RESTORATION AND MONITORING OF COMMON MURRE COLONIES IN CENTRAL CALIFORNIA: ANNUAL REPORT 2021

REPORT TO THE *LUCKENBACH* TRUSTEE COUNCIL

Lauren C. Scopel, Cassie M. Bednar, Gerard J. McChesney, Mark A. Baran, Nadia J. Swanson, Mario V. Balitbit, Melanie Birch, Alec S. Mang, and Richard T. Golightly

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FINAL REPORT
January 2023

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Cover photo: Land-based photograph of Devil's Slide Rock, 10 May 2021 (Humboldt)

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ABBREVIATIONS USED

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

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

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 2021, the *Luckenbach* Oil Spill Trustee Council, comprised of California Department of Fish and Wildlife (CDFW), National Oceanic and Atmospheric Administration (NOAA), and Department of the Interior through U.S. Fish and Wildlife Service (USFWS) and National Park Service, provided funding and oversight.

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EXECUTIVE SUMMARY

Efforts in 2021 were the 26th 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. Additionally, 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 also enhances the restoration of previously injured colonies.

Following the delayed start to the 2020 field season, the 2021 field season started on time. Owing to concerns of virus transmission, we did not monitor the Castle-Hurricane Colony Complex in 2021, and initial training at the monitored field sites was conducted remotely. Monitoring began in early to mid-April at Devil's Slide Rock and Mainland and Point Reyes

Headlands. We conducted monitoring of human disturbance (mainly aircraft and watercraft), non-anthropogenic disturbance, seabird productivity, seabird attendance patterns, and relative population sizes at Devil's Slide and Point Reyes.

Detection rates of aircraft and watercraft were near long-term means in 2021, following especially high detection rates of watercraft in 2020. Detection rates at Point Reyes (0.03 detections/hr) were lower than recent years, especially via the number of detected planes. Disturbance rates at Point Reyes were very low: only a single helicopter event was recorded (0.002 disturbances/hr). Long-term trend analysis (2005-2021) indicated that detection of watercraft at Point Reyes declined following the earliest years of study, but recent increases have occurred, especially in 2020. All other sources of disturbance at Point Reyes were relatively rare during the time series, and no strong trends emerged. At Devil's Slide, detection rates in 2021 were higher than at Point Reyes (0.22 detections/hr). Disturbance rates at Devil's Slide (0.16 disturbances/hr) were the highest since 2012, especially by events involving planes (52%) and helicopters (41%). We recorded 76 total disturbance events at Devil's Slide, 33 (43%) of which involved the displacement or flushing of Common Murres. Long-term trend analysis showed that the detection rate of planes at Devil's Slide decreased over time. Watercraft detections initially decreased at Devil's Slide, but they have increased from 2018 onwards. Disturbances from all sources at Devil's decreased early in the time series, but they have increased since 2017; trends of individual sources were either not significant or of small magnitude (~0.05 disturbances/hr).

Among all detected aircraft and watercraft, general aviation planes (e.g., private or charter) were the most common (32%), followed by private recreational watercraft (26%) and U.S. Coast Guard (USCG) helicopters (17%). Among sources of disturbance, most were caused by general aviation planes (40%), USCG aircraft (25%) and unknown aircraft (17%). Five watercraft caused disturbances in 2021, all at Devil's Slide. One watercraft at Point Reyes and one at Devil's Slide were observed within Special Closure areas.

In our study of non-anthropogenic disturbance, we observed 79 events causing displacement, flushing, or seabird egg or chick loss; 6 occurred at Devil's Slide, and 73 occurred at Point Reyes. Common Ravens (*Corvus corax*) were a major issue at both field sites; at Devil's Slide, ravens caused 18% of non-anthropogenic disturbance events and depredated 9 murre eggs, and at Point Reyes, ravens caused 51% of non-anthropogenic disturbance events and depredated 2 murre eggs. Western Gulls (*Larus occidentalis*) were involved in 60% of non-anthropogenic disturbance events at Devil's Slide, but no eggs were taken. In mid-July, repeated disturbance by a Great Blue Heron at Point Reyes caused the abandonment of one of our murre productivity plots, including some chicks forced off the rock ("forced fledge").

In 2021, seasonal attendance patterns of Common Murres at Point Reyes were generally similar to long-term averages. Attendance at many plots continued later into August than is typical, and two plots had elevated attendance, especially in late June and early July. At Devil's Slide Rock, murre seasonal attendance was considerably greater than average (~24%). Murre attendance at Devil's Slide Mainland was ~600% greater than the long-term mean, suggesting that breeders are becoming more established there.

Common Murre productivity (chicks fledged per pair) in monitored plots was near average at Point Reyes (0.60 chicks/pair), above average at Devil's Slide Rock (0.83 chicks/pair), and similar to 2020 at Devil's Slide Mainland (0.67 chicks/pair), where productivity tends to be very low. Brandt's Cormorant (*Urile penicillatus*) productivity was near average at Devil's Slide (2.00 chicks/pair) and Point Reyes (2.05 chicks/pair). We recorded a land-based daily peak of 324 nests at Devil's Slide (356% greater than 2019), and 320 nests at Point Reyes (7% greater than 2019) when including fairly-built nests. At Devil's Slide, productivity of Pelagic Cormorants (*U. pelagicus*) was below average (1.12 chicks fledged/pair), and productivity of Western Gulls was near average (0.67 chicks fledged/pair). Black Oystercatchers (*Haematopus bachmani*) from one breeding site at Devil's Slide hatched, but none successfully fledged.

Aerial photographic surveys of Double-crested Cormorant, Brandt's Cormorant, and Common Murre colonies were not conducted in 2021.

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 owing to the implementation of restrictions on gill-net fishing, 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 less than <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 associated 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), as 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 2021. 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 2021.

METHODS

Study Sites

We monitored two colony complexes (PRH and DSCC) for productivity, disturbance, and attendance of seabirds in 2021 (Figure 1). We did not monitor CHCC in 2021, owing to concerns of exposure to COVID-19. Bird Island was also not monitored in 2021. 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 and Mainland (DSRM) and San Pedro Rock (SPR; Figures 3-4). The offshore rocks of DSCC 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. 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

Monitoring effort in 2021 was typical, resembling seasons prior to the pandemic. 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.

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 in which 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) owing to 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. Using generalized linear models, we examined and predicted trends in annual detection and disturbance rates between 2005-2021. 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 2021 rate of change examines the change in disturbance rate between 2020 and 2021.

The annual Pacific Coast Dream Machines festival, which typically takes place at the Half Moon Bay Airport, was cancelled owing to the ongoing COVID-19 pandemic in 2021. This event includes an aircraft fly-in and air tours, which in some years has caused high rates of seabird disturbance at Devil's Slide.

In addition to disturbance events, we incidentally 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 CalTIP ("Californians Turn in Poachers") or 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 2021, we recorded non-anthropogenic disturbance events that resulted in flushing or displacement of adult seabirds, or any disturbance to eggs and chicks (exposure, displacement, depredation, or scavenging). At DSRM, observations were structured into two-hour "Avian Disturbance Surveys", modeled after surveys conducted between 1999-2001 and 2017-2020 at overlooks for murre productivity. Each two-hour block between 0600-1800h was surveyed once every two weeks. We also recorded incidental observations from all overlooks. At PRH, observers recorded non-anthropogenic disturbance incidentally, from all observation overlooks (including Lighthouse Rock (LHR; PRH-03-B)). 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 and DSCC. 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 sometimes extended if necessary to complete the count. At productivity plots and a subset of subcolonies and subareas, we compared murre counts to weekly long-term patterns (2008-2020) and 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, we recorded attendance at established index plots. Plots were used at subcolonies with large populations, where whole counts were not practical or feasible. We created plot maps using photographs and recognizable landmarks to maintain consistent boundaries between seasons.

Point Reyes Headlands

We recorded counts of murre attendance at PRH once per week. Index plots were counted three times per survey; we reported the average of all counts. Plots included 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 15 April to 13 August from the Traditional Pullout overlook (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 (Figures 3-4); we counted murres three times per survey and reported the average. For San Pedro Rock (SPR), we conducted murre counts once per week throughout the breeding season from Bunker Overlook (Figure 3).

Common Murre Productivity

Like previous years, productivity (chicks fledged/pair) of murres was monitored at PRH and DSRM. CHCC was not monitored in 2021. 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 plots, we mapped and numbered all monitored sites using photographs of the colony from 2019. At DSR, we mapped and numbered all monitored sites using digiscoped photographs from 2018.

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 for <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 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 2021 to long-term means: PRH 1996-2002, 2005-2015, 2017-2020 (n=22 years), and DSR 1996-2020 (n=25 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 5). Since 2006, as plots continued to fill with more murres, we adjusted plot boundaries based on the visibility of sites. In 2014, we dropped Plot C owing to poor viewing conditions, and in 2015 we added Plot D in an attempt to monitor the edge effects previously captured in Plot C (Figure 5). We periodically dropped sites from the sample if poor viewing conditions obstructed our ability to record productivity data. We added new sites as birds established new territorial or breeding sites (Figure 5).

In 2021, we monitored 208 sites within DSR plots (Figure 5). We monitored all active sites in plots beginning 16 April. With the increased success of mainland-nesting murres in recent years, we monitored an additional 51 sites in a plot on DSRM-05-A-Lower in 2021.

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. 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 typically report the sum of seasonal peak counts of well-built nests (including nests with chicks) at each subcolony or subarea; in 2021, owing to larger numbers of fairly built nests with eggs, we report the number of well-built and fairly built nests.

Brandt's Cormorant Productivity

When vantage points provided adequate viewing at PRH and DSRM, we monitored Brandt's Cormorants for breeding phenology and reproductive success (clutch sizes, brood sizes, and chicks fledged per pair). CHCC was not monitored. We create new plots each year near overlooks with clear vantages. At PRH in 2021, we monitored Beach Rock (PRH-10-E), Arch Rock (PRH-11-D), Spine Point (PRH-11-E-Spine), Wishbone Point (PRH-11-E-Wish), Sloppy

Joe (PRH-12-A), West Cone (PRH-13-WC), Area B (PRH-14-B), and Mainland (PRH-14-E; Figure 2). At DSRM, we monitored Lower Mainland South (DSRM-05-A Lower), Upper Mainland South (DSRM-05-A-Upper), Turtlehead (DSRM-05-B), DSRM-05-C, and DSRM-05-AF (Figures 3-4).

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 identify without marking (Carter and Hobson 1988, McChesney 1997). We compared results from 2021 to long-term means for PRH (1997-2001, 2006-2015, 2017-2019; n=18 years) and DSRM (1997-2007, 2009-2019; n=22 years).

Pelagic Cormorant, Black Oystercatcher, and Western Gull Productivity

At DSRM, we monitored the productivity of Pelagic Cormorants, Black Oystercatchers, and Western Gulls 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 ≥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). We compared 2021 results to long-term averages (2006-2019; n=14 years).

Pigeon Guillemot Surveys

To assess relative population sizes and seasonal attendance patterns of Pigeon Guillemots, we conducted standardized counts from mid-April to late June at PRH and DSCC. We conducted surveys twice per week from mid-April to 5 May, when numbers often peak, and once per week thereafter. 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 0830h. 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).

Common Murre and Brandt's Cormorant Breeding Population Sizes

We did not conduct aerial surveys in 2021. All relative population sizes are estimated from land-based counts of visible breeding areas.

RESULTS

Anthropogenic Disturbance

During the 2021 field season, we performed 1106 hours of monitoring effort at PRH and DSCC combined (Table 1). Following exceptionally high detection rates of watercraft in 2020, detection rates in 2021 were closer to long-term means. Detection and disturbance rates were higher at DSRM than at PRH, as is typical. We recorded 91 aircraft within our detection zones at PRH and DSRM; these included 37 helicopters, 54 planes, and 3 uncrewed aerial systems (UAS, i.e., drones; Tables 2-3). Overall, 71 (78%) of these overflights resulted in disturbance to seabirds (agitation, displacement, or flushing). The sources of disturbance events included 39 planes and 32 helicopters. Flushing or displacement of murres resulted from events involving 23 helicopters and 8 planes. The most frequently detected aircraft types were general aviation, USCG, and unknown affiliation (Figure 6, Appendix 1-2). At PRH from 2005-2021, there were no significant trends in detection or disturbance rates of aircraft (Appendix 3). At DSRM from 2005-2021, there were significant declining trends in annual plane detection rates, and complex but small changes in helicopter detection and disturbance rates (Appendix 4).

We observed 37 watercraft within the 1,500-ft detection zone around our monitored colonies, including 31 recreational motor vessels, 2 kayaks, 1 commercial motor vessel, and 1 sailboat (Tables 2-3, Figure 7). We observed 5 disturbance events involving watercraft; 2 resulted in agitation, and 3 caused displacement or flushing (Appendix 2). Long-term trend analysis at PRH and DSRM indicated that watercraft detection rates declined early in the time series, but they increased in recent years, especially in 2020. There were no significant trends in watercraft disturbance rates at PRH and declines of small magnitude at DSRM (Appendix 3-4). Owing to inconsistencies in the recording of watercraft detections at DSRM between 2015-2018, trends including those years should be considered with caution.

We submitted 71 SPN Wildlife Disturbance Reports in 2021 (1 from PRH, 70 from DSCC). These included 32 reports of flushing or displacement, and 39 reports where only agitation was documented. We reported 65 events involving aircraft disturbance and 5 involving watercraft disturbance.

We recorded multiple watercraft in Special Closures in 2021. At PRH, one watercraft entered the Special Closure but caused no disturbance. At DSRM, one vessel caused two disturbance events on the same day, both involving agitation and flushing.

Point Reyes Headlands

At PRH, we recorded 18 watercraft, 5 aircraft, and 1 UAS within our detection zones in 2021 (Table 2; Figure 8); we saw fewer planes compared to 2020. We recorded only one disturbance event, where a USCG helicopter caused murres and other seabirds to flush (Figure 9). We recorded 0.039 detections/hr, and 0.002 disturbances/hr, reflecting a decrease in detections and disturbance rates in 2021 (Figures 8, 10, Appendix 3).

Long-term trends at PRH were complex. Watercraft detection rates decreased between 2006-2013 (annual mean rate of change 29%, range 6-49%) and increased thereafter (annual mean rate of change 50%, range 3-90%; Appendix 3). Among all anthropogenic sources, watercraft were the most commonly observed (55% of total detections, annual range 0-83%), so long-term total trends showed a similar pattern to watercraft detection rates. Disturbance rates were generally very low; across all sources, disturbance rates declined between 2006-2010 (annual mean rate of change 31%, range 1-60%), then fluctuated at low numbers afterwards (Appendix 3).

Devil's Slide Rock and Mainland

At DSRM, we detected 53 planes, 33 helicopters, 19 watercraft, and 2 UAS in 2021 (Table 3). We recorded 0.22 detections/hr and 0.16 disturbances/hr (Figures 8, 10). Disturbance rates in 2021 were the highest recorded since 2012, reflecting increasing rates of aircraft disturbance (Appendix 4). We recorded 70 overflights resulting in disturbance to seabirds (39 planes and 31 helicopters), as well as 5 watercraft (Table 3). One loud motorcycle on the Devil's Slide Trail also caused agitation to murres.

There were 30 total flushing events caused by aircraft, including 10 USCG helicopters, 7 general aviation helicopters, 4 unknown helicopters, 4 general aviation planes, 2 military planes, 1 military helicopter, 1 USCG plane, and 1 unknown plane (Appendix 1). Watercraft caused 3 additional flushing events, all by private or recreational vessels. The largest disturbance event occurred on 15 May when a military medical helicopter caused 1,500 murres to be agitated, and 600 murres, 8 Brandt's Cormorants, 1 Pelagic Cormorant, and 1 Pigeon Guillemot to flush (Figures 11-12).

Long-term trends in aircraft detection rates fluctuated. Plane detections decreased beginning in 2014 (annual mean rate of change 12%, no range), and helicopter detections initially decreased (2010-2017 annual mean rate of change 10%, range 2-13%), but helicopter detection rates increased beginning in 2018 (annual mean rate of change 13%, range 2-30%, Appendix 4). Watercraft detection rates decreased between 2006-2013 (annual mean rate of change 22%, range 3-40%) and increased afterwards (annual mean rate of change 34%, range 4-68%). Among all anthropogenic sources, aircraft are more commonly observed than watercraft (87% vs. 12% of detections, respectively; ranges 41-97%, 2-57%), so long-term trends show a net decline. Owing to relatively low disturbance rates, trends are best described by all sources combined: disturbance rates increased between 2006-2008 (annual mean rate of change 22%, range 13-30%), decreased between 2010-2017 (annual mean rate of change 9%, range 2-13%), and increased afterwards (annual mean rate of change 19%, range 2-44%, Appendix 4). These recent increases were driven by aircraft disturbance.

Non-Anthropogenic Disturbance

Point Reyes Headlands

Incidental Non-Anthropogenic Disturbance

We observed 73 incidental events of non-anthropogenic disturbance at PRH in 2021; 71 involved displacement or flushing (97%). Common Ravens (*Corvus corvax*) caused most of the disturbance events (51%) and depredated 2 murre eggs. We also observed disturbance by Turkey Vultures (*Cathartes aura*, 14% of observations), a Great Blue Heron (*Ardea herodias*, 12%), unknown sources (10%), Brown Pelicans (*Pelecanus occidentalis,* 5%), Peregrine Falcons (4%), Western Gulls (*Larus californicus,* 3%), and Red-tailed Hawks (*Buteo jamaicensis*, 1%).

A Great Blue Heron caused major disturbances on 14 and 16 July in Edge Plot on LHR. The heron stalked and harassed adult murres and depredated chicks. On 14 July, most adults flushed from the plot, but some remained with their chicks, and several chicks were still seen in the plot on 15 July. On 16 July, all adults and chicks were flushed from the plot by the heron ("forced fledge"), and no chicks returned afterwards. The heron was seen sporadically throughout the rest of the season, taking younger-staged chicks from other parts of LHR.

Devil's Slide Rock and Mainland

Avian Disturbance Surveys

At DSR, we conducted 92.17 hours of avian disturbance surveys and recorded 716 disturbance events (7.77 events/hr). Common Ravens caused 18% of disturbance events (Figure 13), but they were also involved in the most severe disturbances, depredating 7 murre eggs. Western Gulls (*Larus occidentalis*) caused 60% of disturbance events, and they were responsible for ~50% of the disturbance events resulting in displacement or flushing, but no eggs were taken. Brown Pelicans (13%), Heermann's Gulls (*Larus heermanni*, 8%), Great Blue Herons (<1%), one California Gull, and one Snowy Egret (*Egretta thula*) caused additional disturbance events.

Incidental Non-Anthropogenic Disturbance

We recorded 6 incidental disturbance events. Brown Pelicans caused 3 (50%), Common Ravens caused 2 (33%), and a Great Blue Heron caused 1 (17%). The largest event occurred on 6 June when a heron flew over the colony, causing 1500 murres to head-bob, and 200 murres and 3 Brandt's Cormorants to flush. We observed 14 murre eggs taken during the season, 13 by ravens and 1 by a Western Gull. We also observed 1 murre chick get taken by ravens.

Common Murre Seasonal Attendance Patterns

Point Reyes Headlands

In 2021, we observed peak counts at subcolonies between 22 April – 14 July. Attendance patterns at most established count plots resembled long-term patterns, with numbers declining abruptly in late July as adults and chicks departed the colony (Figures 14-15). Counts at Edge Plot and Cone Rock were above average in June and early July, and may reflect continuing colony growth. Counts at other subcolonies tended to be greater than counts in 2019, and most peak counts occurred earlier in the season (Figures 16-19). We first observed unattended subcolonies on July 29 (PRH-04, PRH-11-B), and by the last count on 12 August, 61% of active subcolonies were unattended.

Subcolonies with more variable counts usually reflected more activity from socializing non-breeders in roosting areas ("clubs"). At Wishbone Point (PRH-11-E-Wish) and Sloppy Joe

(PRH-12-A), murre attendance didn't begin until mid-May, but breeding was confirmed at both subcolonies. We have considered these subcolonies to be ephemeral breeding areas, with murres present in some years but not others, although recently Sloppy Joe has been used more consistently.

Devil's Slide Rock & Mainland and San Pedro Rock

Devil's Slide Rock

We observed murres attending on all count days between 15 April and 7 August. The peak count occurred on 14 May with 1,731 murres (Figure 20), two weeks after the first egg was observed (30 April); this count was 12% lower than the peak count of 1,972 murres in 2019. During the pre-laying period, we observed murres leaving DSR in large numbers in the afternoon. Attendance patterns were generally consistent through the breeding period; from 24 May to 23 July, counts averaged 1,339 murres (range: 1,056-1,589), but after 23 July numbers decreased quickly as chicks and adults departed from the colony. By 9 August, all murres had departed the colony for the season.

Attendance patterns in 2021 resembled the long-term pattern (2008-2020), except that mean attendance was ~24% greater than the long-term mean (Figure 20). While early years of the time series reflected a much smaller colony than today's, counts in recent years have been closer to counts in 2021. We changed our counting protocols in 2018 from real-time counts through spotting scopes to digital counts from photographs. Digital counts from photographs appear to be much less variable than counts by spotting scope, and this may affect comparisons to previous years. Any use of these data for long-term analyses should take these differences into account.

Devil's Slide Mainland and San Pedro Rock

We consistently observed murres attending Lower Mainland South (DSRM-05-A Lower), Upper Mainland South (DSRM-05-A-Upper), Turtlehead (DSRM-05-B), and South of Turtlehead Cliffs (DSRM-05-C). Murres bred successfully on the mainland in 2021, with at least one large (Stage IV) chick seen in each of these subareas. Additionally, we observed murres intermittently amongst nesting and roosting Brandt's Cormorants at other Mainland South subareas (DSRM-05-A Roost, DSRM-05-AF), but we did not confirm any breeding behavior. In 2021, seasonal attendance at mainland subcolonies was much greater than in previous years; counts averaged ~50% greater than 2019, and ~600% greater than the long-term mean (2008-2020; Figure 20). We observed no murres on San Pedro Rock in 2021.

