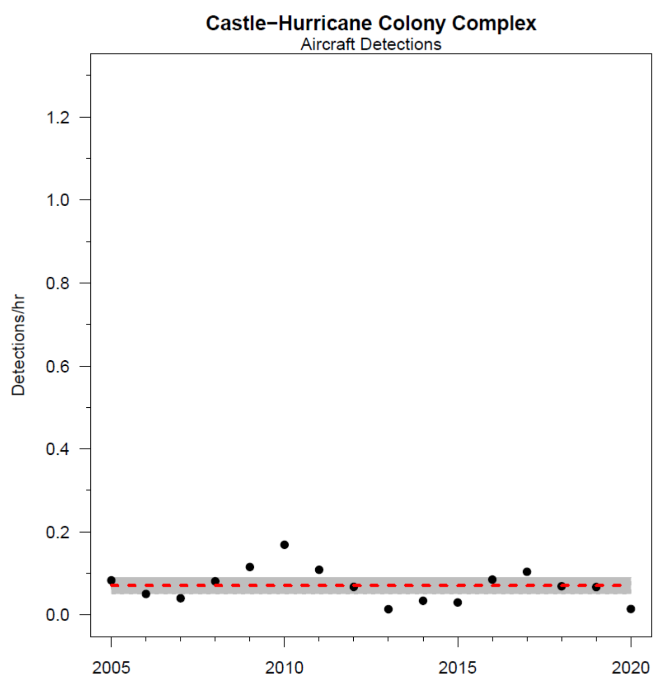

Devil's Slide Rock and Mainland
Aircraft Disturbance
Disturbances/hr
0.0
0.1
0.2
0.3
0.4
0.5
2005
2010
2015
2020

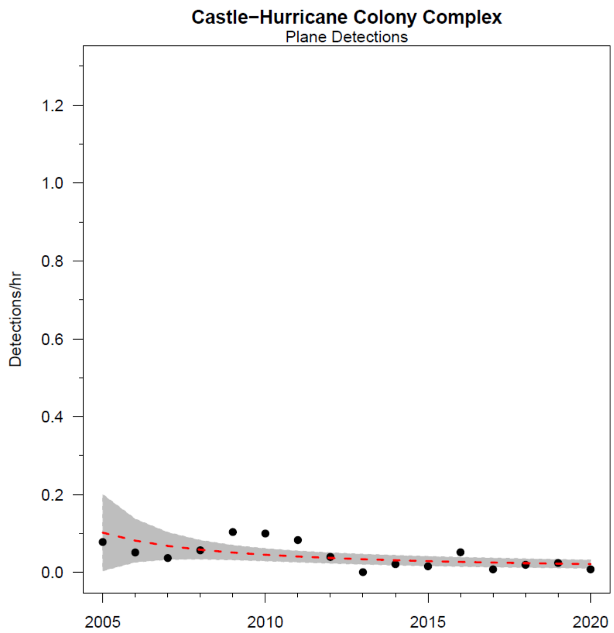

Devil's Slide Rock and Mainland
Plane Disturbance
Disturbances/hr
0.0
0.1
0.2
0.3
0.4
0.5
2005
2010
2015
2020


Devil's Slide Rock and Mainland
Helicopter Disturbance
Disturbances/hr
0.0
0.1
0.2
0.3
0.4
0.5
2005
2010
2015
2020
Devil's Slide Rock and Mainland
Detections, helicopters
Percent change
−100
−50
0
50
100
2006
2008
2010
2012
2014
2016
2018
2020
Devil's Slide Rock and Mainland
Watercraft Disturbance
Disturbances/hr
0.0
0.1
0.2
0.3
0.4
0.5
2005
2010
2015
2020
Devil's Slide Rock and Mainland
Disturbance, watercraft
Percent change
−100
−50
0
50
100
2006
2008
2010
2012
2014
2016
2018
2020