Common Murre Productivity

Point Reyes Headlands

In 2021 we monitored 195 sites in Ledge (n=111) and Edge (n=84) plots on LHR; 162 of these were breeding sites (83%), 32 were territorial sites (16%), and 1 was sporadic (1%). The mean egg laying date (including only first clutch dates) was 22 May ± 6.89 (range 8 May–12 June, n=86; Table 4), five days earlier than the long-term mean (27 May ± 1.8 days). We recorded 13 replacement eggs. Hatching success was 76.3%, and fledging success was 75%. Productivity of 0.60 chicks fledged/pair was slightly higher than the long-term mean (0.50 chicks fledged/pair, Figure 21). Chicks fledged at a mean age of 24 ± 0.48 days, and the last chick was observed on 5 August (Table 4).

In Edge Plot, major disturbances events by a Great Blue Heron took place on 14 and 16 July, which resulted in a forced fledge of all chicks left in the plot (see above). Some chicks may have departed without their parents, but we considered chicks from this plot as fledged if they were ≥15 days old when last observed and were not known to have perished.

Devil's Slide Rock and Mainland

Of 208 attended sites at DSR, 187 (90%) were breeding, 15 (7%) were territorial, and 6 (3%) were sporadic. We observed the first murre egg on 30 April, in productivity plot B, and it was depredated by ravens. At all sites combined, the mean egg-laying date for first eggs was 24 May ± 6.15 (range 13 May–12 June, n = 69; Table 5), near the long-term mean (26 May ± 1.7 days). We recorded 187 eggs laid, including 3 replacement eggs. Overall productivity of 0.83 chicks fledged/pair was above average (0.65 ± 0.05; Figure 18). High productivity was bolstered by both high hatching (84.7%) and fledging (95.6%) success. Chicks that fledged remained on DSR for an average of 22.75 ± 0.50 days (n = 36), and the last chick was seen on 1 August (Table 5).

Of 51 sites monitored on DSM, 49 (96.1%) were breeding and two (3.9%) were sporadic. We observed the first murre egg on 13 May. Monitoring of most breeding sites did not begin until we confirmed that an egg was present, thus we cannot calculate most egg-laying dates with high precision. We recorded 54 eggs laid, including 4 replacement eggs. Overall productivity of 0.67 chicks fledged/pair was similar to 2020 and greater than the long-term mean (0.31; Table 5, Figure 21). Hatching success was fairly low (68.5%), but fledging success was high (94.4%). Chicks fledged on average at 23.14 ± 0.80 days (n = 14), and the last chick was seen on 31 July (Table 5).

Brandt's Cormorant Nest Surveys and Productivity

We reported seasonal peak nest counts of Brandt's Cormorants obtained from weekly land-based surveys (PRH and DSRM; Table 6). Not all nests were visible from our observation points, so nest counts should be considered a minimum. Consequently, comparisons to previous years should be considered with caution.

Point Reyes Headlands

Nest surveys

We conducted Brandt's Cormorant nest surveys weekly from 22 April–7 July. We recorded well-built nests at Beach Rock (PRH-10-E), Arch Rock (PRH-11-D), Wishbone Pt. (PRH-11-E-Wish), Spine Pt. (PRH-11-E-Spine), Sloppy Joe (PRH-12-A), West Cone (PRH-13-WC), Area B

(PRH-14-B), and Area B Mainland (PRH-14-E). Nesting areas with fairly built and poorly built nests also included Little Rock (PRH-10-G), the mainland area of PRH-10, and Tim Tam (PRH-10-H). When counting only well-built nests, we recorded a high count of 90 nests on 3 July, which we feel did not accurately reflect the size of the breeding cormorant population; many eggs were laid in fairly built nests. We therefore added fairly built nests to the high count, resulting in 320 nests on 7 July (Table 6). The sum of land-based seasonal peak counts from each subcolony was 334 including fairly built nests (102 without); this represents a 10% increase over 2019 (303 nests).

Productivity

At PRH, we monitored 125 nests at 8 subareas, all of which were egg-laying sites (Table 7). We observed the first eggs on April 29, and the mean date of clutch initiation in was 30 May ± 8.87 (range 2 May–17 June, n=112), later than the long-term mean (17 May ± 3 days). The first chicks hatched on 4 June. For all subareas combined, productivity was 2.05 chicks fledged/pair (subarea range 0.67–2.50), near the long-term mean (1.84 ± 0.14 chicks fledged/pair, Figure 22). Breeding success/nest (egg-laying nests that fledged at least one chick) was 0.87 (subarea range = 0.33–1.00; Table 7), indicating low nest failure.

Devil's Slide Rock and Mainland

Nest surveys

We counted nests and territorial sites between 19 April–6 July. We observed the first well-built nests on 16 April. When counting only well-built nests, the single-day peak count was 264 on 6 July, but when fairly-built nests were included, the single-day peak count was 324 nests on 28 June (Table 6). The single-day peak count including fairly-built nests was 356% higher than in 2019 (91 nests; 290% higher without fairly-built nests). The peak count of nests on DSR was 17 on 28 June when including fairly-built nests (8 without; 3 June). On the mainland, nesting occurred on Turtlehead (DSRM-05-B; peak count 87 nests), April's Finger (DSRM-05-AF; peak count 85 nests), Lower Mainland South (DSRM-05-A-Lower; peak count 42 nests), Upper Mainland South (DSRM-05-A-Upper; peak count 81 nests), and South of Turtlehead Cliffs (DSRM-05-C; peak count 26 nests). The sum of land-based seasonal peak counts by subcolony totaled 346 nests when including fairly-built nests (281 without), 353% higher than in 2019 (98 nests; 287% higher without fairly-built nests).

Productivity

We monitored 156 breeding sites at 5 subareas in 2021 (Table 8). We first observed eggs on 15 April on both DSRM-05-B and DSRM-05-C. For all subareas combined, the mean clutch initiation date was 8 May ± 10.67 days (range = 14 April–17 June, n=145), earlier than the long-term mean (13 May ± 2.2 days). We recorded the first hatched chicks on 15 May. Overall productivity was 2.00 chicks fledged/pair (range = 0–4; n = 150), which was significantly higher than the long-term mean (1.72 ± 0.15 chicks fledged/pair; Figure 22). Overall breeding success/nest was 0.91 (subarea range 0.80-1.00; Table 8), indicating low 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 6). 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 considered 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.

The 2021 peak standardized count for Pigeon Guillemots at PRH was 71 birds on 16 April, 26% lower than the peak count in 2019. The 2021 peak standardized count at DSRM was 102 guillemots on 26 April, 38% lower than the peak count in 2019.

Productivity

We summarized the results of productivity monitoring for Western Gulls, Black Oystercatchers, and Pelagic Cormorants at DSRM (Table 9).

Pelagic Cormorant

At DSRM, we monitored Pelagic Cormorant productivity at 24 nest sites on DSRM-04, DSRM-05-A-Lower, DSRM-05-A-Upper, DSRM-05-B, DSRM-05-C, and DSRM-05-D. We observed the first egg on 27 April on DSRM-05-C. Overall productivity of 1.30 chicks fledged/pair was near the long-term mean (1.45 ± 0.19; Table 9, Figure 23).

Western Gull

We monitored 6 Western Gull nests at DSRM in 2021. We observed the first egg on 14 May. Gull productivity at DSRM was 0.67 chicks fledged/pair, which was near the long-term mean (0.64 ± 0.12; Figure 24).

Black Oystercatcher

One Black Oystercatcher nest was visible and followed for productivity. We observed the pair incubating 11 June on Keyhole Point (within DSRM-07). At least one chick hatched by 9 July, but it disappeared subsequently and is assumed not to have fledged.

DISCUSSION

COVID-19 continued to affect our monitoring in 2021. While we were able to monitor the entire breeding season in 2021, multiple measures were required to ensure the safety of our field crews, including virtual training and the suspension of monitoring at Castle-Hurricane Colony Complex. Some protocols may have been inadequately communicated while in a virtual space, especially the distinction between different types of cormorant nests. We continue to carefully monitor state and federal recommendations for safe work practices, while maintaining the quality of our long-term data and monitoring efforts.

Anthropogenic Disturbance

Like recent years, Devil's Slide was subject to the highest anthropogenic detection and disturbance rates among our study areas. Despite increasing watercraft detection rates, increasing overall disturbance rates appear to be driven only by planes and helicopters. While disturbance rates were still well below the maximum observed in 2012, these rates are beginning to match and surpass some rates recorded prior to 2012. At Point Reyes, we observed only one disturbance event in 2021, and disturbances by aircraft have declined since 2019. General aviation aircraft and USCG helicopters continue to be the main sources of aircraft disturbance to seabirds. Disturbances by low-flying military aircraft are less frequent, but also tend to cause large seabird flushing events. The Pacific Coast Dream Machines event was cancelled in 2020 and 2021, and it is unclear how aircraft disturbance rates may change in the future should the event be held again.

We observed three instances of watercraft in Special Closures, but the two at Point Reyes did not cause disturbance, and at Devil's Slide two disturbance events were caused by one boat. The increased detection rates of watercraft at both field locations may reflect the impacts of the COVID-19 pandemic, where people may be seeking safe recreational opportunities that limit disease transmission. Nearly all watercraft disturbances were from small recreational vessels, as is typical.

Non-Anthropogenic Disturbance

Non-anthropogenic disturbance rates from systematic surveys at Devil's Slide were 278% higher than 2019, and ~1300% higher than 2018. Resident ravens were the greatest threat to productivity, and we observed them taking eggs and chicks, but Western Gulls were a more persistent nuisance, and caused most of the observed disturbance events. Murre productivity was above average in 2021, which suggests that these events weren't a major problem, but avian disturbance and predation could pose a greater threat to murres in the future if they increase.

At Point Reyes, ravens were the most common source of disturbance. Productivity at Ledge Plot was above average in 2021, but Edge Plot was only average, mainly because of predatory incursions by the Great Blue Heron. This was the first time that we recorded disturbances by herons on this project, and the impacts were severe, including predation, site abandonment, and forced fledging.

Attendance and Reproductive Success

Seabird colony attendance and productivity were robust in 2021, especially for Common Murres and Brandt's Cormorants. This is an encouraging sign following the extremely low productivity and delays in egg laying recorded in 2019. Our monitoring during the 2020 season was delayed by the COVID-19 pandemic, and too short to get good insights into the status of our murre and cormorant populations that year.

We recorded high abundance of our focal species in 2021. Brandt's Cormorants nested in high numbers at multiple subcolonies at both Point Reyes and Devil's Slide, with average to above average productivity. Cormorant abundance was especially high at Devil's Slide Rock relative to recent years, reflecting regional increases. Cormorants nested slightly earlier than usual at Devil's Slide, but they were considerably later at Point Reyes; high winds during nest-building at Point Reyes likely disrupted them. On Devil's Slide Rock, murre abundance was similar to recent years, and the colony appears to be near saturation. Increasing murre abundance at survey areas at Devil's Slide Rock and Point Reyes suggest these colonies may still be growing after an apparent leveling in the late 2010s (Bednar et al. 2020); aerial photographic surveys will be needed to confirm current trends.

Murre breeding success also rebounded following the poor 2019 season. Productivity at Devil's Slide Rock was among the six highest recorded since monitoring began in 1996. Murres at Point Reyes continued a trend of lower productivity than at Devil's Slide, but despite issues with a predatory heron, the murres performed around average.

On Devil's Slide Mainland, murre attendance and productivity were among the greatest we have recorded. Murres attended and bred in multiple small groups, mostly in association with Brandt's Cormorants, including areas that are not attended annually. When murres breed at new or infrequently-used colonies, it is nearly always in association with Brandt's Cormorants and can increase murre breeding success (Carter et al. 2001, McChesney et al. 2022). The large numbers of nesting cormorants on the mainland in both 2020 and 2021 likely encouraged murre attendance in areas that are normally vacant, and enhanced murre productivity. Murre attendance on Devil's Slide Mainland has varied dramatically since birds first bred in 2005, and productivity has been poor in most years. Relatively high breeding success in both 2020 and 2021 is an encouraging sign that murres breeding on the mainland may become more established and productive in the near future.

Numbers of Pelagic Cormorant nests were above average relative to recent years, but comparisons are difficult because birds switch nesting areas annually and many breeding areas cannot be seen from our mainland vantage points. This is especially true for Pelagic Cormorants at Point Reyes; in past years when we conducted boat surveys, the majority of nests were found during those surveys. Productivity for Pelagic Cormorants and Western Gulls was near the long-term mean in 2021, but considerably greater than in 2019 and 2020.

In 2021, most marine indices in the central California Current Ecosystem, including the Gulf of the Farallones, were indicative of La Niña, including high upwelling, chlorophyll, and prey (e.g., juvenile northern anchovies (*Engraulis mordax*), juvenile rockfish (*Sebastes* spp.), and market squid (*Doryteuthis opalescens*)), and low sea surface temperatures (Spears et al. 2022, Thompson et al. 2022). This is a major shift from 2019, when oceanographic indices indicated a weak El Niño phase, which was associated with elevated sea surface temperatures, low upwelling, reduced primary productivity, and few of the preferred prey of breeding murres, guillemots, or Pelagic Cormorants (Thompson et al. 2019, Harvey et al. 2020). The rebound in productivity that we observed for most of our monitored species in 2021 likely comes from a shift to La Niña in late 2020 (Thompson et al. 2022), which benefited the birds greatly. Oceanographic indices are predicted to stay in La Niña or become neutral in 2022 (Climate Prediction Center 2022), so we anticipate that breeding behavior should remain around average or better in 2022.

At the nearby South Farallon Islands, which serve as a reference colony in this region, most seabird species were present in relatively high numbers with above average productivity. Murres may have been one exception, owing to low productivity in one of the study plots; this plot had low fledge success, for unknown reasons. Murres fed their chicks primarily anchovies and juvenile rockfish (Spears et al. 2022).

Recommendations for Future Management, Monitoring, and Research

• Continued flexibility and vigilance are necessary to operate during the COVID-19 pandemic, and to react and respond to sudden and unforeseen changes.

• Outreach and education efforts targeting aircraft and watercraft user groups should be continued, and adapted to changing sources of disturbance. We suggest outreach focus on general aviation aircraft, USCG helicopters, and private recreational fishermen. Outreach efforts to military helicopter operators may also help reduce seabird disturbances.

• 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.

• New online tools are becoming available to identify and document aircraft flying over colonies. Efforts are needed to continually search for, identify, and use the methods that are most effective and user-friendly.

• Raven disturbance and nest predation should be monitored closely for potential increases in impacts to murre colonies.

• The Devil's Slide pedestrian trail was completed in March of 2014, and the 2021 field season marked the eighth 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.

• The presence of thousands of visitors on Devil's Slide Trail throughout the seabird season provide a great opportunity for outreach about seabirds and the prevention of human disturbance. These outreach opportunities could be expanded further.

• 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.

• 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, April 2021 to August 2021.

Colony or Colony Complex	Start date	End date	Observation days	Total hours
Point Reyes Headlands	04/08/2021	8/12/2021	115	615
Devil's Slide Rock & Mainland	4/15/2021	8/13/2021	117	490
San Pedro Rock	4/19/2021	6/27/2021	14	1

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, 2021. UAS indicate 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	4	1	5	18	**24**
Detections/Hour	0.002	0.006	0.002	0.008	0.029	**0.039**
# of Agitation Events	0	0	0	0	0	**0**
# of Displacement Events	0	0	0	0	0	**0**
# of Flushing Events	0	1	0	1	0	**1**
Total Disturbed/Hour	0.000	0.002	0.000	0.002	0.000	**0.002**
Total Flushed or Displaced/Hour	0.000	0.002	0.000	0.002	0.000	**0.002**

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, 2021. UAS indicate 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	53	33	2	86	19	1	**108**
Detections/Hour	0.108	0.067	0.004	0.175	0.039	0.002	**0.220**
# of Agitation Events	31	9	0	40	2	1	**43**
# of Displacement Events	0	0	0	0	0	0	**0**
# of Flushing Events	8	22	0	30	3	0	**33**
Total Disturbed/Hour	0.080	0.063	0.000	0.143	0.010	0.002	**0.155**
Total Flushed or Displaced/Hour	0.016	0.045	0.000	0.061	0.006	0.000	**0.067**

Table 4. Common Murre breeding phenology and reproductive success at Point Reyes Lighthouse, 2021. 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). 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	84	73	20 May (8 May – 10 June; 39)	79	21 June (6 June – 3 July; 21)	76% (79)	15 July (July 3 – 21 July; 27)	63% (60)	0.49 (65)
PRH-03-B Ledge	111	89	23 May (13 May – 12 June; 47)	96	25 June (17 June – 13 July; 19)	77% (94)	23 July (14 July – 10 August; 59)	85% (72)	0.69 (83)
Plots Combined	**195**	**162**	**22 May (8 May – 12 June; 86)**	**175**	**23 June (6 June – 13 July; 40)**	**76% (173)**	**20 July (3 July – 10 August; 86)**	**75% (132)**	**0.60 (148)**

Table 5. Common Murre breeding phenology and reproductive success at Devil's Slide Rock and Mainland, 2021. 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). 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	107	95	23 May (13 May – 5 June; 43)	96	26 June (16 June – 4 July; 25)	87% (98)	20 July (7 July-2 Aug; 77)	95% (85)	0.86 (93)
DSRM-01-Plot B	74	69	24 May (18 May – 4 June; 19)	68	26 June (23 June – 3 July; 11)	83% (69)	20 July (12 July- 29 July; 48)	95% (55)	0.78 (67)
DSRM-01-Plot D	27	23	27 May (19 May – 12 June; 7)	23	1 July (1)	83% (23)	21 July (16 July-22 July; 18)	100% (19)	0.83 (23)
DSR Plots Combined	**208**	**187**	**24 May (13 May – 12 June; 69)**	**187**	**26 June (16 June – 4 July; 37)**	**85% (190)**	**20 July (7 July-2 Aug; 143)**	**96% (159)**	**0.83 (183)**
DSRM-05-A	51	50	N/A	54	25 June (16 June – 1 July; 14)	69% (54)	19 July (7 July-28 July; 34)	94% (36)	0.67 (43)

Table 6. High counts of nests and breeding birds from land-based surveys for Brandt's Cormorants, Pelagic Cormorants, Western Gulls, and Black Oystercatchers, 2021. 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.

Colony	Brandt's Cormorant	Pelagic Cormorant	Western Gull	Black Oystercatcher	Pigeon Guillemot
Point Reyes Headlands	334	27	75	4	71[1]
Devil's Slide Rock & Mainland	346	31	8	1	102

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

Table 7. Brandt's Cormorant breeding phenology and reproductive success from monitored subareas at Point Reyes Headlands, 2021. 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. 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
Beach Rock (PRH-10-E)	47	30 May (15 May – 5 June; 44)	2.93	70% (139)	2.13 (0-3; 45)	0.91 (45)	90% (44)
Arch Rock (PRH-11-D)	3	24 May (24 May – 24 May; 3)	2.33	22% (7)	0.67 (0-2; 3)	0.33 (3)	100% (1)
Wishbone Pt. (PRH-11-E-Wish)	17	9 June (3 June – 17 June; 14)	2.79	68% (45)	1.67 (0-3; 15)	0.80 (15)	96% (14)
Spine Pt. (PRH-11-E-Spine)	4	9 June (9 June – 9 June; 3)	3.33	69% (13)	2.25 (2-3; 4)	1.00 (4)	100% (4)
Sloppy Joe (PRH-12-A)	23	6 June (31 May – 17 June; 20)	3.05	65% (69)	2.14 (0-4; 21)	0.86 (21)	95% (19)
West Cone (PRH-13-WC)	12	25 May (20 May – 9 June; 12)	3.25	73% (42)	2.50 (0-3; 12)	0.92 (12)	92% (12)
Area B Mainland (PRH-14-E)	19	19 May (2 May – 5 June; 16)	2.88	58% (60)	1.94 (0-3; 16)	0.88 (16)	91% (18)
Point Reyes Total	**125**	**30 May (2 May – 17 June; 112)**	**2.96**	**66% (375)**	**2.05 (0-4; 116)**	**0.97 (60)**	**92% (112)**

Table 8. Brandt's Cormorant breeding phenology and reproductive success from monitored subareas at Devil's Slide Rock and Mainland (DSRM), 2021. 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. 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-Lower	28	11 May (17 Apr – 26 May; 26)	3.19	51% (101)	1.89 (0-4; 28)	0.93 (28)	88% (27)
DSRM-05-A-Upper	13	8 May (18 Apr-23 May; 12)	2.83	61% (45)	2.08 (1-3; 12)	1.00 (12)	96% (13)
DSRM-05-B	85	8 May (15 Apr-17 Jun; 81)	3.24	66% (277)	2.15 (0-4; 80)	0.91 (80)	90% (79)
DSRM-05-C	25	29 Apr (14 Apr-16 May; 21)	3.15	47% (80)	1.56 (0-3; 25)	0.80 (25)	77% (23)
DSRM-05-AF	5	25 May (23 May-28 May; 5)	2.80	57% (17)	2.20 (1-3; 5)	1.00 (5)	80% (5)
DSRM Combined	**156**	**8 May (14 Apr-17 Jun; 145)**	**3.17**	**59% (520)**	**2.00 (0-4; 150)**	**0.91 (150)**	**88% (147)**

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Table 9. Productivity of Pelagic Cormorants and Western Gulls at Devil's Slide Rock and Mainland, 2021. 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**	**Western Gull**
Number Breeding Sites	24	6
Number Chicks Fledged	30	4
Number of Chicks Fledged/Pair (Productivity)	1.30 (0-4; 23)	0.67 (0-2; 6)
Breeding Success/Nest	0.52 (23)	0.33 (6)

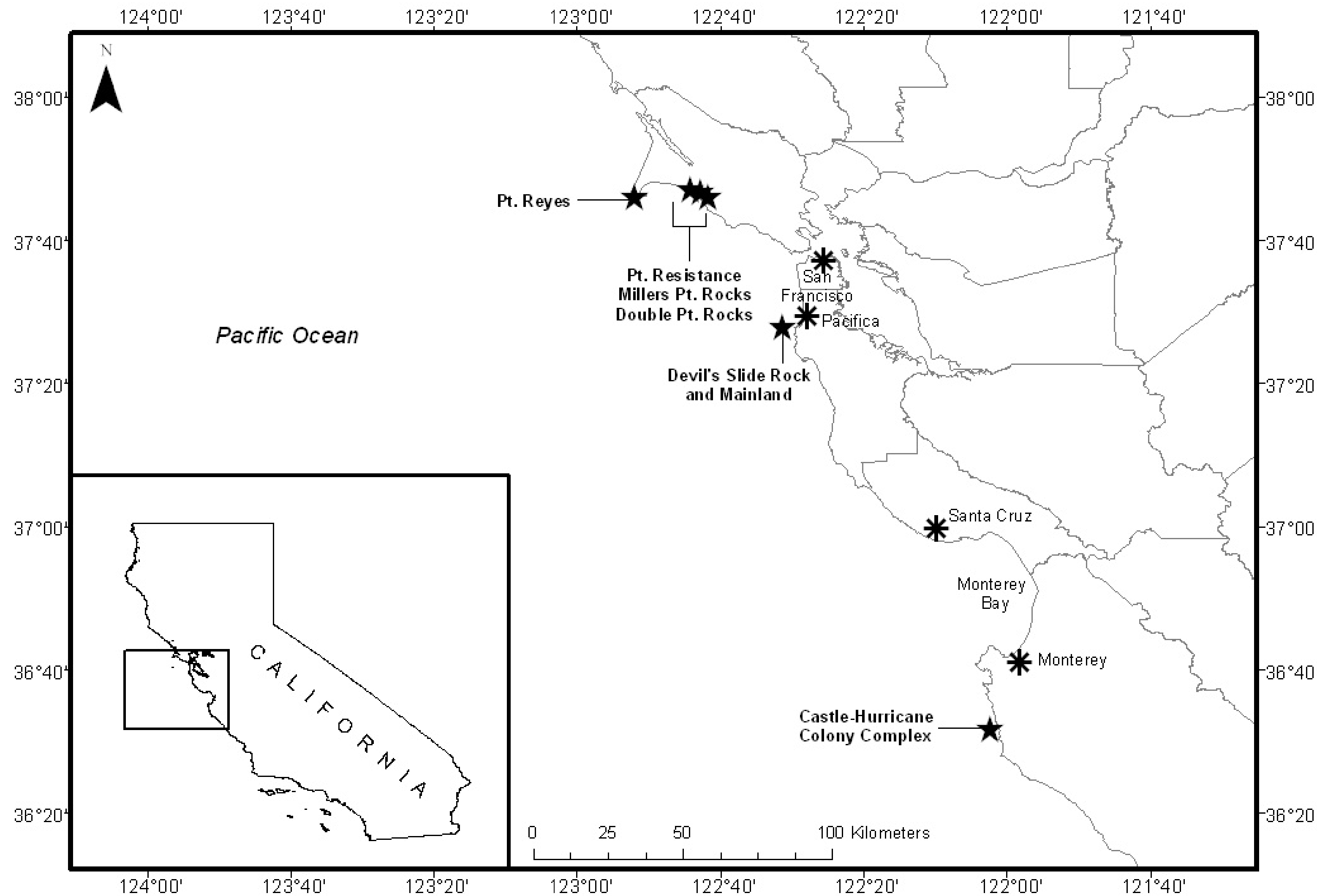


Figure 1. Study area, showing locations of study colonies or colony complexes along the Central California coast where we monitored seabird disturbance, attendance, and reproductive success. Pt. Resistance, Miller's Pt., Double Pt., and Castle-Hurricane Colony Complex were not monitored in 2021.

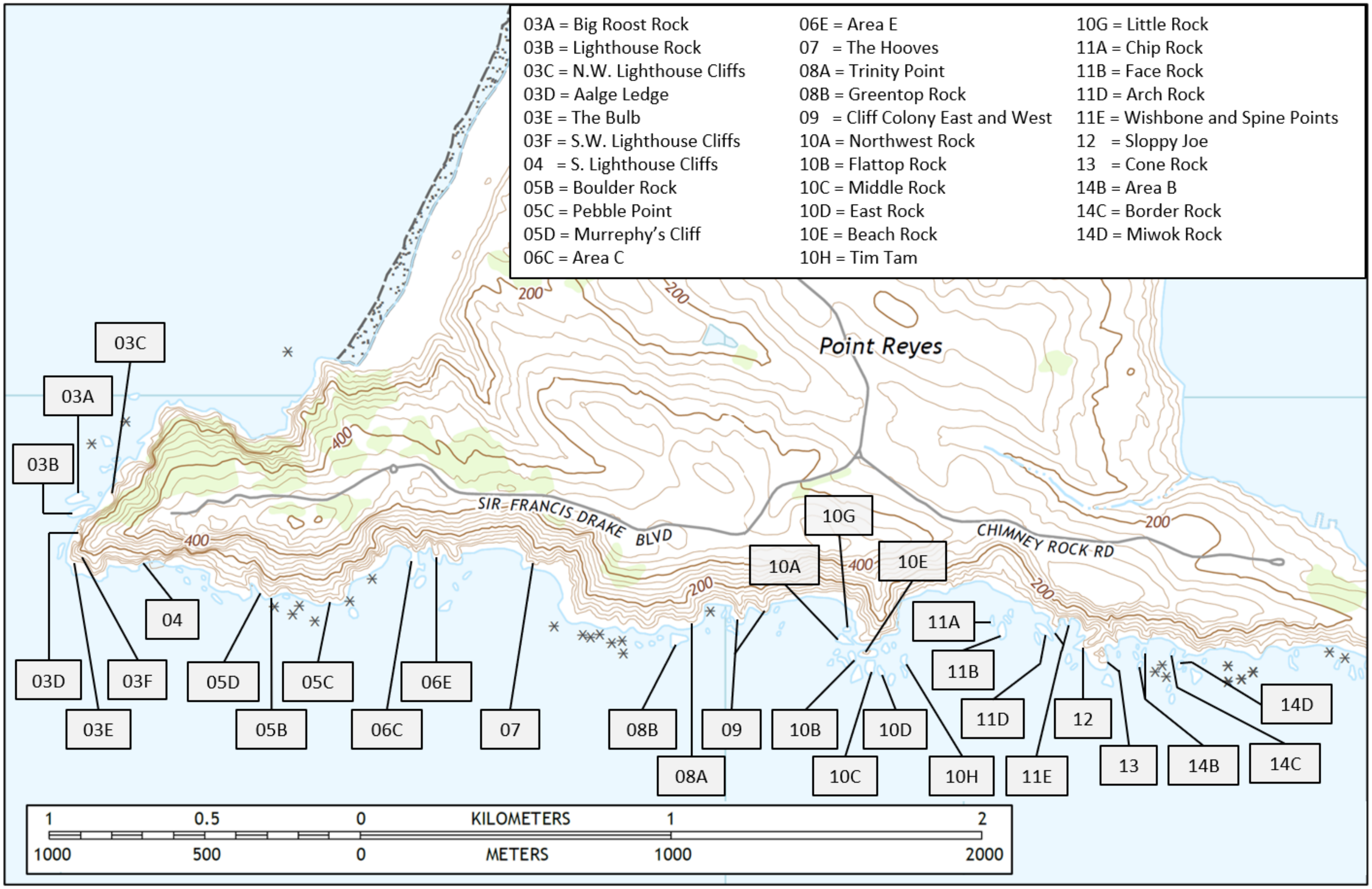


Figure 2. Point Reyes Headlands, including subcolonies 03A through 14D.

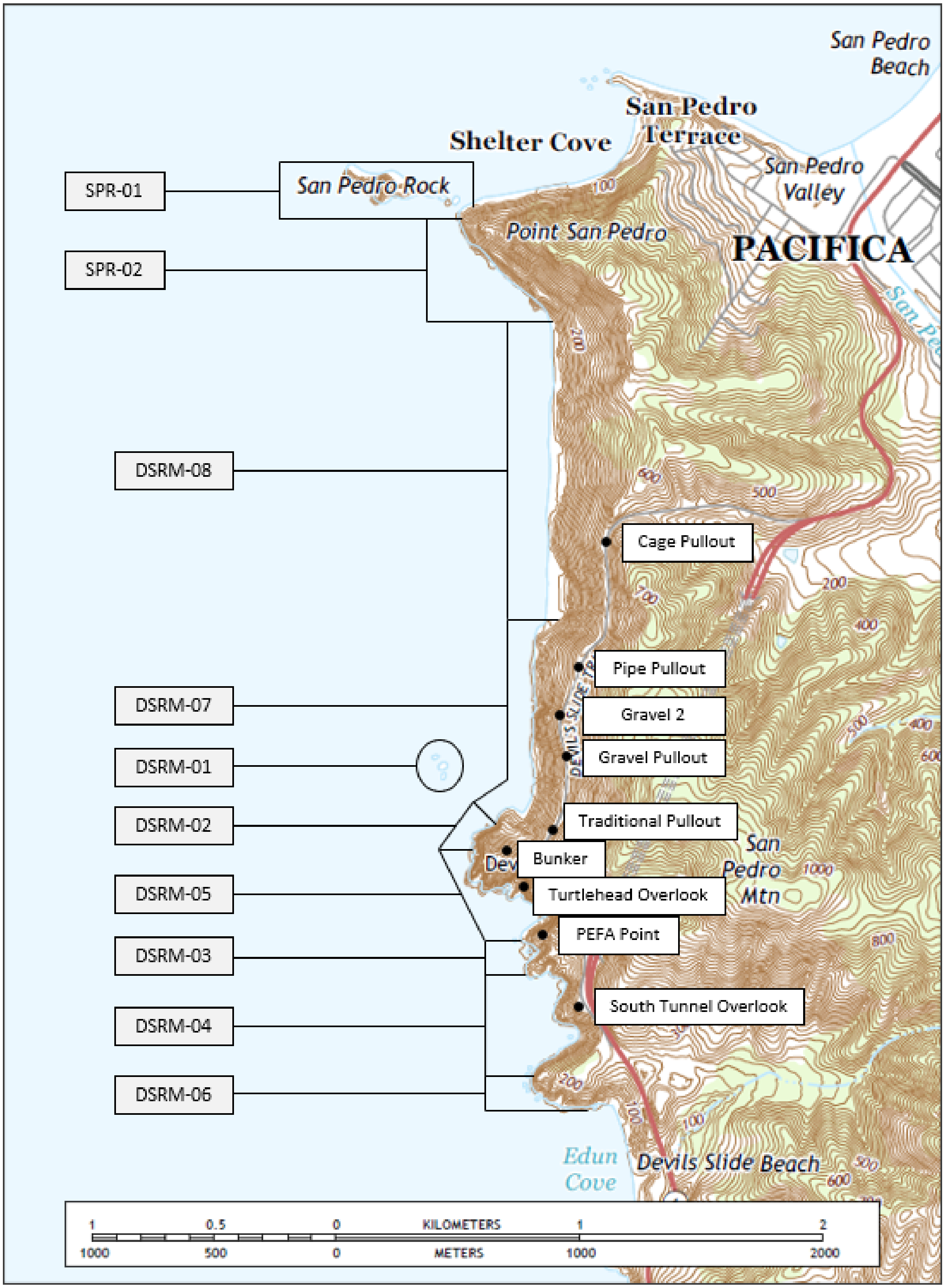


Figure 3. Devil's Slide Colony Complex, including San Pedro Rock and the colonies and subcolonies of Devil's Slide Rock & Mainland.

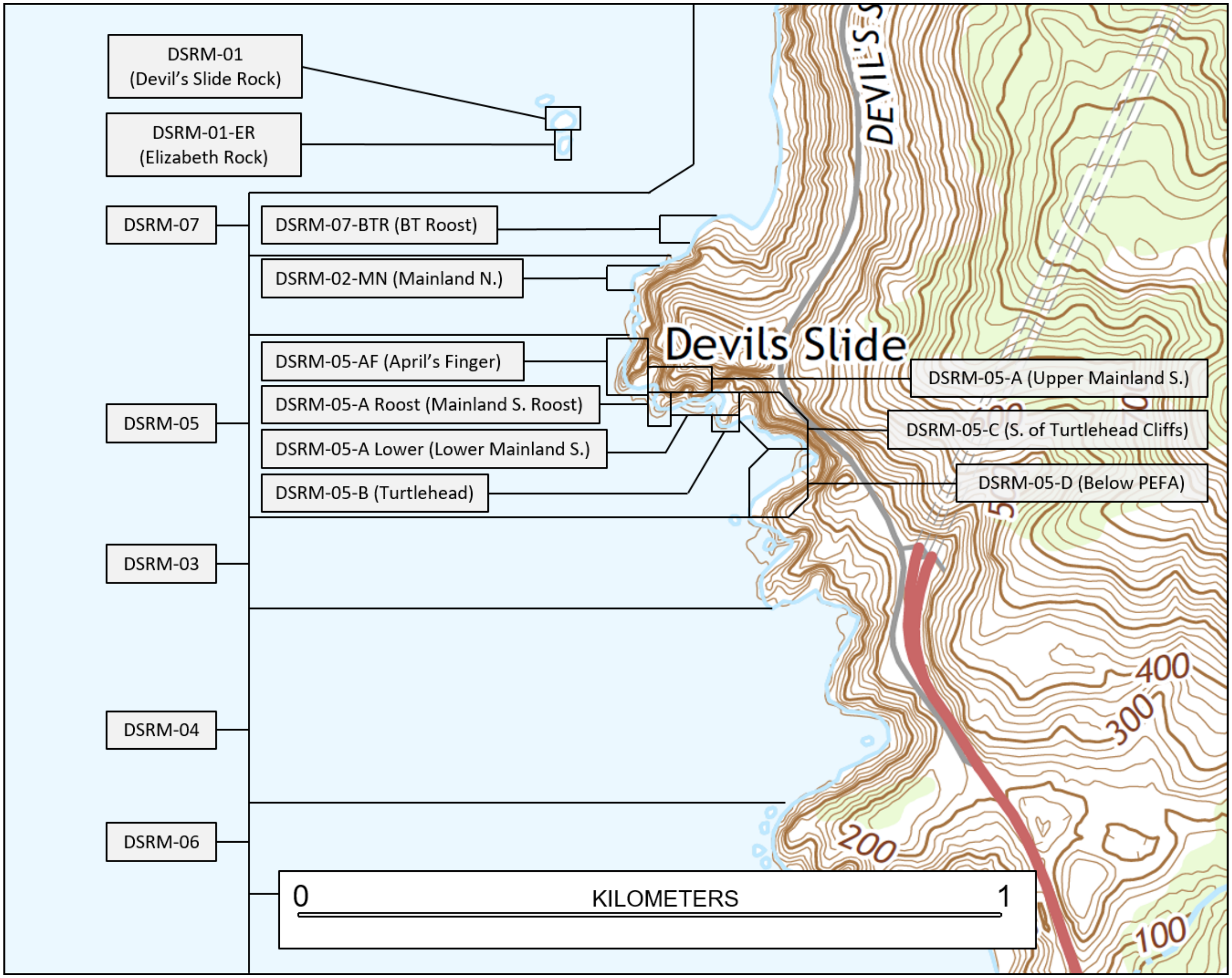


Figure 4. Detailed view of Devil's Slide Rock & Mainland (DSRM) subcolonies.

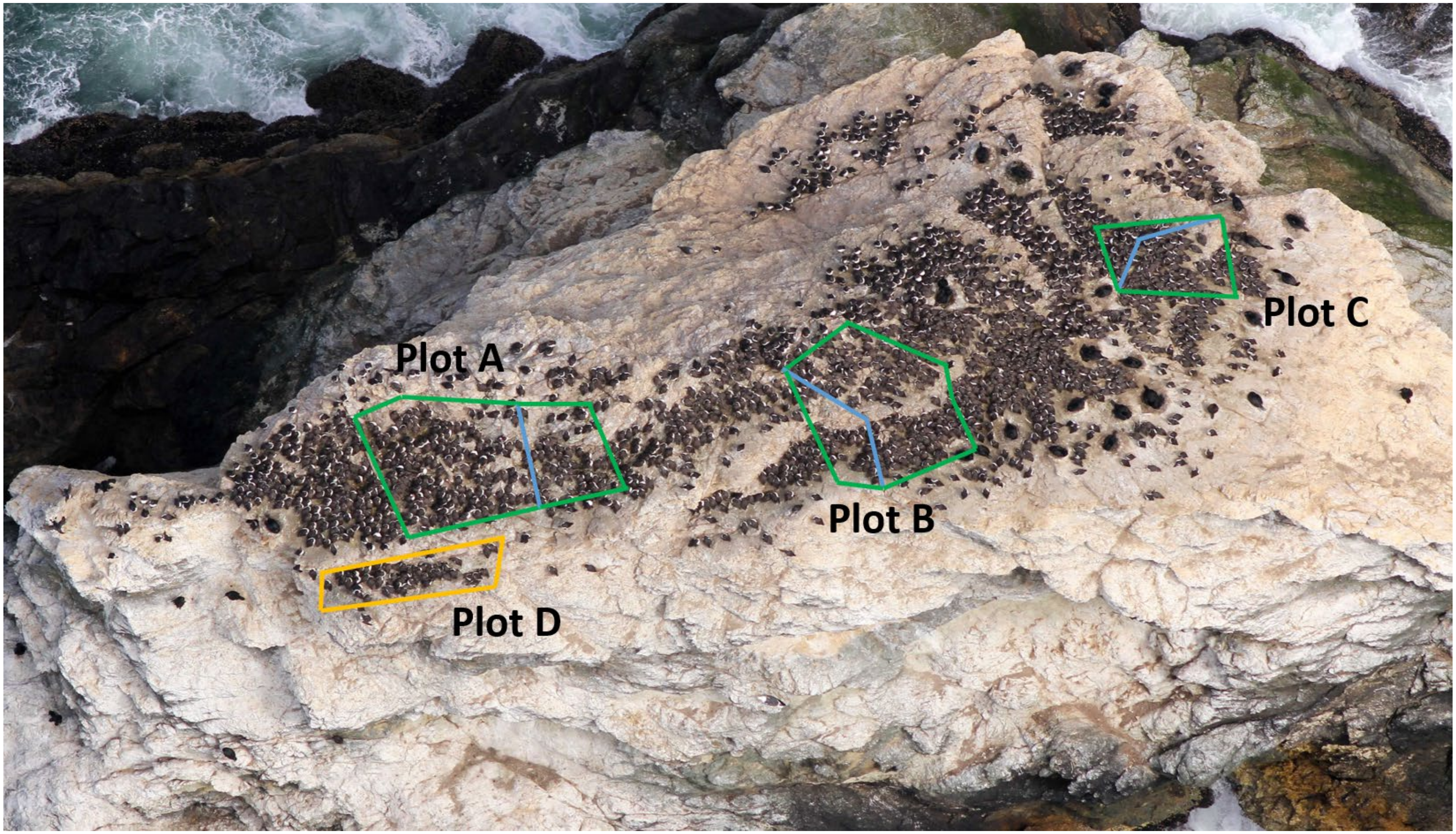


Figure 5. Aerial view (from the south) of Common Murre plot boundaries used on Devil's Slide Rock from 2006-2021. Green polygons show plot boundaries for the 2006 season, blue boundaries show adjustments made to Plots A, B, and C for 2007 and subsequent seasons (productivity was followed in remaining larger sections only). Plot C was no longer followed beginning in 2014, and Plot D was added for the 2015 and subsequent seasons.

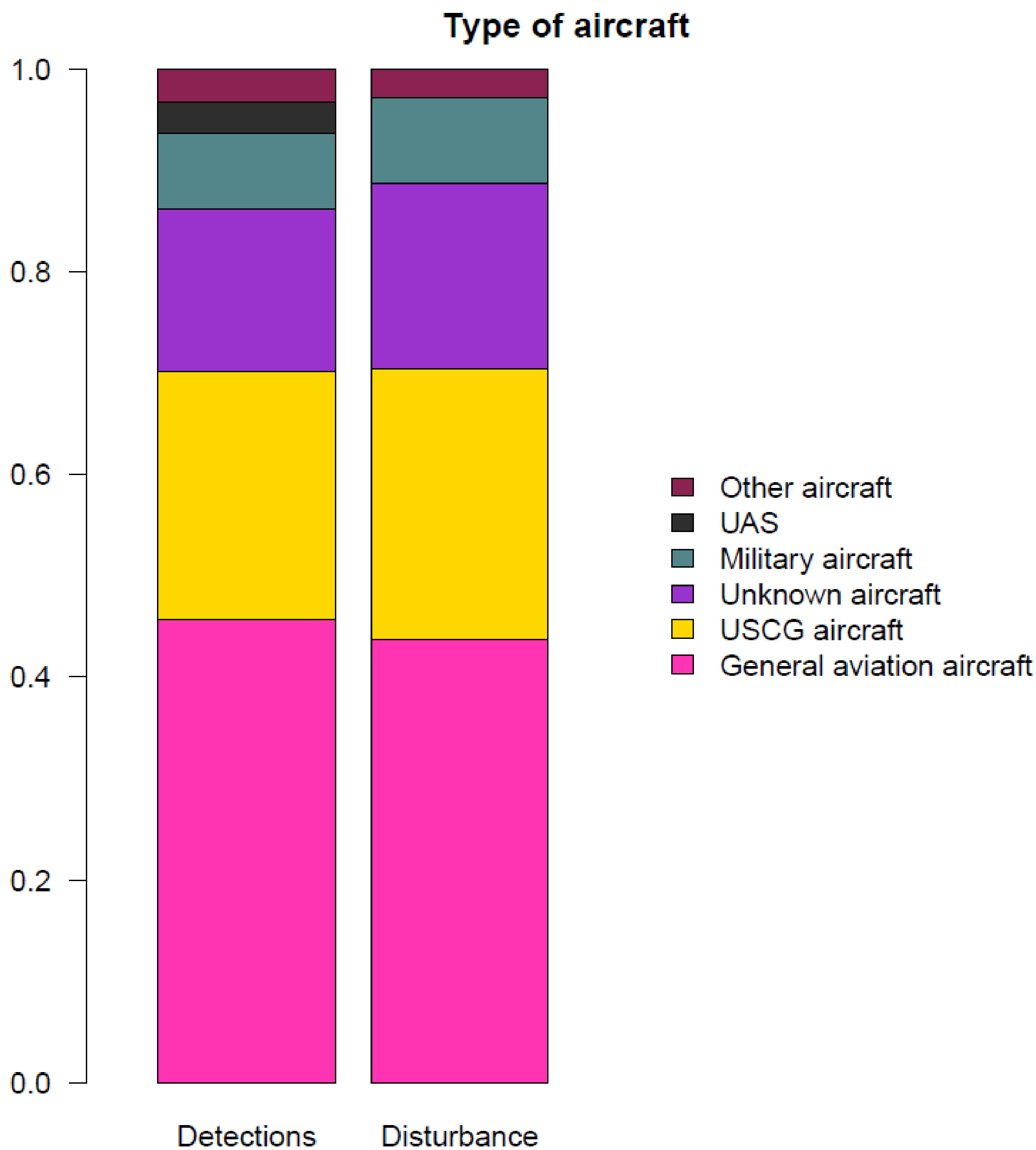


Figure 6. Aircraft detections (n = 94) and disturbances (n = 71) at Point Reyes Headlands and Devil's Slide Rock & Mainland, 2021, categorized by type. "UAS" indicates an uncrewed aerial system (i.e., drone).