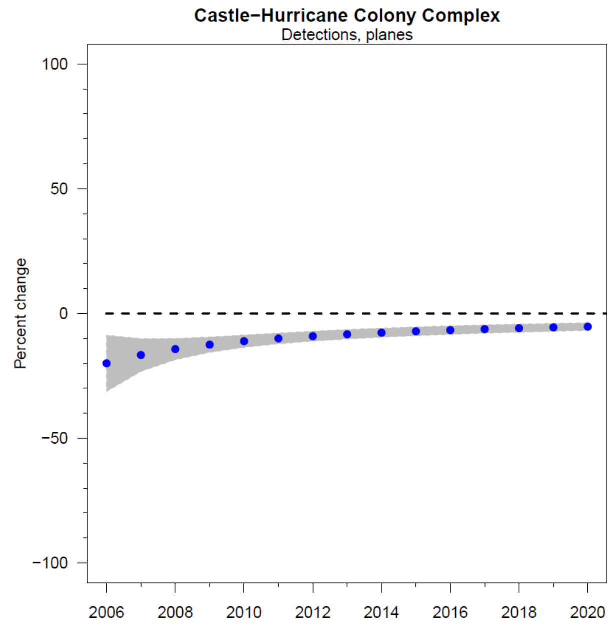
Appendix 5. Trends in anthropogenic detection rates, disturbance rates, and annual rates of change at Castle-Hurricane Colony Complex, 2005-2020. The left column shows rates and their trendlines based on generalized linear models. The right column displays the percent annual change in detection or disturbance rates. Percent annual changes are shown only if the relationships are statistically significant, with 95% confidence intervals that do not bound 0. Red dots indicate increasing rates, whereas blue dots indicate decreasing rates. Missing dots are not statistically significant.



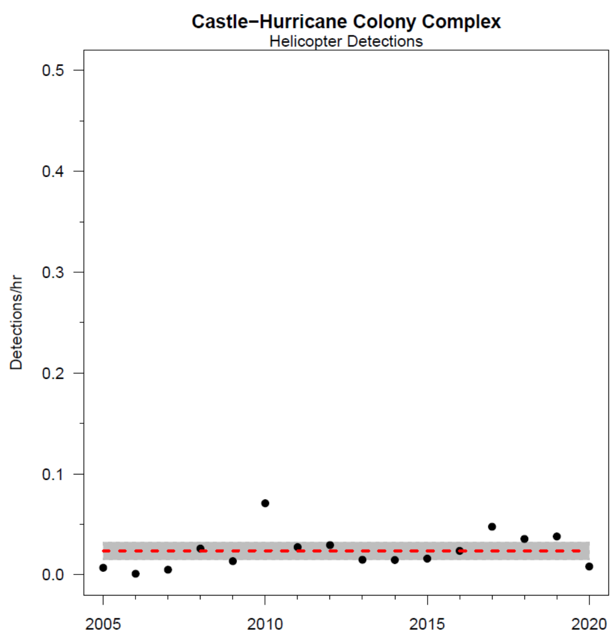




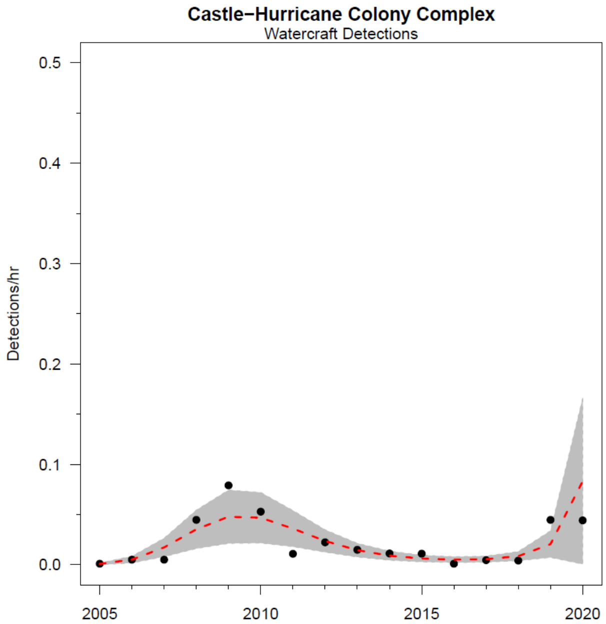
Castle−Hurricane Colony Complex
Plane Detections
Detections/hr
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2005
2010
2015
2020