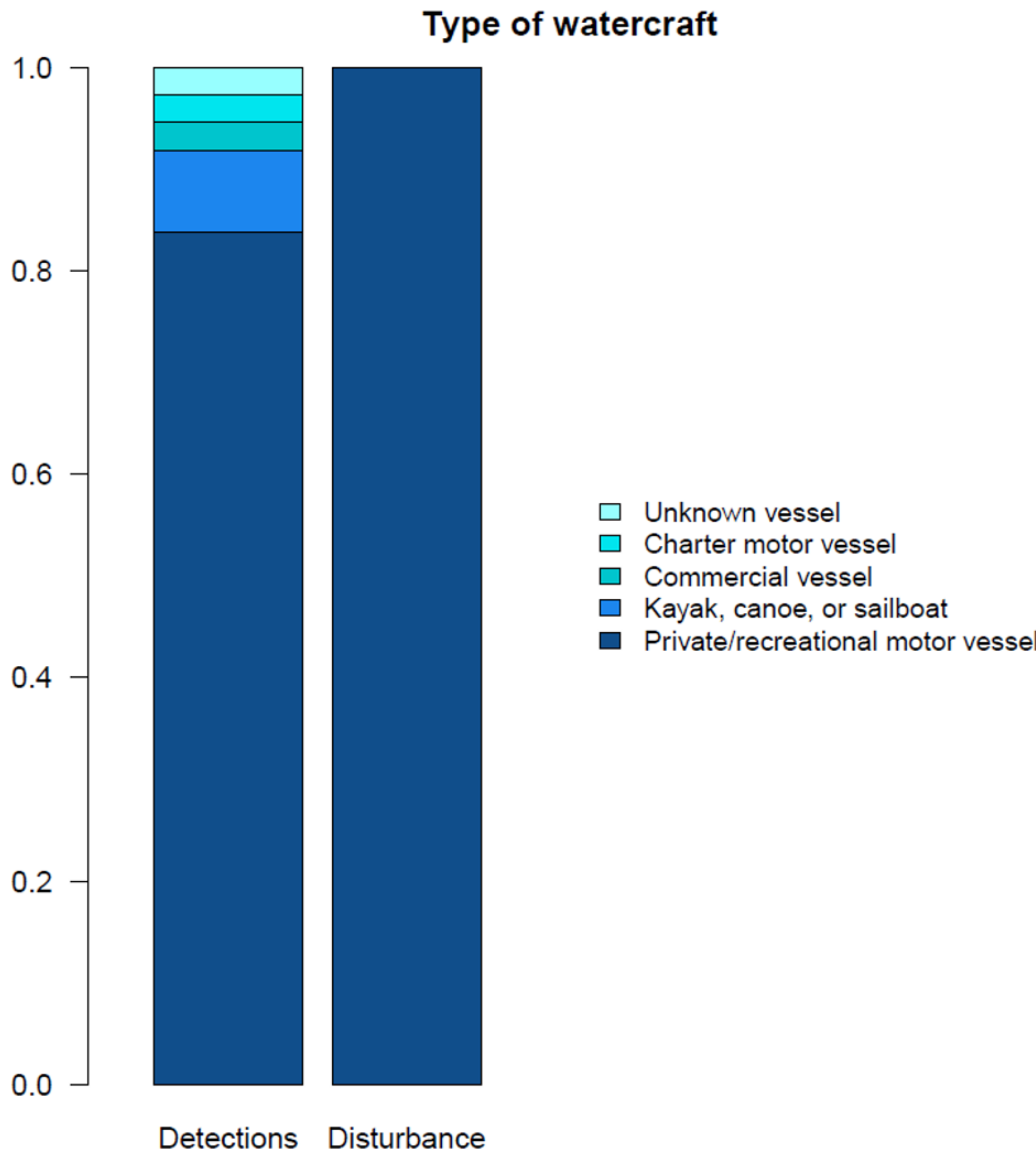


Figure 7. Watercraft detections (n = 37) and watercraft disturbances (n = 5) at Point Reyes Headlands and Devil's Slide Rock & Mainland, 2021, categorized by type.

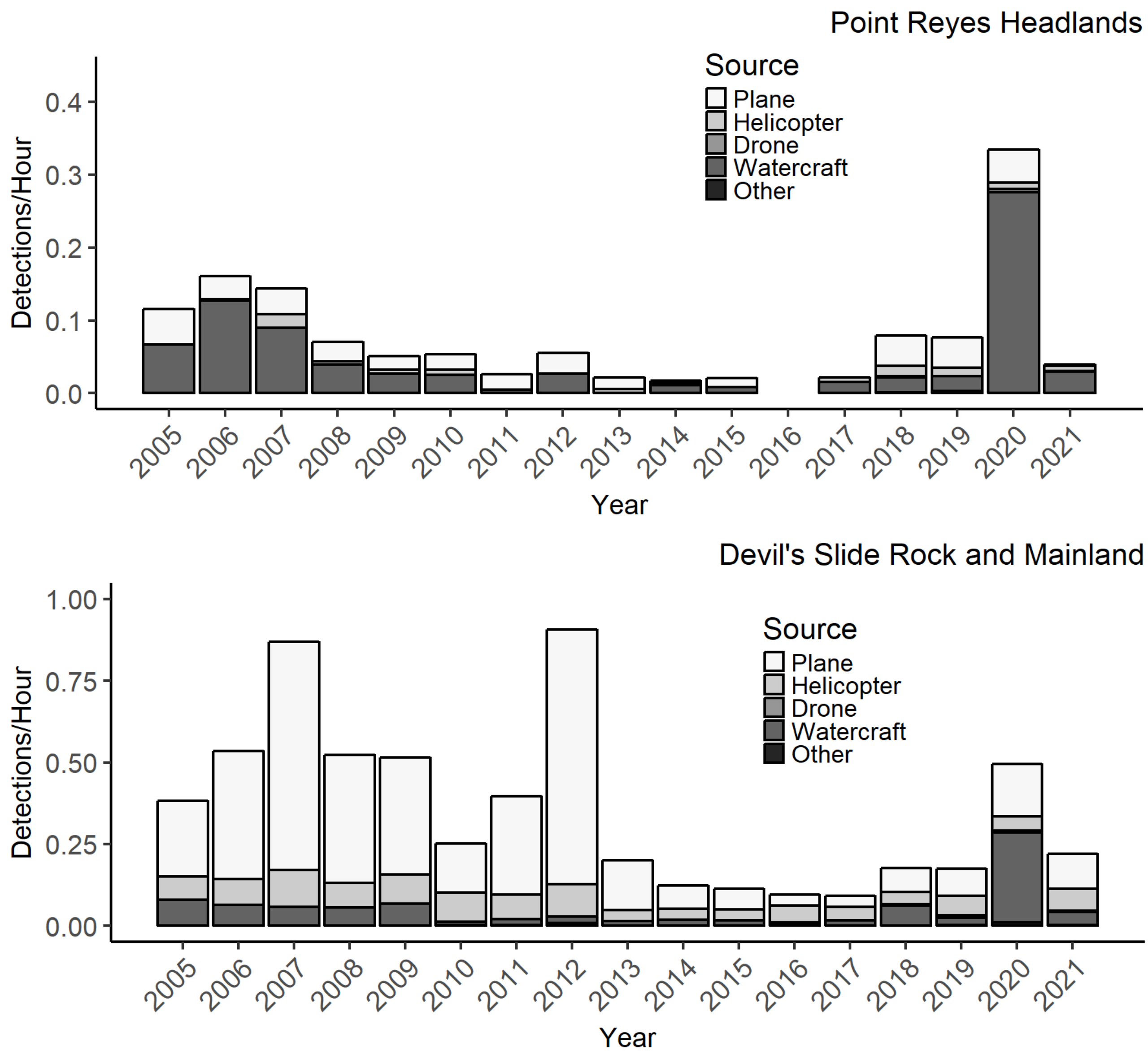


Figure 8. Detection rates (number of detections per observation hour) of watercraft, helicopters, planes, drones, and other anthropogenic sources at Point Reyes Headlands and Devil’s Slide Rock & Mainland, 2005-2021. Note different scales between graphs. Point Reyes Headlands was not monitored in 2016.

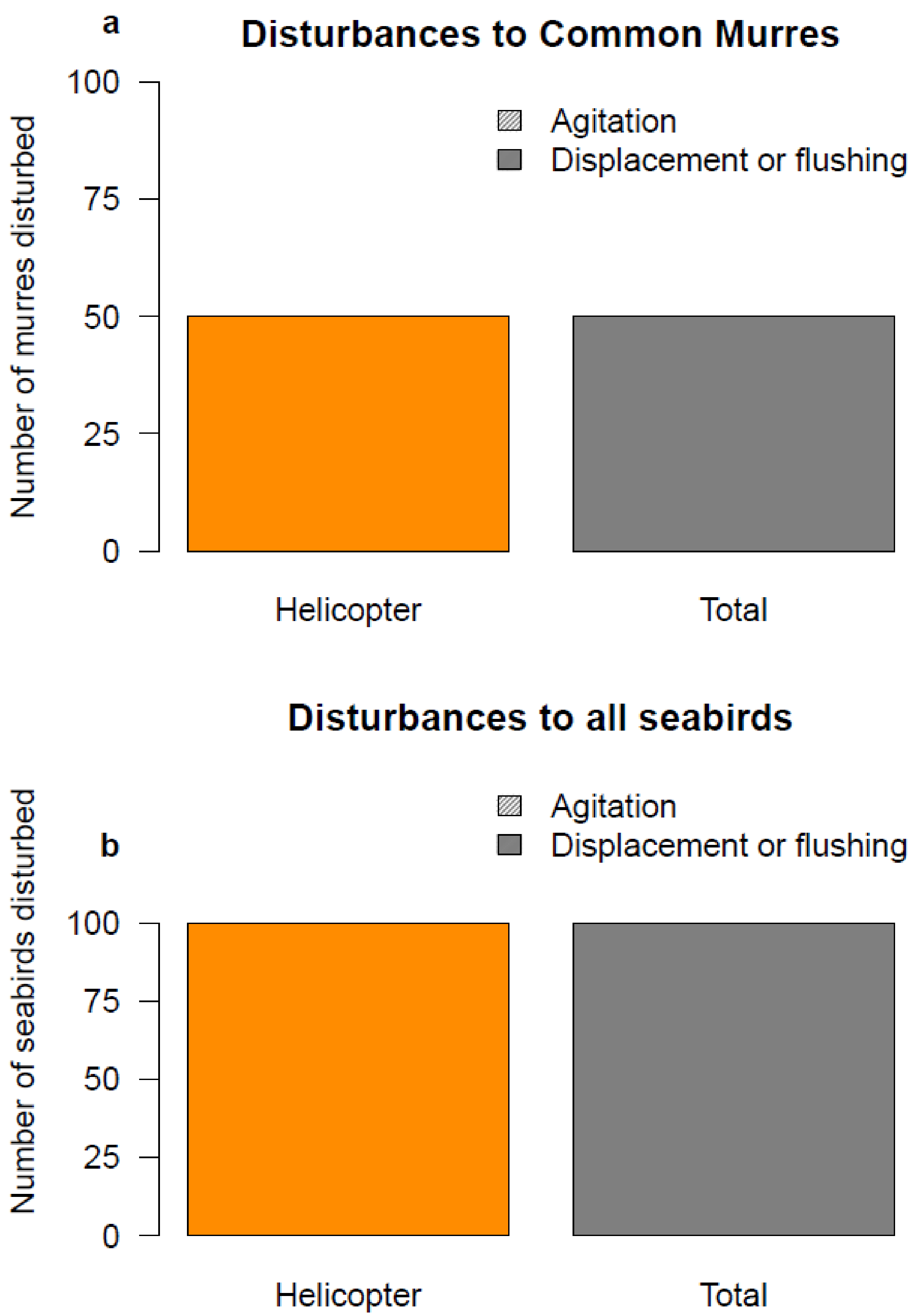


Figure 9. Mean numbers of (a) Common Murres and (b) total seabirds disturbed (agitated, displaced, and/or flushed) by anthropogenic sources at Point Reyes Headlands, 2021. Only one disturbance event was observed in 2021, so no ranges are displayed.

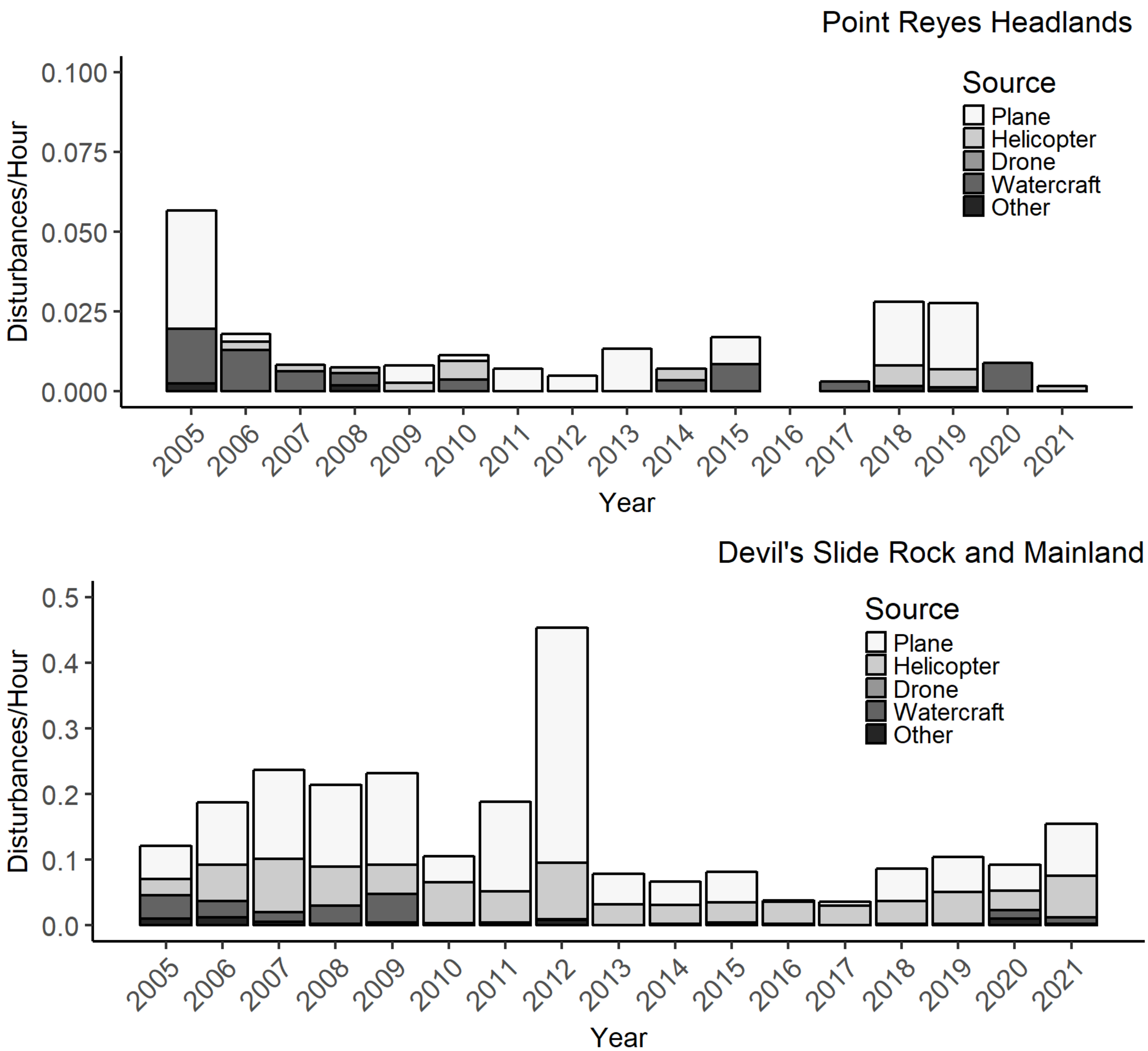


Figure 10. Disturbance rates (number of disturbances per observation hour) of watercraft, helicopters, planes, drones, and other anthropogenic sources at Point Reyes Headlands and Devil's Slide Rock & Mainland, 2005-2021. Note different scales between graphs. Point Reyes Headlands was not monitored in 2016.

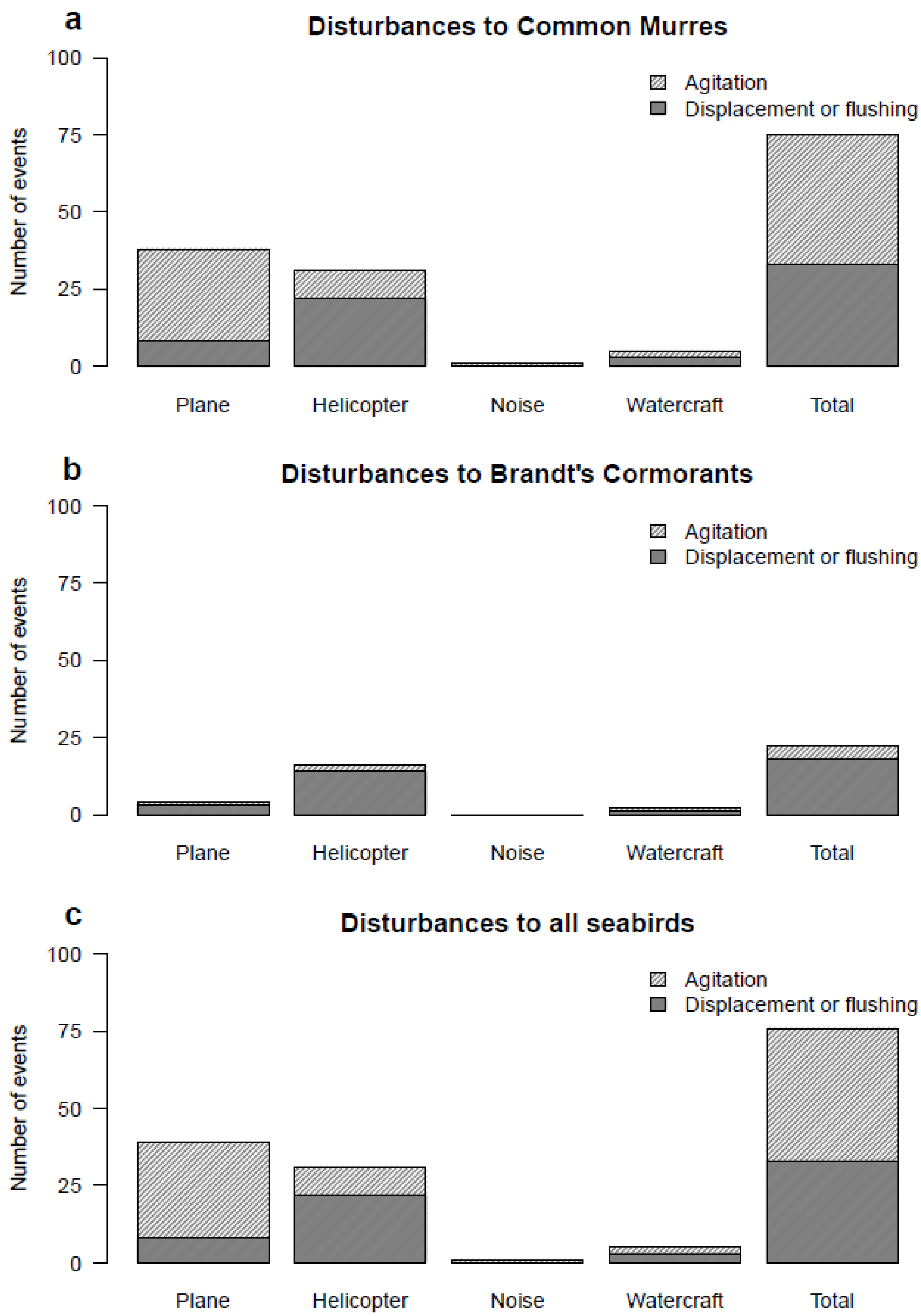


Figure 11. Number of disturbance events from anthropogenic sources of (a) Common Murres, (b) Brandt's Cormorants, and (c) total seabirds disturbed (agitated, displaced and/or flushed) at Devil's Slide Rock and Mainland, 2021.

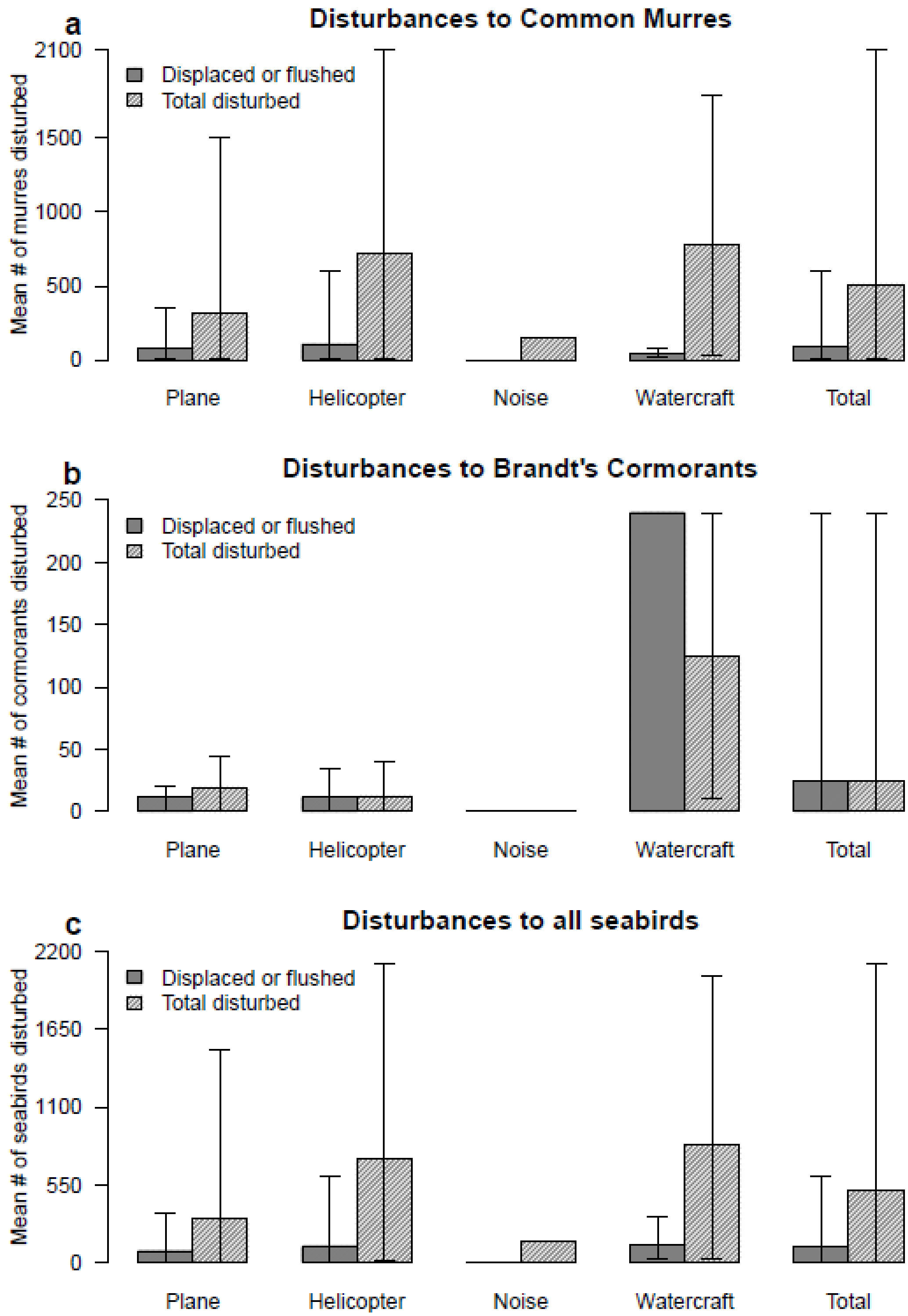


Figure 12. Mean number of (a) Common Murres, (b) Brandt's Cormorants, and (c) total seabirds disturbed (agitated, displaced and/or flushed) by anthropogenic sources at Devil's Slide Rock and Mainland, 2021. Error bars indicate ranges.

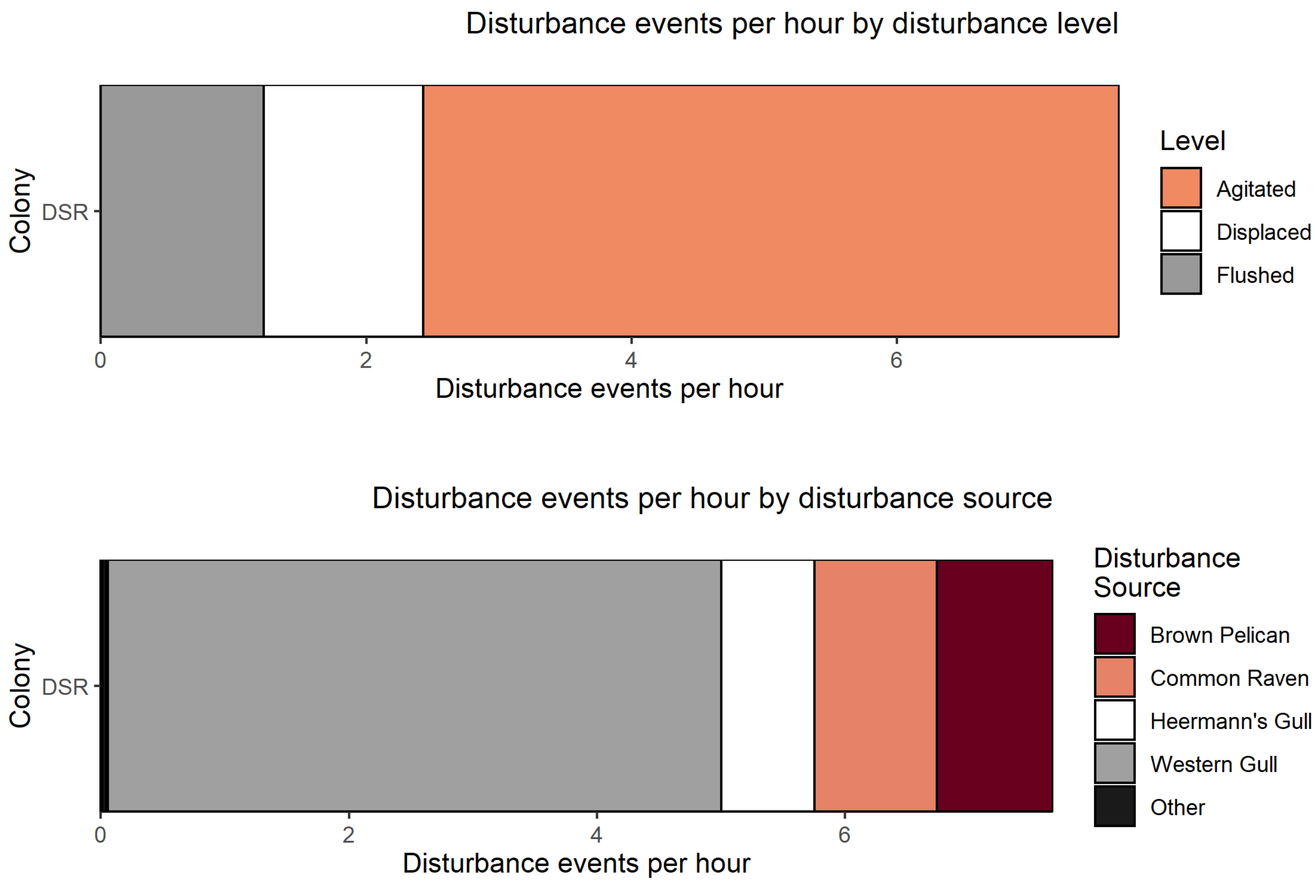


Figure 13. Non-anthropogenic disturbance events per hour during predator watch surveys at Devil's Slide Rock & Mainland, 2021, by disturbance level and disturbance source. Species included in "Other" caused ≤5 disturbance events, and includes California Gull, Great Blue Heron, and Snowy Egret.

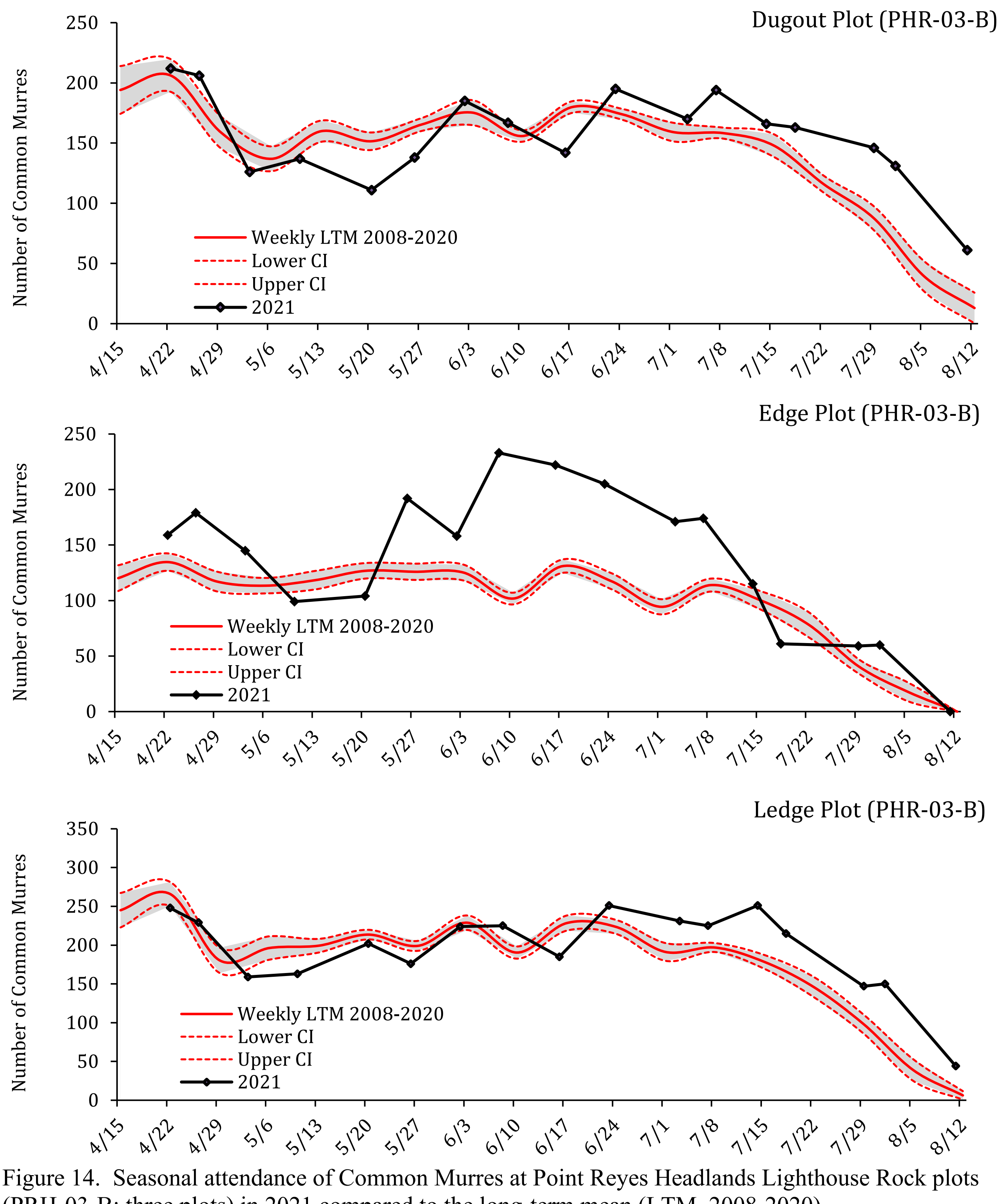
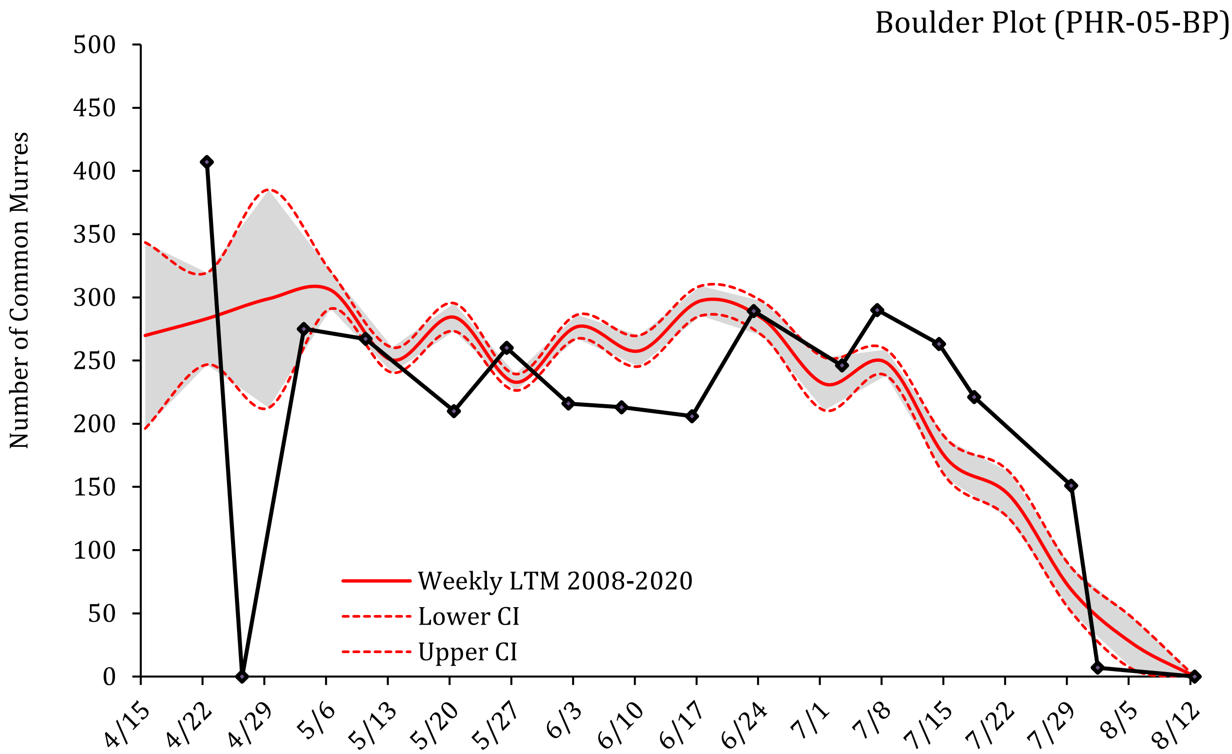


Figure 14. Seasonal attendance of Common Murres at Point Reyes Headlands Lighthouse Rock plots (PRH-03-B; three plots) in 2021 compared to the long-term mean (LTM, 2008-2020).



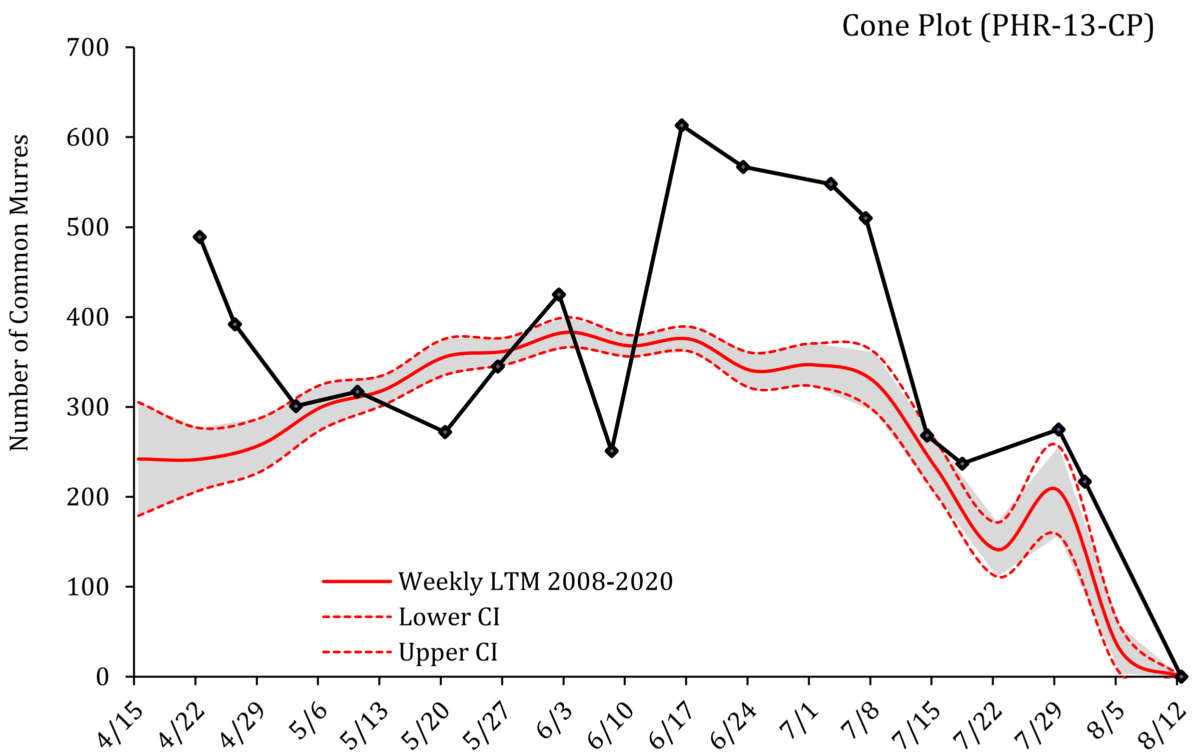


Figure 15. Seasonal attendance of Common Murres at Point Reyes Headlands plots on Boulder and Cone Rocks (subcolonies: PRH-05-BP and PRH-13-CP) in 2021 compared to the long-term mean (LTM, 2008-2020).

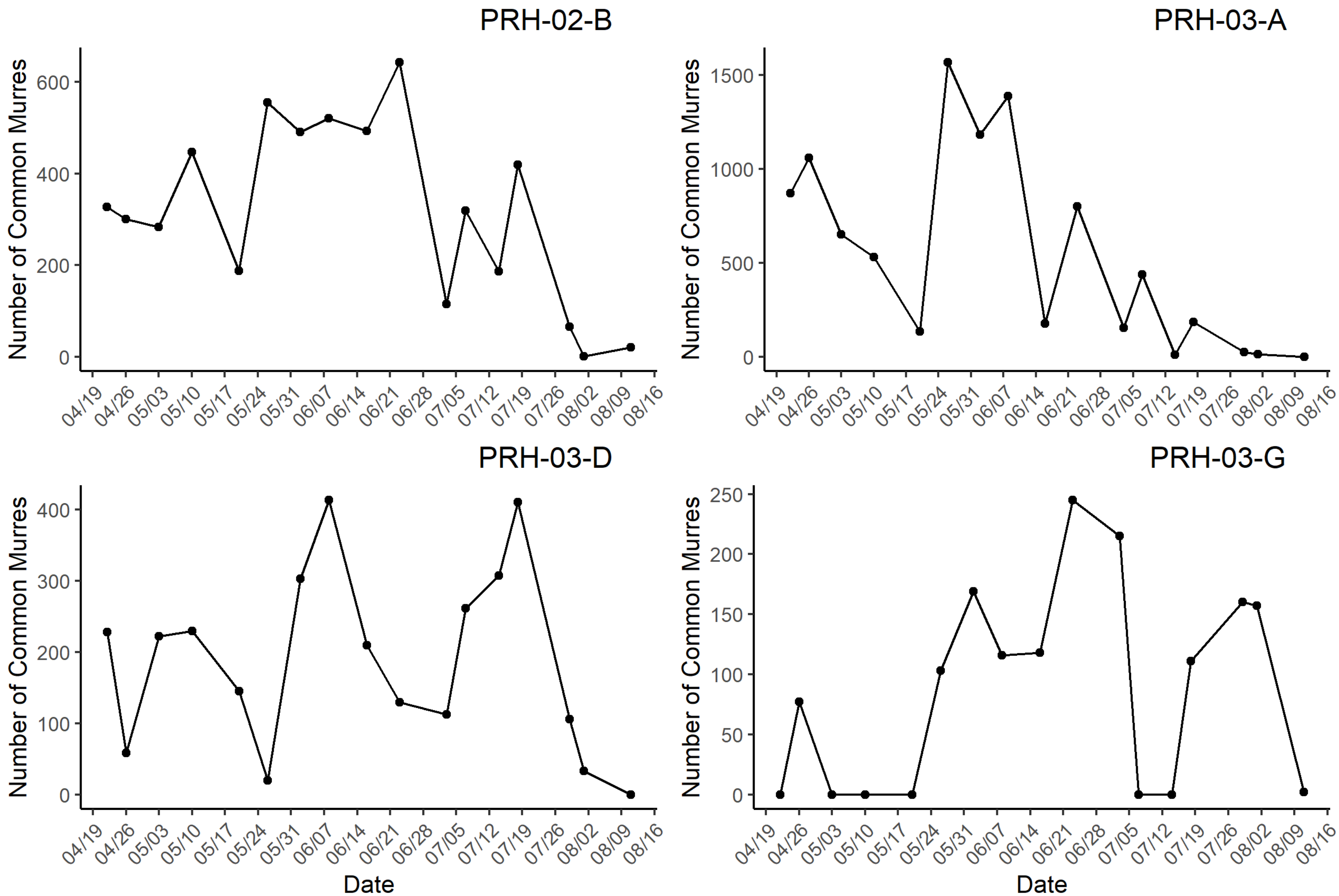


Figure 16. Seasonal attendance of Common Murres at Point Reyes Headlands (subcolonies: PRH-02-B (Rock 2), PRH-03-A (Big Roost Rock), PRH-03-D (Aalgae Ledge), and PRH-03-G (Levin's Rock)) from 22 April to 12 August, 2021.