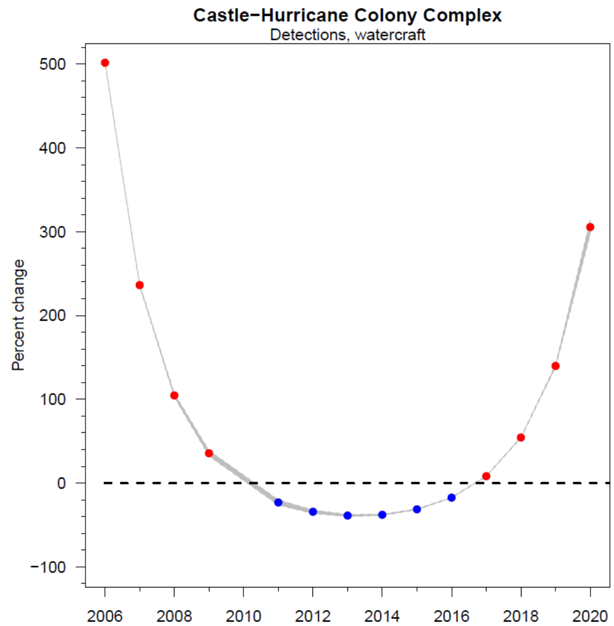


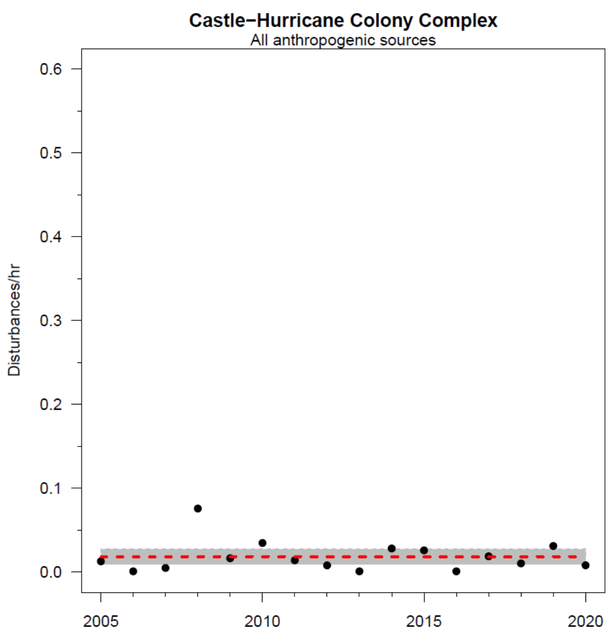
Castle−Hurricane Colony Complex
Detections, planes
Percent change
100
50
0
−50
−100
2006
2008
2010
2012
2014
2016
2018
2020

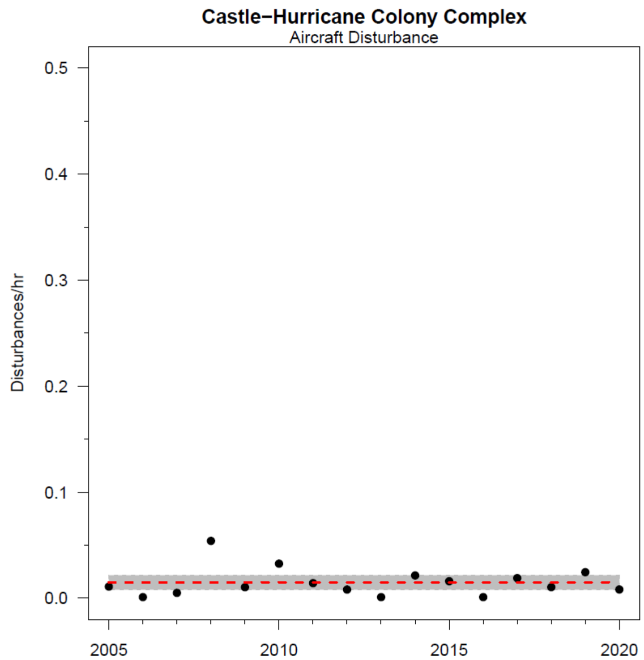


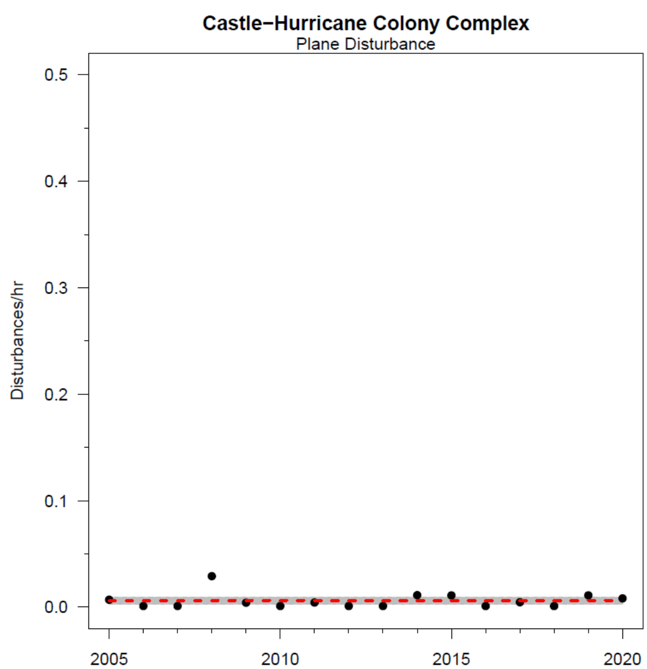
Castle−Hurricane Colony Complex
Helicopter Detections
Detections/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