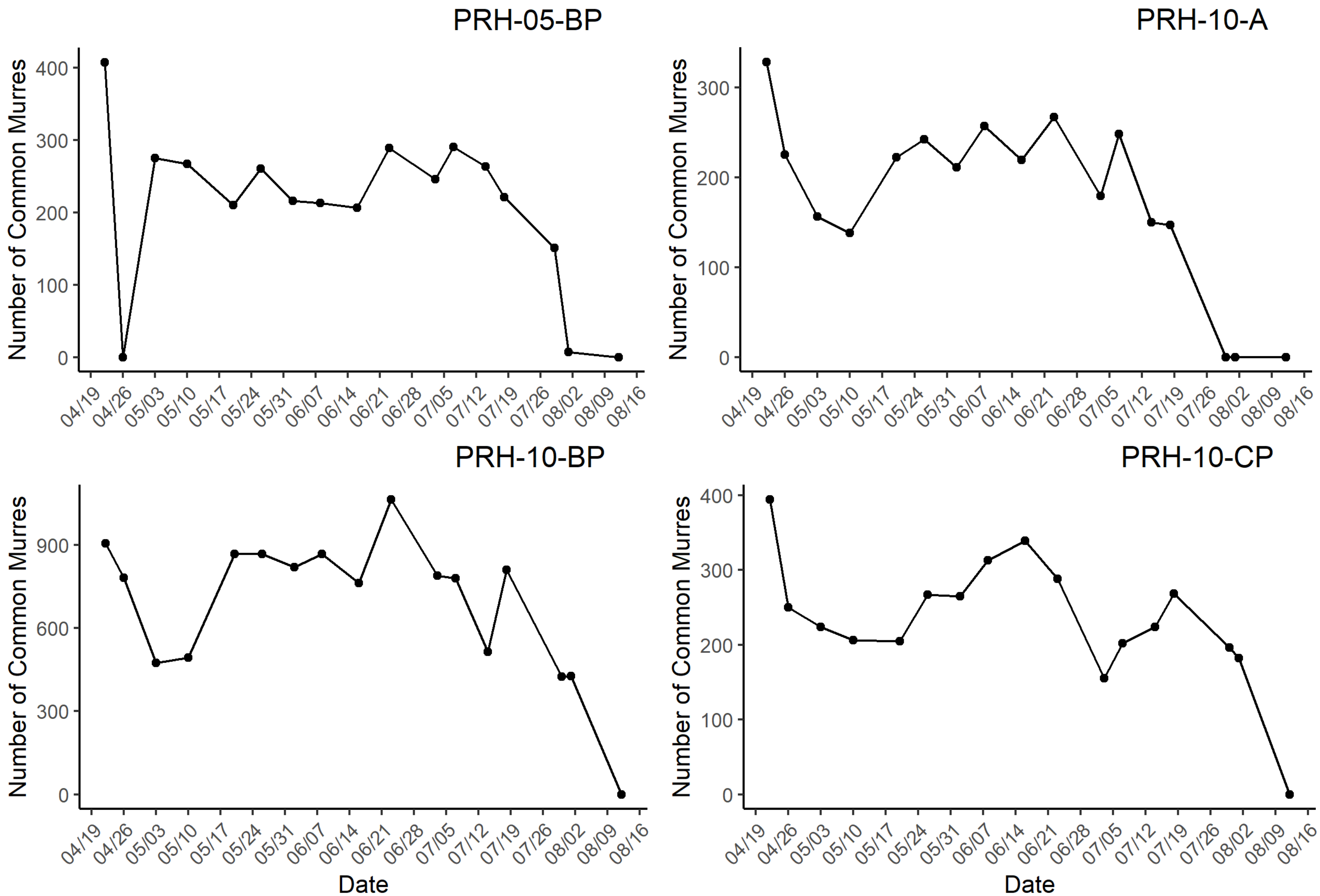


Figure 17. Seasonal attendance of Common Murres at Point Reyes Headlands (subcolonies: PRH-05-BP (Boulder Rock Plot), PRH-10-A (Northwest Rock), PRH-10-BP (Flattop Rock Plot) and PRH-10-CP (Middle Rock Plot)) from 22 April to 12 August, 2021.

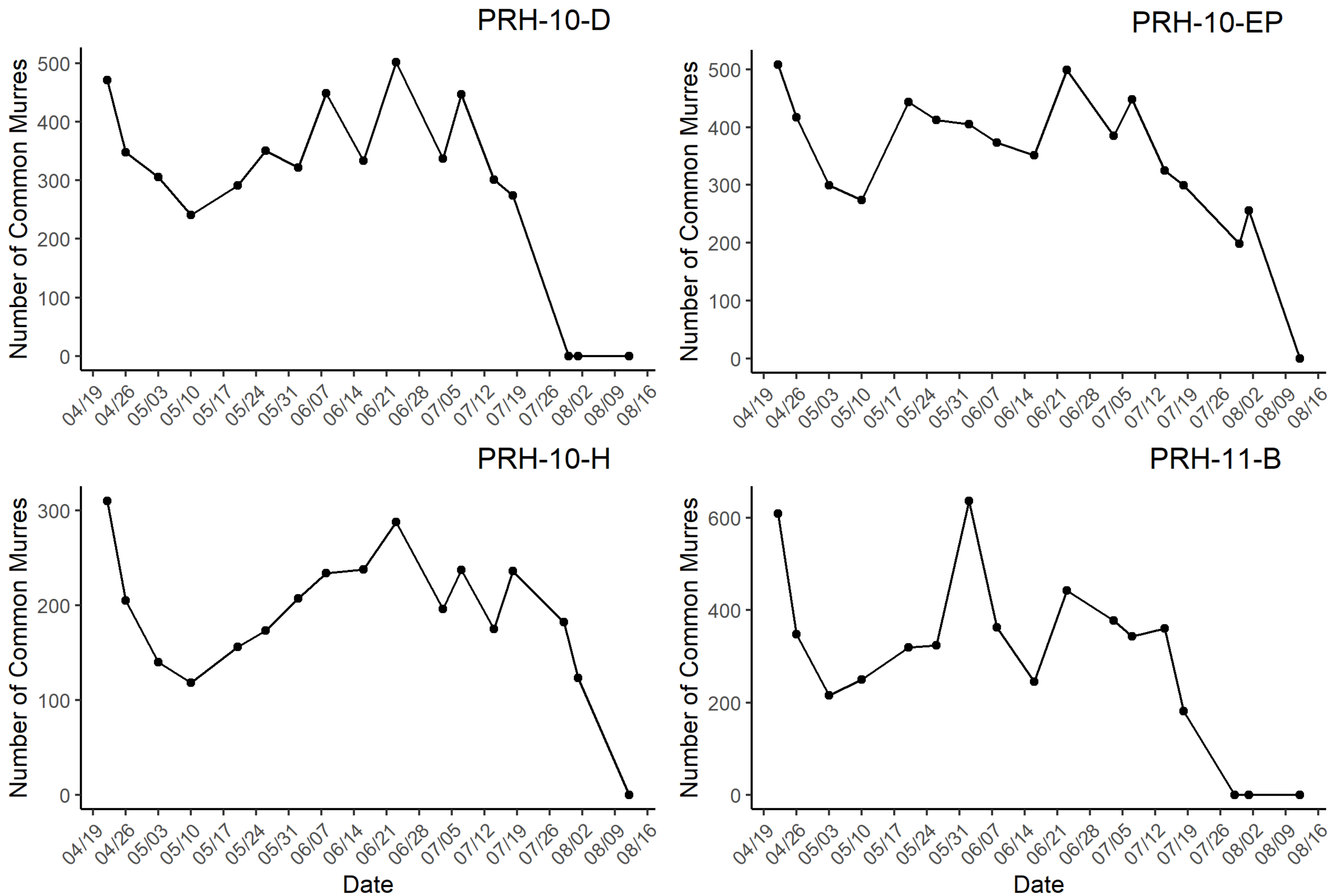


Figure 18. Seasonal attendance of Common Murres at Point Reyes Headlands (subcolonies: PRH-10-D (East Rock), PRH-10-EP (Beach Rock Plot), PRH-10-H (Tim Tam Rock) and PRH-11-B (Face Rock)) from 22 April to 12 August, 2021.

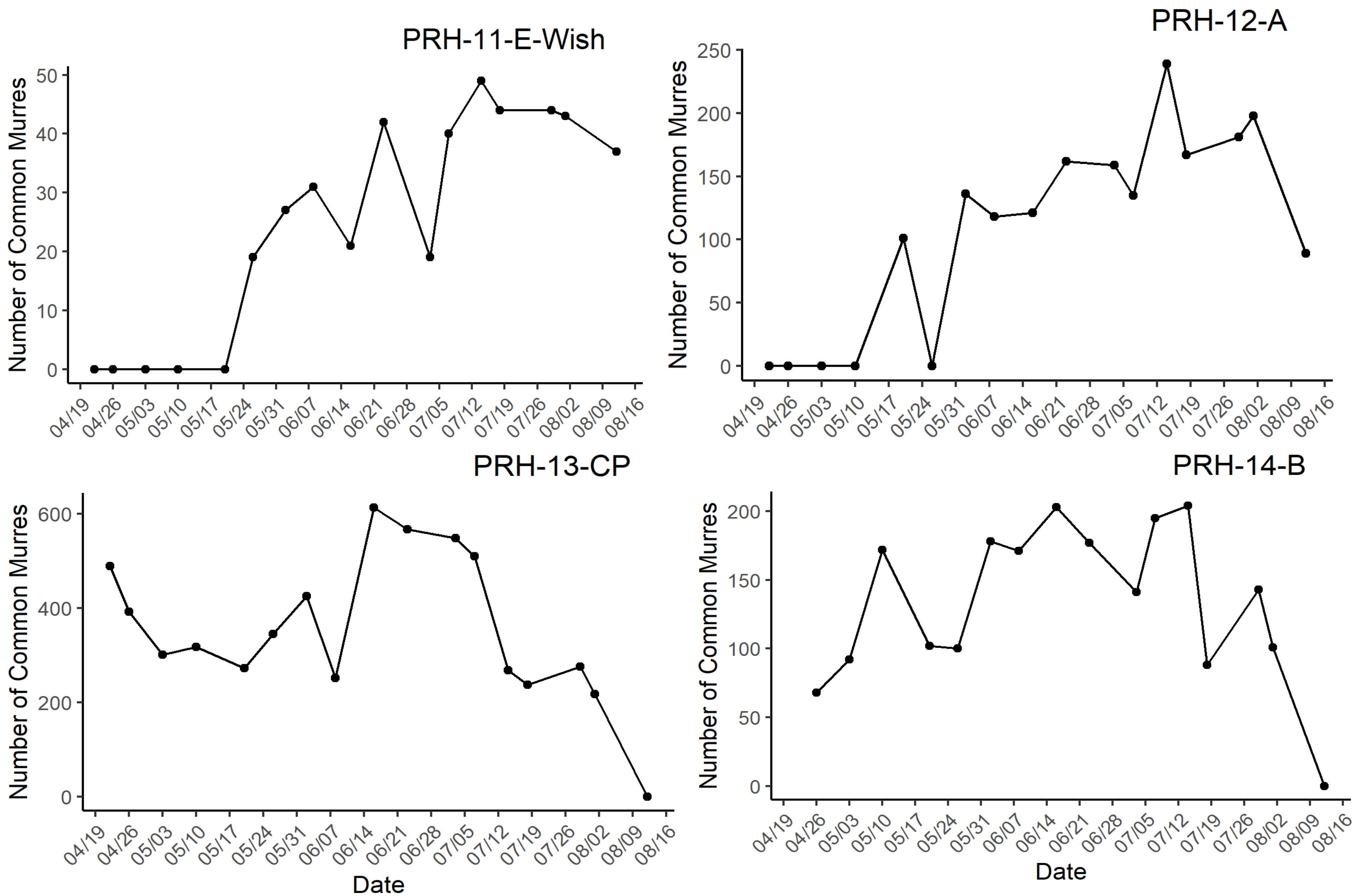


Figure 19. Seasonal attendance of Common Murres at Point Reyes Headlands (subcolonies: PRH-11-E-Wish (Wishbone Point), PRH-12-A (Sloppy Joe), PRH-13-CP (Cone Plot) and PRH-14-B (Area B)) from 22 April to 12 August, 2021.

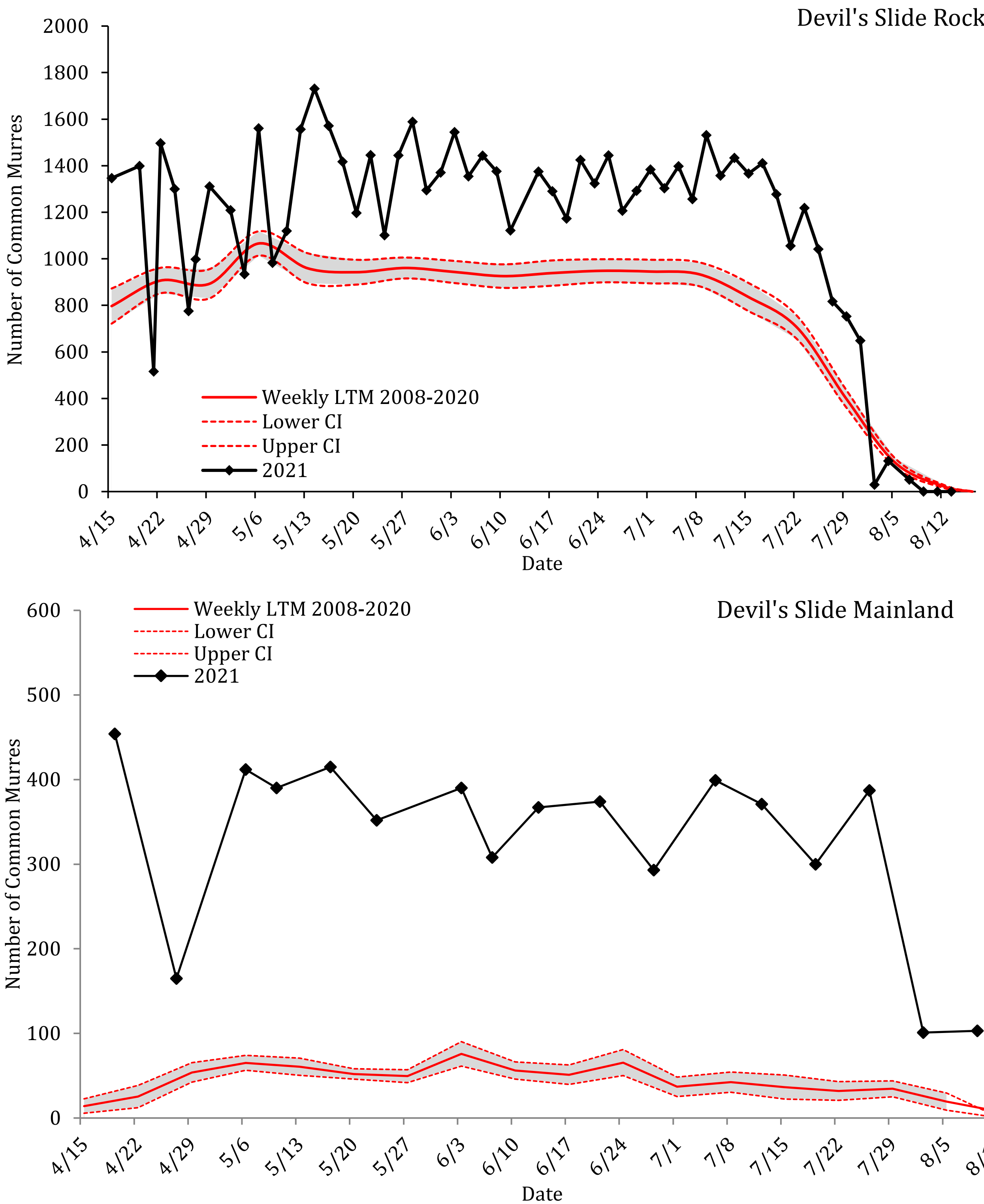


Figure 20. Seasonal attendance of Common Murres at Devil's Slide Rock (DSRM-01) and all Devil's Slide Mainland (DSM) subcolonies in 2021 compared to the long-term mean (LTM, 2008-2020).

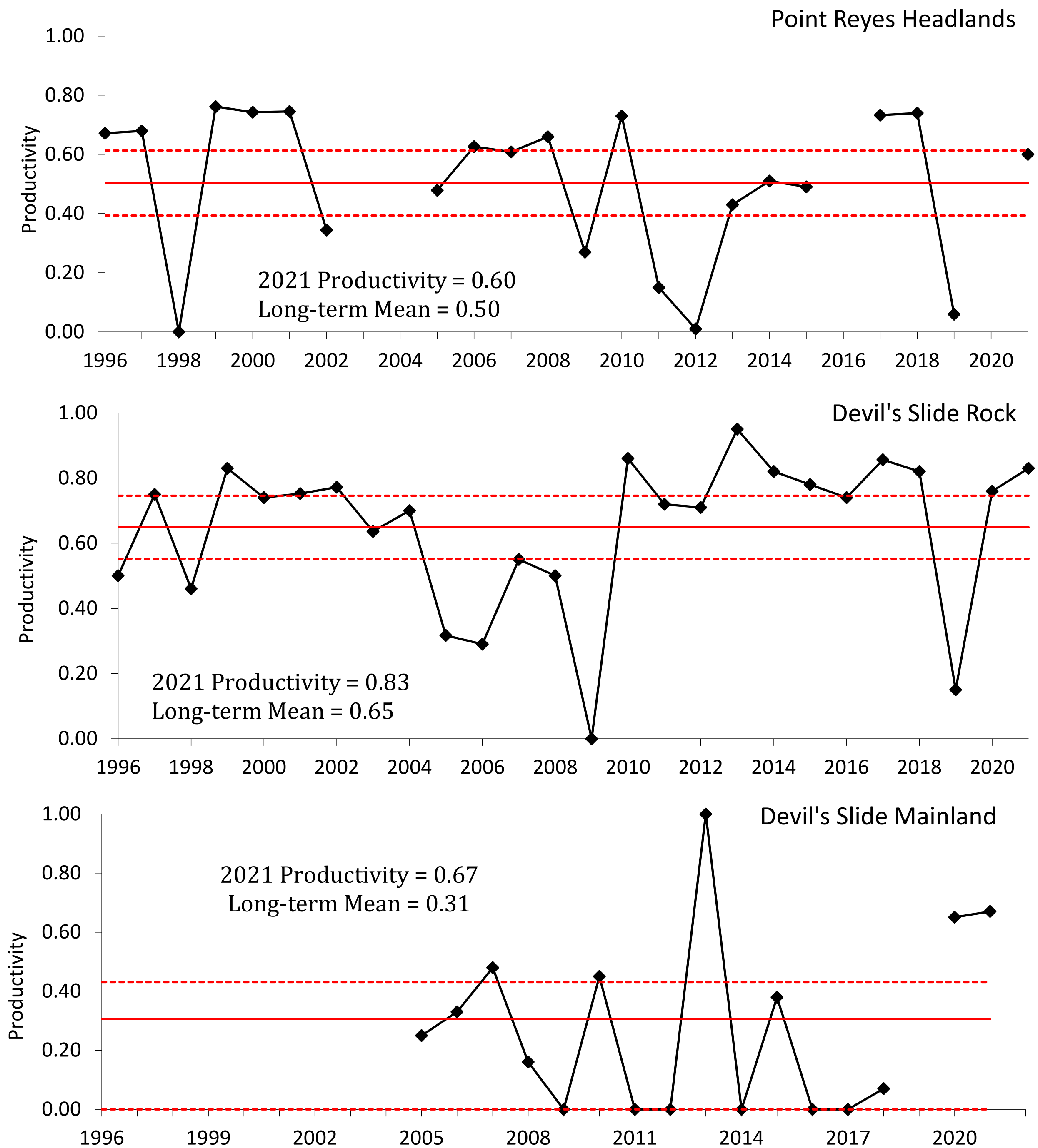


Figure 21. Productivity (chicks fledged per pair) of Common Murres at Point Reyes Headlands, Devil's Slide Rock, and Devil's Slide Mainland from 1996-2021. The solid horizontal line indicates the long-term weighted mean (1996-2020), and the dashed lines represent the 95% confidence interval.

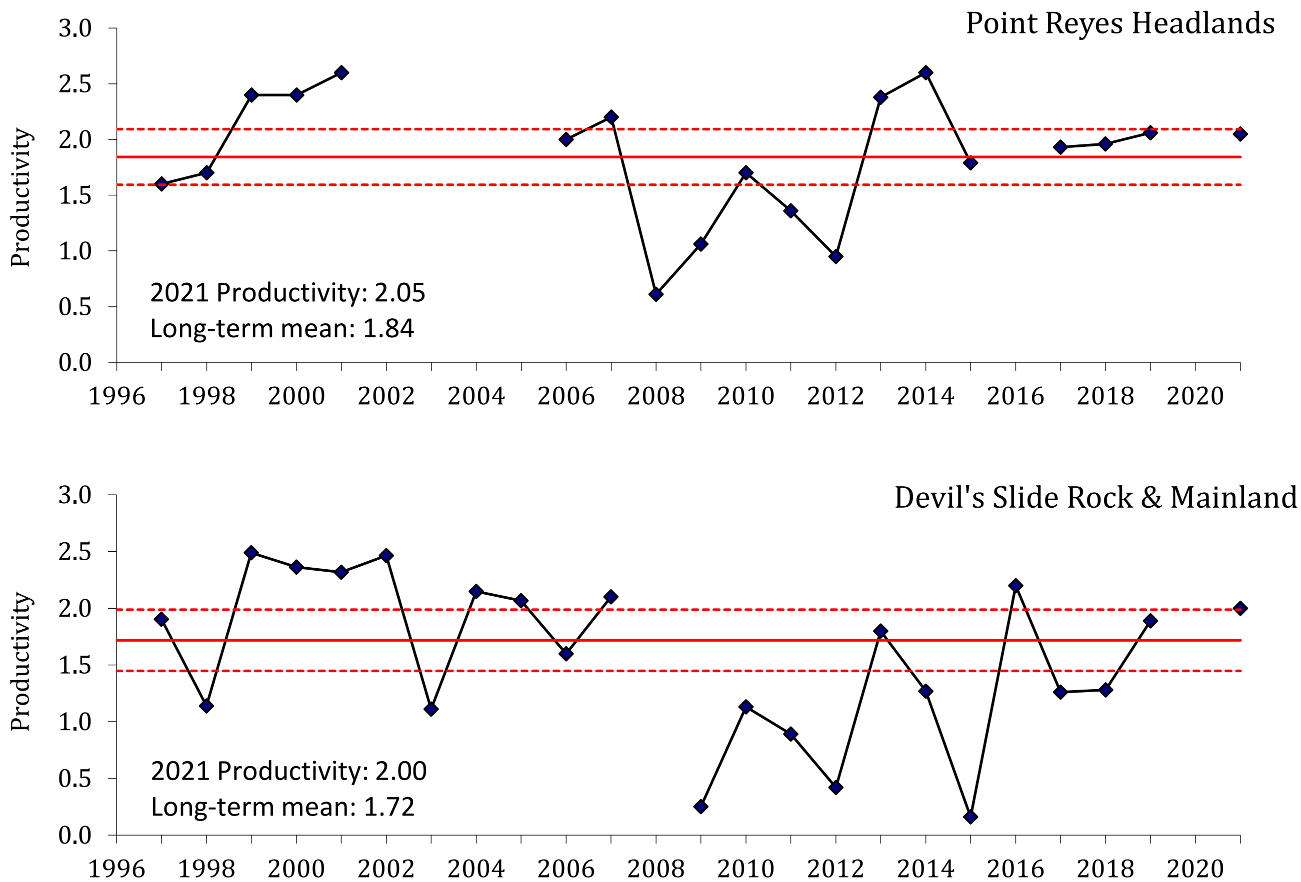


Figure 22. Productivity (chicks fledged per pair) of Brandt's Cormorants at Point Reyes Headlands and Devil's Slide Rock & Mainland, 1997-2021. The solid horizontal line indicates the long-term weighted mean (1997-2019), and the dashed lines represent the 95% confidence interval.

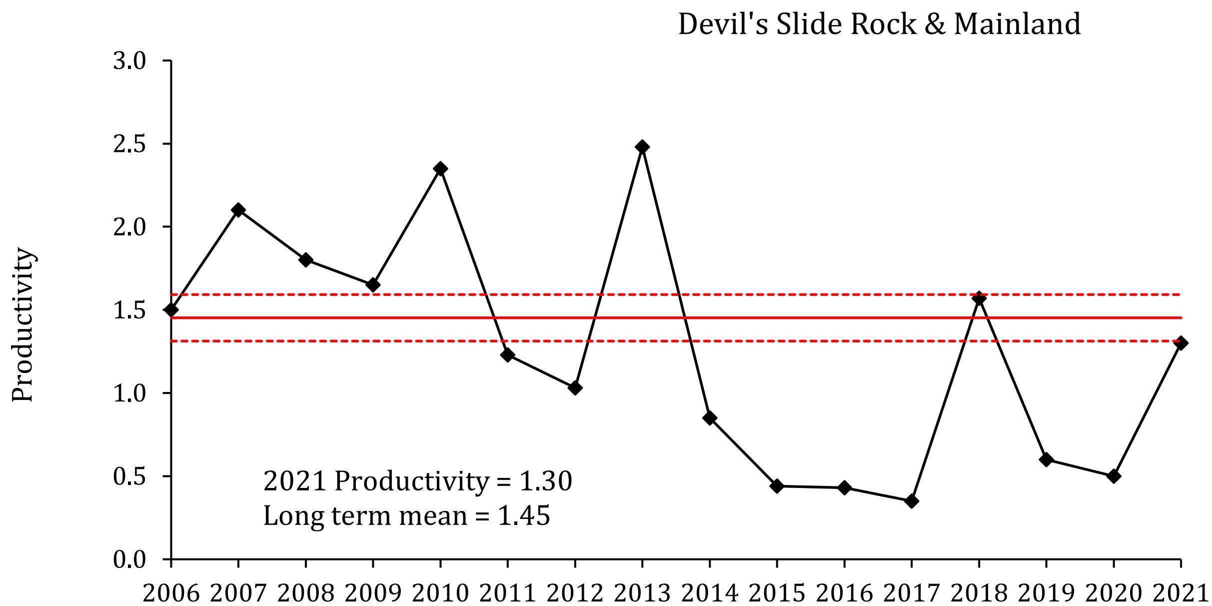


Figure 23. Productivity (chicks fledged per pair) of Pelagic Cormorants at Devil's Slide Rock and Mainland from 2006-2021. The solid horizontal line indicates the long-term weighted mean (2006-2020), and the dashed lines represent the 95% confidence interval.

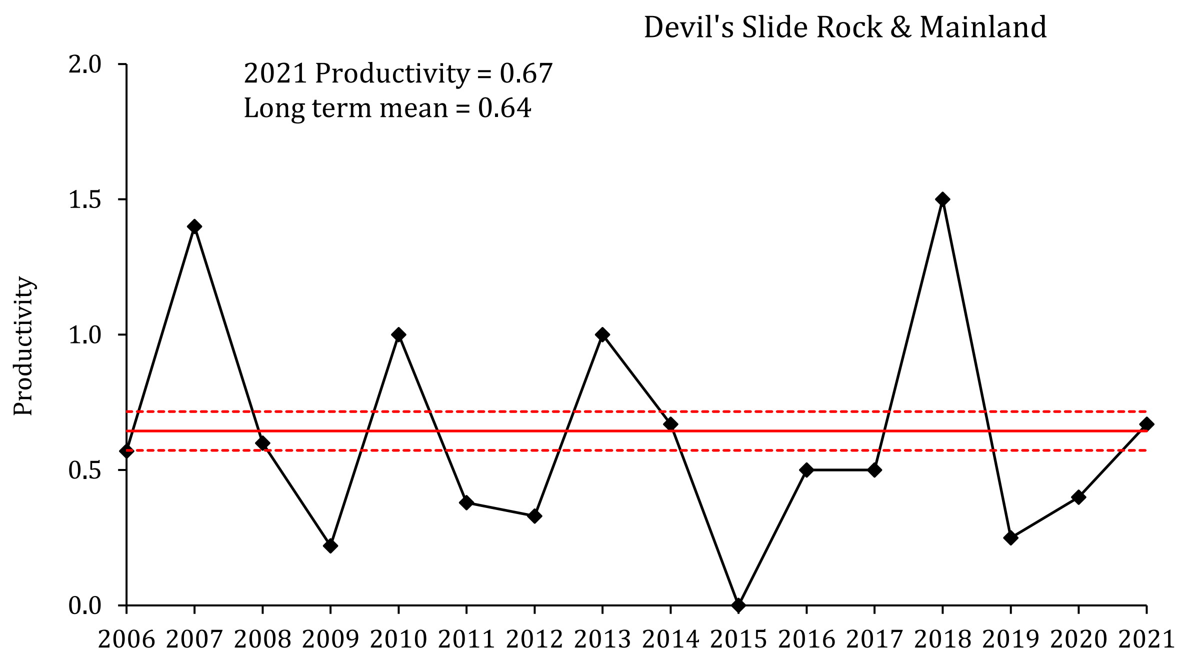


Figure 24. Productivity (chicks fledged per pair) of Western Gulls at Devil's Slide Rock & Mainland from 2006-2021. The solid horizontal line indicates the long-term weighted mean (2006-2020), and the dashed lines represent the 95% confidence interval.

Appendix 1. Number of aircraft overflights and land-based sources observed (detections and disturbances), separated by aircraft affiliation, at Point Reyes Headlands and Devil's Slide Rock & Mainland, 2021. UAS indicates an uncrewed aerial system (i.e., drone).

a) Detections

Affiliation	Helicopter	Motor Vehicle Noise	Plane	UAS	Total
Commercial			1		1
Law Enforcement			1		1
Media	1				1
Military	1		6		7
Private/recreational	10	1	33	2	46
Unknown	5		10	1	16
USCG	20		3		23
Total	**37**	**1**	**54**	**3**	**95**

b) Disturbance events

Affiliation	Helicopter	Motor Vehicle Noise	Plane	Total
Commercial			1	1
Media	1			1
Military	1		5	6
Private/Recreational	9	1	22	32
Unknown	5		8	13
USCG	16		3	19
Total	**32**	**1**	**39**	**72**

Appendix 2. Number of watercraft observed (detection and disturbances), categorized by type, at Point Reyes Headlands and Devil's Slide Rock and Mainland in 2021.

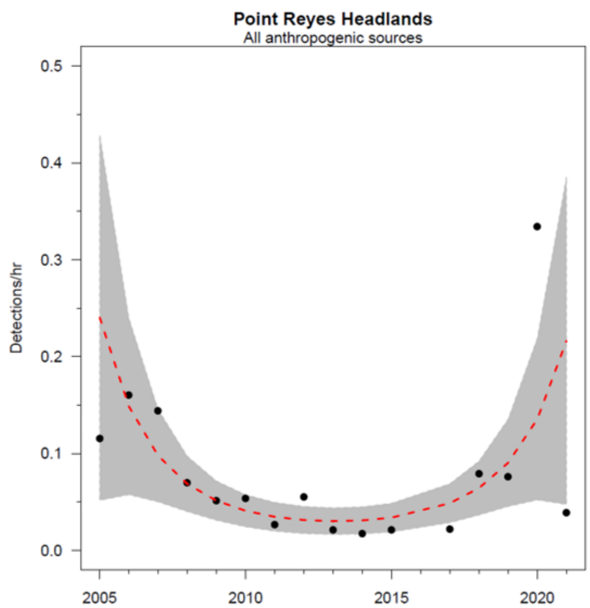
a) Detection events

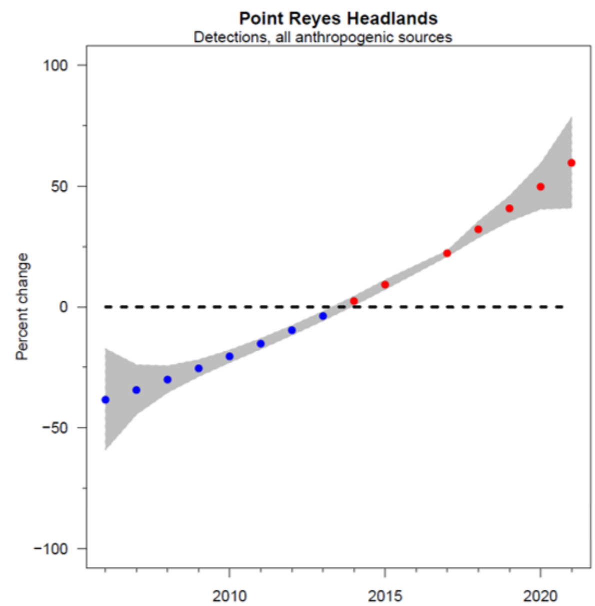
Affiliation	Motor Vessel (<25')	Motor Vessel (>25')	Kayak/Canoe (<25')	Sailboat (<25')	Total
Charter	1				1
Commercial		1			1
Private/Recreational	27	4	2	1	34
Unknown	1				1
Total	**29**	**5**	**2**	**1**	**37**

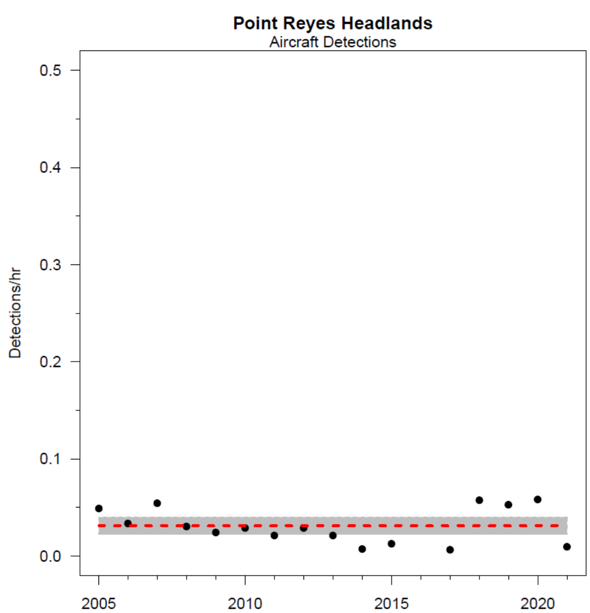
b) Disturbance events

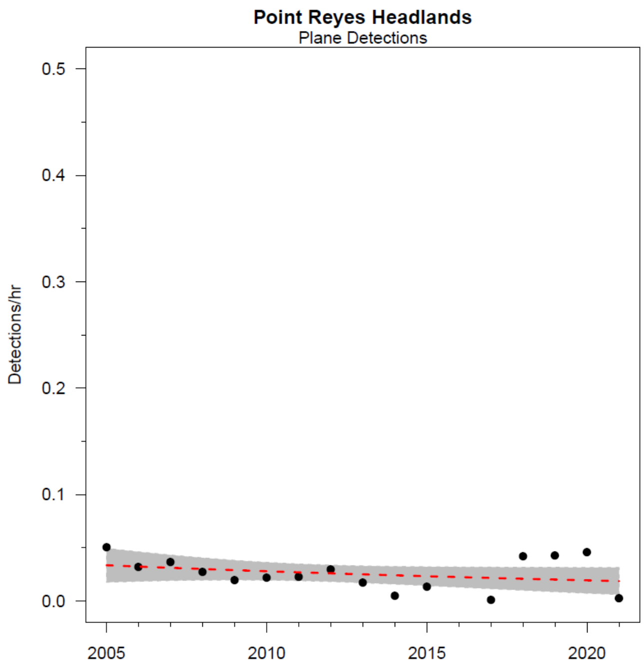
Affiliation	Motor Vessel (<25')	Total
Private/Recreational	5	5
Total	**5**	**5**

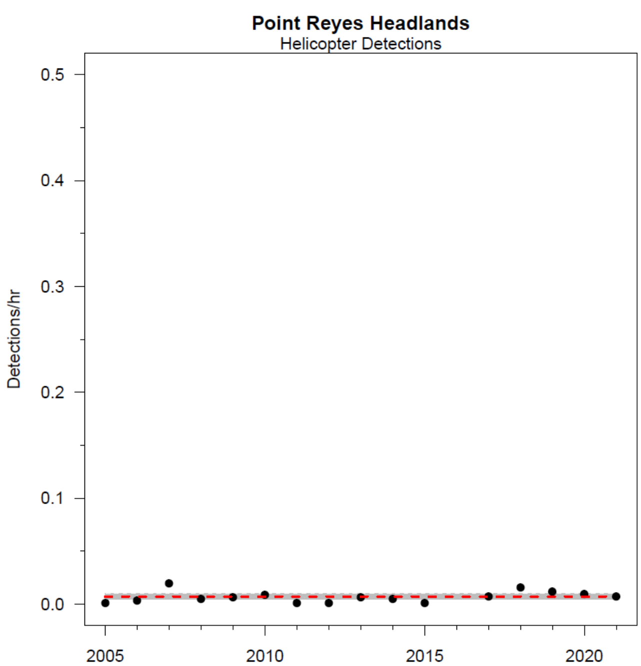
Appendix 3. Trends in anthropogenic detection rates, disturbance rates, and annual rates of change at Point Reyes Headlands, 2005-2021. The left column shows rates and their trendlines based on generalized linear models. The right column displays the percent annual change in detection or disturbance 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.

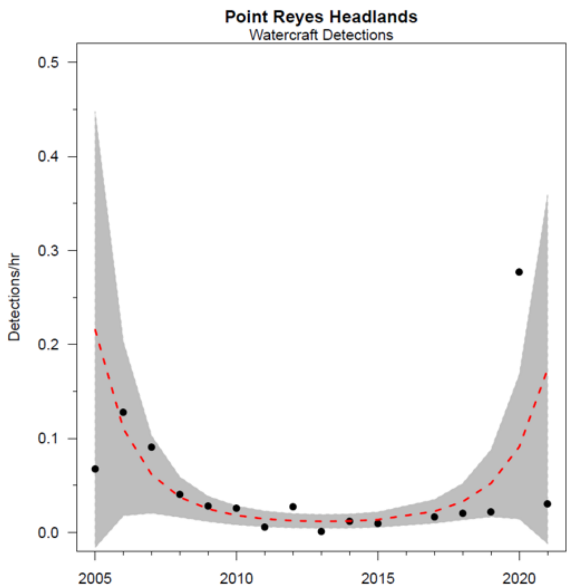


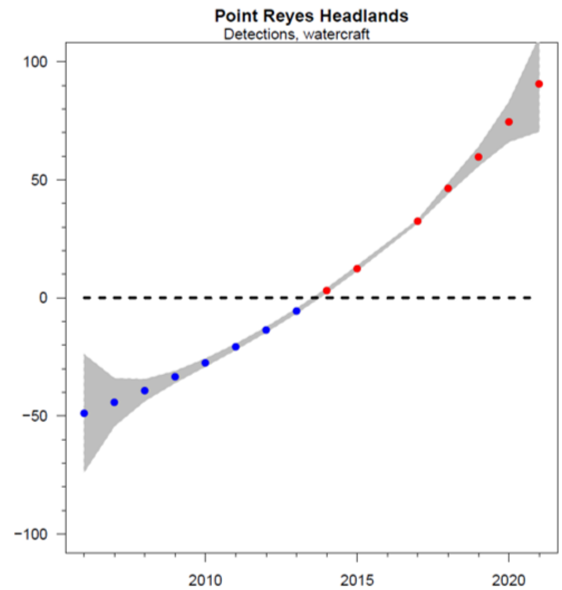


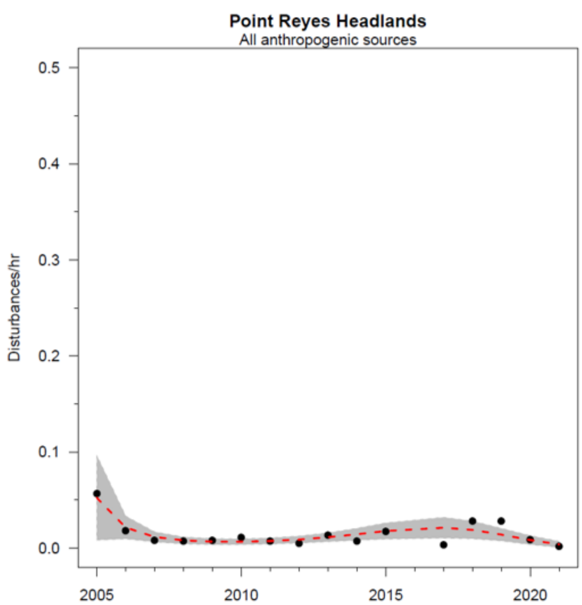


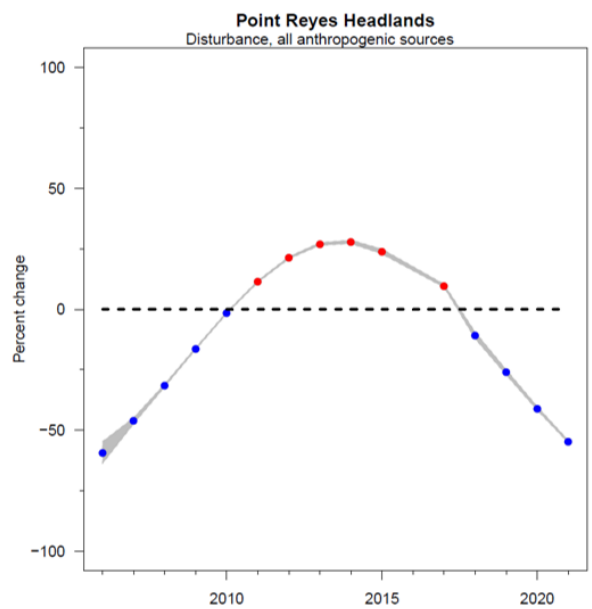

Point Reyes Headlands
Plane Detections
Detections/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

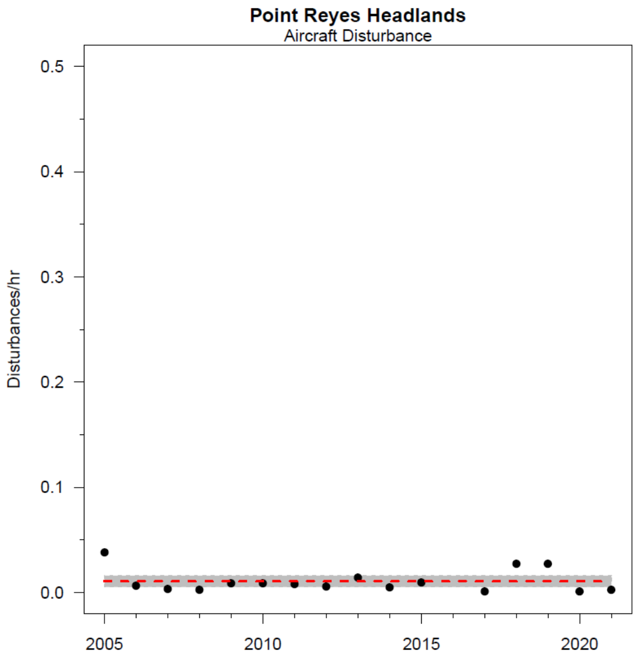

Point Reyes Headlands
Helicopter Detections
Detections/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

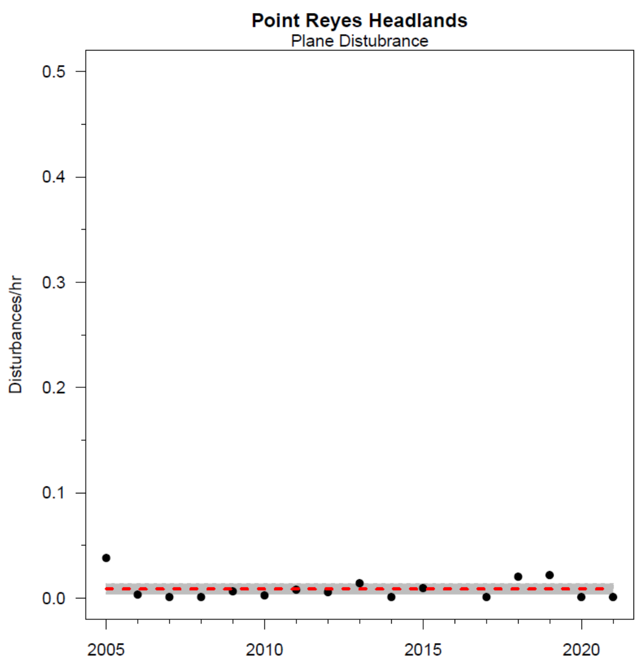

Point Reyes Headlands
Watercraft Detections
Detections/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