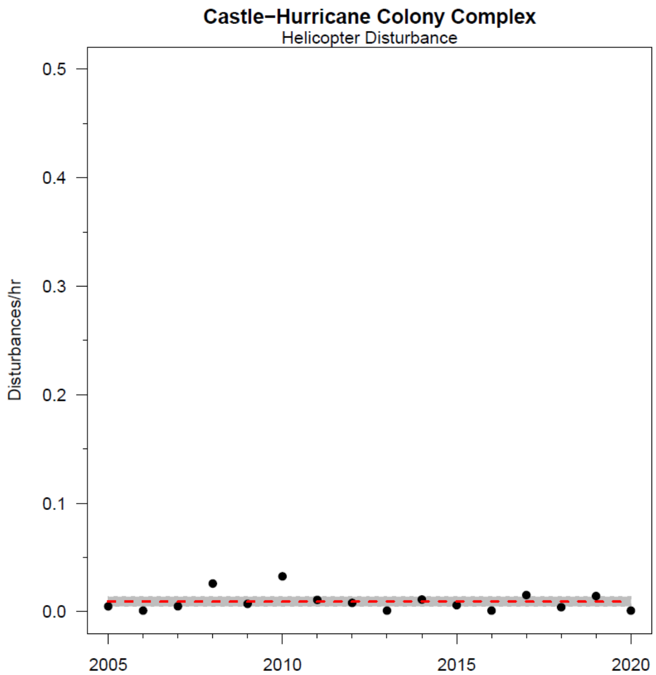

Castle−Hurricane Colony Complex
Watercraft Detections
Detections/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

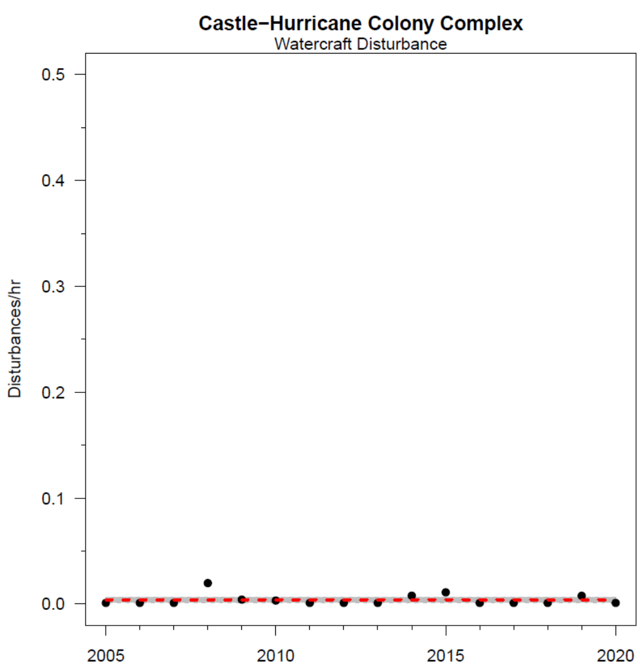

Castle−Hurricane Colony Complex
Detections, watercraft
Percent change
500
400
300
200
100
0
−100
2006
2008
2010
2012
2014
2016
2018
2020


Castle−Hurricane Colony Complex
All anthropogenic sources
Disturbances/hr
0.6
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020


Castle−Hurricane Colony Complex
Aircraft Disturbance
Disturbances/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020


Castle−Hurricane Colony Complex
Plane Disturbance
Disturbances/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020


Castle−Hurricane Colony Complex
Helicopter Disturbance
Disturbances/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020


Castle−Hurricane Colony Complex
Watercraft Disturbance
Disturbances/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

Appendix 6. Number of watercraft (detections and disturbances), categorized by type, at Point Reyes Headlands, Devil's Slide Rock & Mainland, and Castle-Hurricane Colony Complex, 2020.

a) Detection events

Affiliation	Motor Vessel (<25')	Motor Vessel (>25')	Kayak/Canoe (<25')	Sailboat (>25')	Total
Charter		40			40
Commercial		6			6
Law Enforcement		1			1
Private/Recreational	75	21	7	2	105
Research	2				2
Unknown		1			1
USCG		1			1
Total	**77**	**70**	**7**	**2**	**156**

b) Disturbance events

Affiliation	Motor Vessel (<25')	Motor Vessel (>25')	Kayak/Canoe (<25')	Total
Charter		1		1
Private/Recreational	4		1	5
Total	**4**	**1**	**1**	**6**