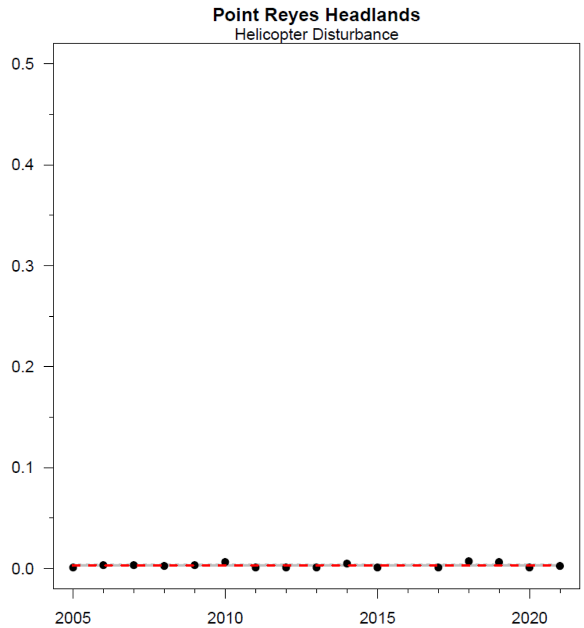

Point Reyes Headlands
Detections, watercraft
100
50
0
−50
−100
2010
2015
2020

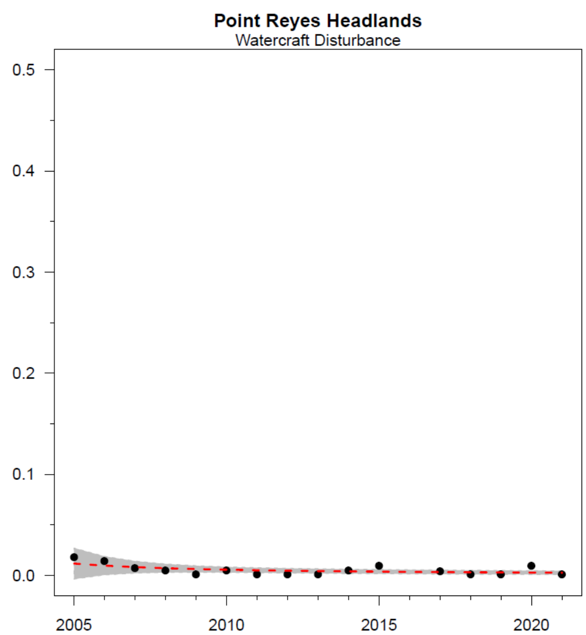

Point Reyes Headlands
All anthropogenic sources
Disturbances/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020


Point Reyes Headlands
Disturbance, all anthropogenic sources
Percent change
100
50
0
−50
−100
2010
2015
2020

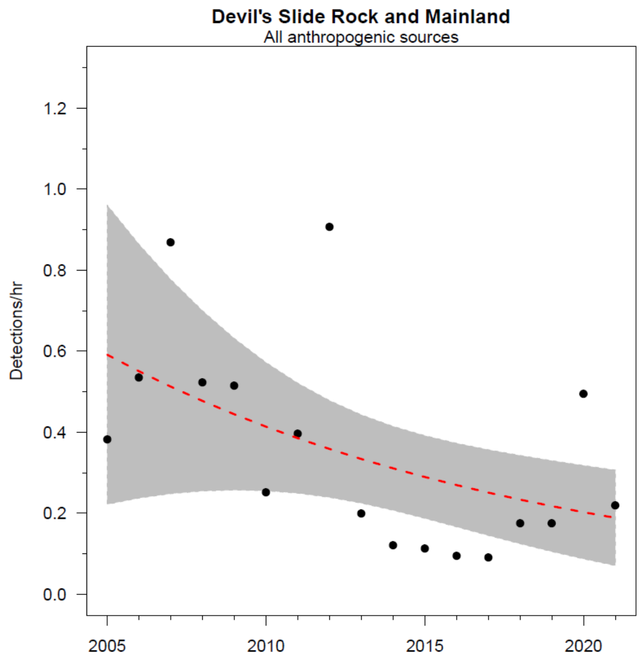

Point Reyes Headlands
Aircraft Disturbance
Disturbances/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

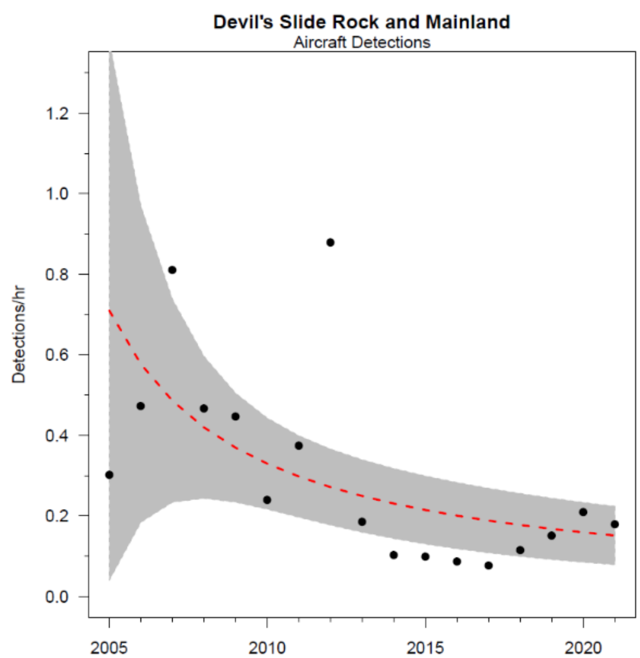

Point Reyes Headlands
Plane Distubrance
Disturbances/hr
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

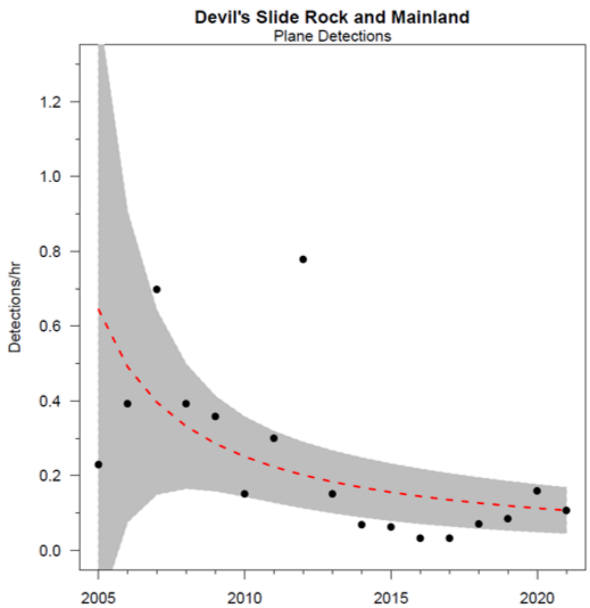

Point Reyes Headlands
Helicopter Disturbance
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

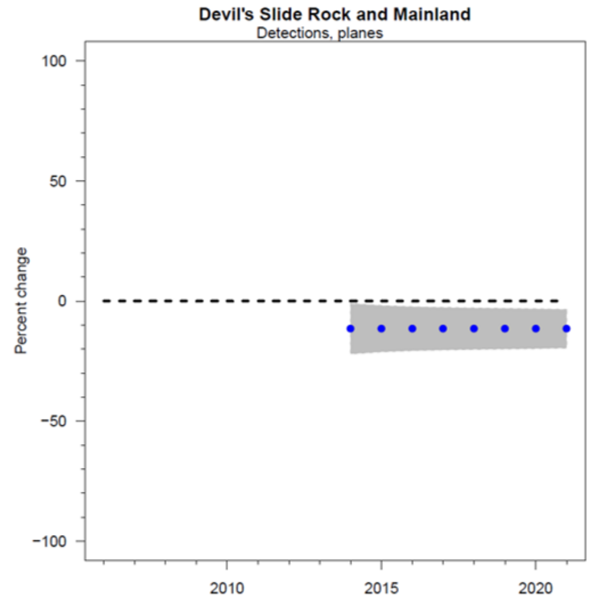

Point Reyes Headlands
Watercraft Disturbance
0.5
0.4
0.3
0.2
0.1
0.0
2005
2010
2015
2020

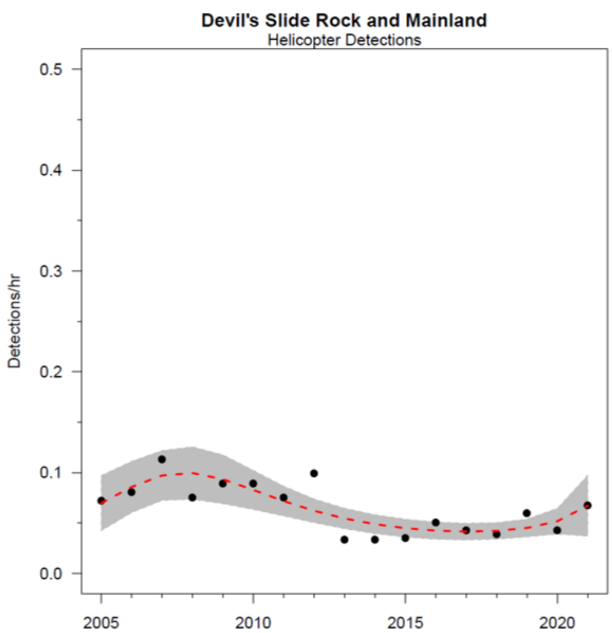
Appendix 4. Trends in anthropogenic detection rates, disturbance rates, and annual rates of change at Devil's Slide Rock & Mainland, 2005-2021. The left column shows rates and their trendlines based on generalized linear models. The right column displays the percent annual change in detection or disturbance 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.

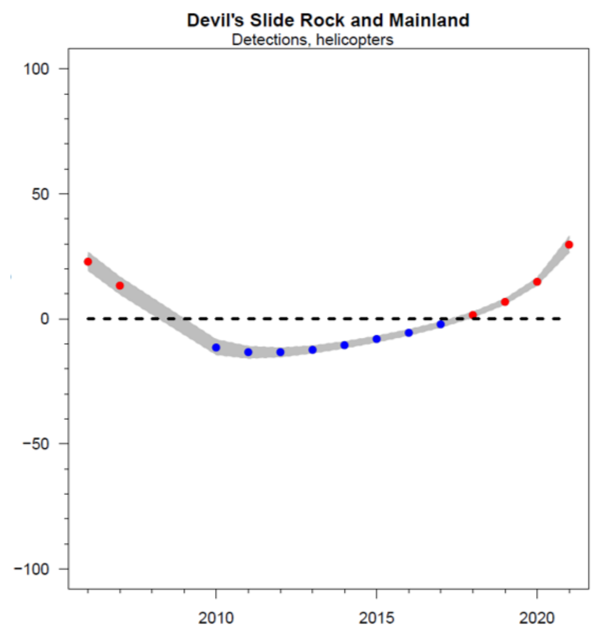


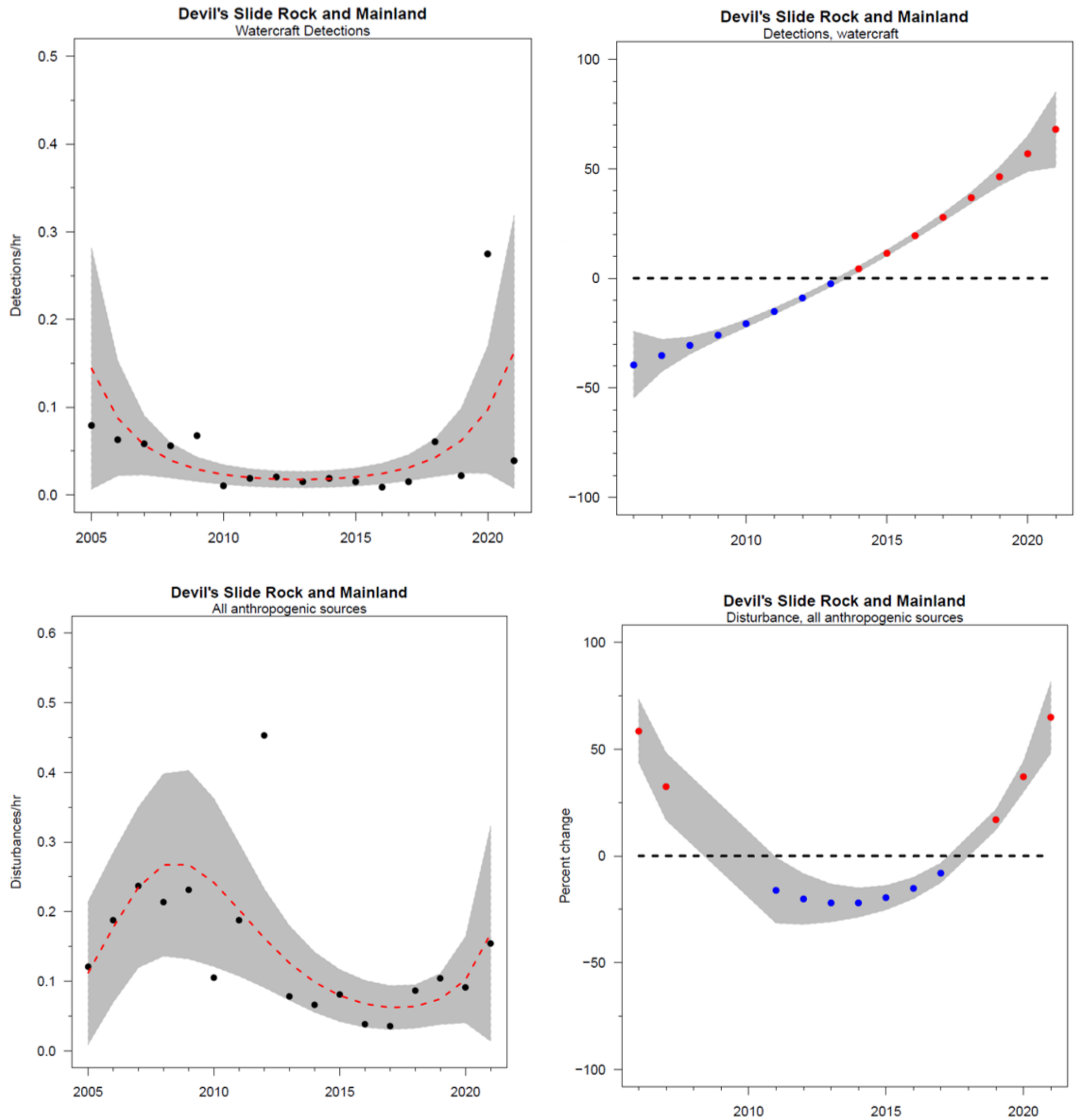


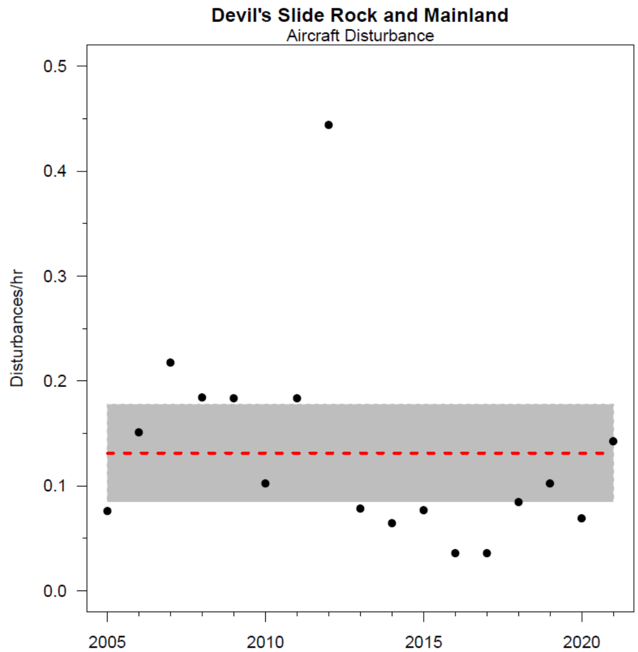

Devil's Slide Rock and Mainland
Plane Detections
Detections/hr
0.0
0.2
0.4
0.6
0.8
1.0
1.2
2005
2010
2015
2020

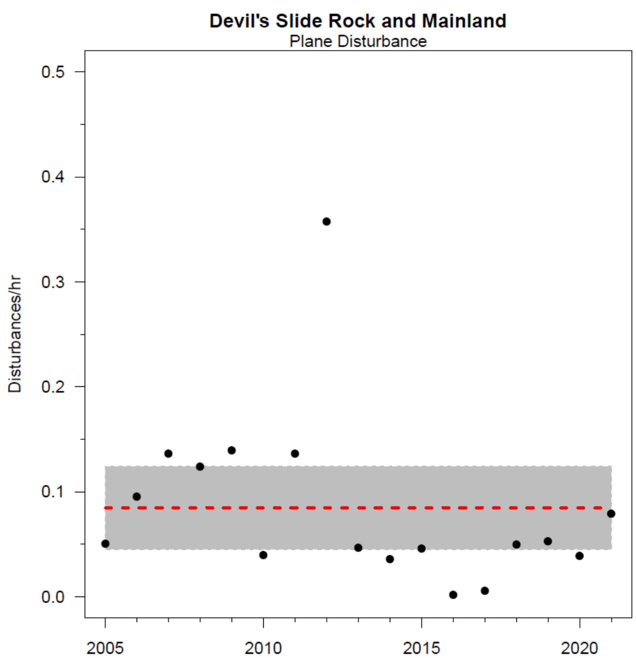

Devil's Slide Rock and Mainland
Detections, planes
Percent change
100
50
0
-50
-100
2010
2015
2020

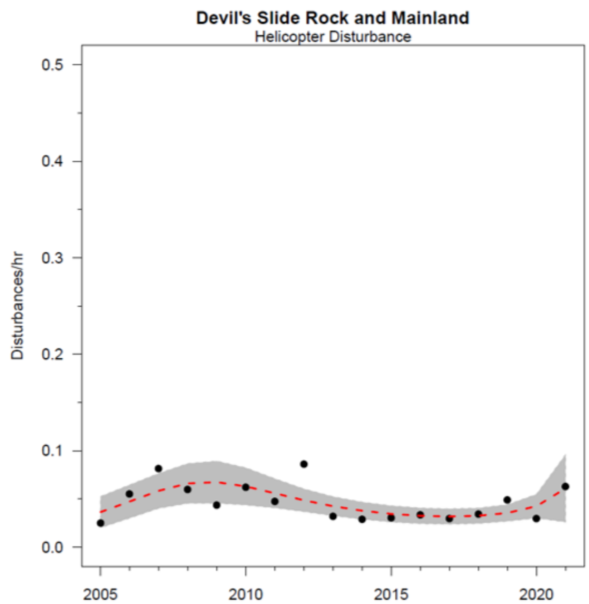

Devil's Slide Rock and Mainland
Helicopter Detections
Detections/hr
0.0
0.1
0.2
0.3
0.4
0.5
2005
2010
2015
2020

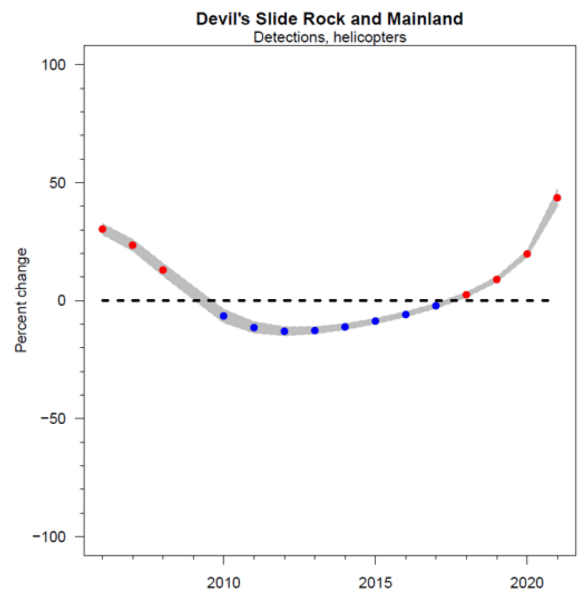

Devil's Slide Rock and Mainland
Detections, helicopters
100
50
0
-50
-100
2010
2015
2020

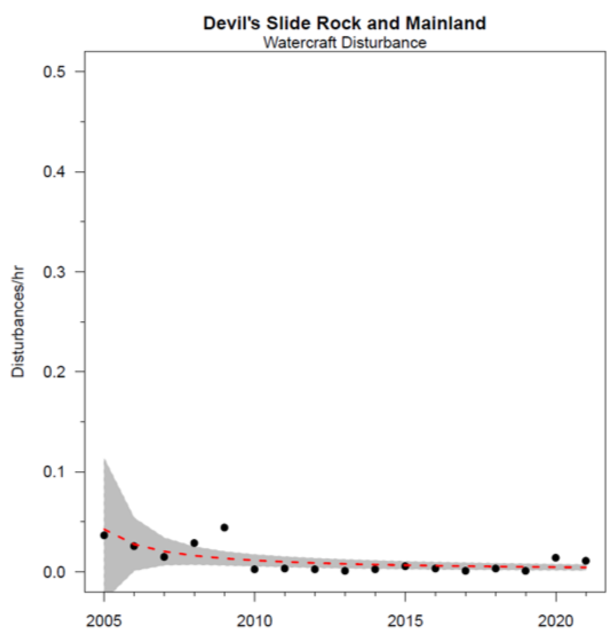

Devil's Slide Rock and Mainland
Watercraft Detections
Detections/hr
Devil's Slide Rock and Mainland
Detections, watercraft
Devil's Slide Rock and Mainland
All anthropogenic sources
Disturbances/hr
Devil's Slide Rock and Mainland
Disturbance, all anthropogenic sources
Percent change

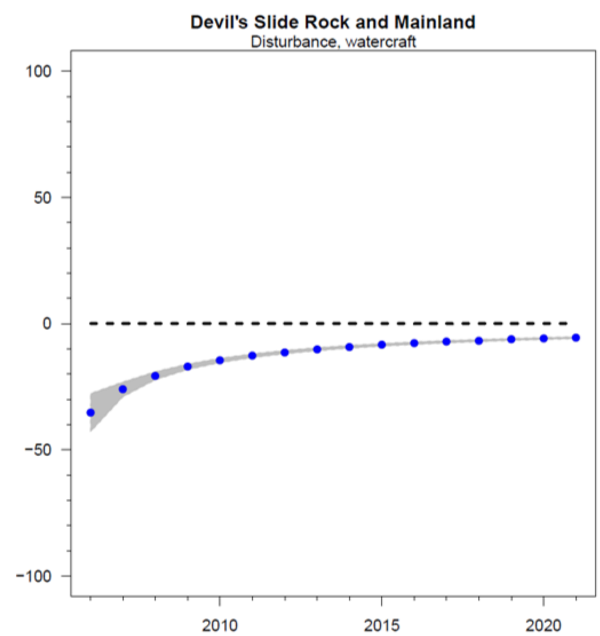

Devil's Slide Rock and Mainland
Aircraft Disturbance
Disturbances/hr
0.0
0.1
0.2
0.3
0.4
0.5
2005
2010
2015
2020


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
0.5
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
2010
2015
2020


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


Devil's Slide Rock and Mainland
Disturbance, watercraft
100
50
0
−50
−100
2010
2015
2020