AIRCRAFT AND VESSEL DISTURBANCES TO COMMON MURRES *URIA AALGE* AT BREEDING COLONIES IN CENTRAL CALIFORNIA, 1997–1999

NORA A. ROJEK[1,2], MICHAEL W. PARKER[3,4], HARRY R. CARTER[1,5] & GERARD J. McCHESNEY[3]

[1]Department of Wildlife, Humboldt State University, 1 Harpst Street, Arcata, California, 95521, USA (Nora_Rojek@fws.gov)
[2]Current address: US Fish and Wildlife Service, Fairbanks Fish and Wildlife Field Office, 101 12th Avenue, Room 110, Fairbanks, Alaska, 99701, USA
[3]US Fish and Wildlife Service, San Francisco Bay National Wildlife Refuge Complex, 9500 Thornton Avenue, Newark, California, 94560, USA
[4]Current address: US Fish and Wildlife Service, Red Rock Lakes National Wildlife Refuge, 27820 Southside Centennial Road, Lima, Montana, 59739, USA
[5]Current address: Carter Biological Consulting, 1015 Hampshire Road, Victoria, British Columbia, V8S 4S8, Canada

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SUMMARY

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From 1997 to 1999, we documented aircraft and vessel disturbances of Common Murres Uria aalge at three central California breeding colonies: Castle-Hurricane Colony Complex, Devil's Slide Rock, and Point Reyes. Most aircraft disturbances occurred when flyovers were ≤305 m above sea level. Helicopters tended to cause more disturbance than fixed-wing aircraft did, likely because of higher noise levels. At Castle–Hurricane, low aircraft flyovers occurred 49% and 656% more frequently than at Devil's Slide Rock and Point Reyes respectively. Flyovers also resulted in flushing of adult murres more frequently at Castle–Hurricane (31% of flyovers) and Point Reyes (25%) than at Devil's Slide (4%). Boat disturbance to murres also was substantially higher at Castle–Hurricane than at the other two colonies, resulting in lost eggs and chicks. Most boat disturbances occurred when vessels approached within 50 m of active nesting areas and remained in the area for extended periods. The central California murre population declined extensively during the 1980s mainly because of mortality from gillnet fishing and oil spills. Although numbers increased at most colonies in the 1990s, the Castle–Hurricane Colony Complex only partly recovered—to about half of pre-decline numbers by 1997. Although population impacts are difficult to measure, disturbance effects are probably additive to impacts from continued mortality attributable to gillnet fishing and other factors that have led to slow recovery at this colony complex.

Key words: Common Murre, *Uria aalge,* central California, aircraft, vessel, disturbance, alcid, colonial waterbirds, seabirds, Castle-Hurricane Colony Complex, Devil's Slide Rock, Point Reyes

INTRODUCTION

As human populations and activities increase in coastal marine habitats, disturbance levels to seabird breeding colonies and roosts are likely to increase unless management actions are taken to control such disturbances. Although several studies have found aircraft disturbance to be a problem for colonial nesting waterbirds (Bunnell *et al.* 1981, Burger 1981, Wanless 1983, Jones 1986, Fjeld *et al.* 1988, Culik *et al.* 1990, Olsson & Gabrielsen 1990, Wilson *et al.* 1991, Zonfrillo 1993, Mehlum & Bakken 1994, Curry 1995, Carney & Sydeman 1999, Giese & Riddle 1999), other studies did not observe much effect from low flyovers (Dunnet 1977, Kushlan 1979). Habituation to continual aircraft flyovers may occur in some situations (Dunnet 1977, Curry 1995). Without habituation, irregular flyovers or other human activities near colonies can greatly affect reproductive success, colony size, and continued use of the colony site over time for many sensitive species. In particular, aircraft, as well as boat disturbance, have been implicated as factors affecting certain colonies of Common Murres *Uria aalge* and Brandt's Cormorants *Phalacrocorax penicillatus* in California (Carter *et al.* 1998, 2001; McChesney *et al.* 1998; Thayer *et al.* 1999).

Since 1996, the Common Murre Restoration Project has worked to restore extirpated murre colonies at Devil's Slide Rock and San Pedro Rock in central California (Fig. 1) using social attraction techniques (Carter *et al.* 2003a, Parker *et al.* 2007). Monitoring of attendance and reproduction at restoration colonies and reference colonies at Castle–Hurricane and Point Reyes has provided data to

- measure the success of restoration efforts,
- investigate needs for additional restoration actions,
- identify and measure various impacts to murres, and
- further assess the status and biology of murres in central California.

Castle–Hurricane is also being managed for restoration needs because of severe murre declines in the 1980s.

During colony monitoring, low-flying aircraft were observed to cause disturbances to murre colonies. Some protection from aircraft disturbances is afforded to all of these colonies under various federal and state laws. All three colonies occur within National Marine Sanctuaries (Monterey Bay and Gulf of the Farallones) managed by the National Oceanic and Atmospheric Administration (NOAA). NOAA regulations prohibit overflights of motorized aircraft below 305 m altitude (stated as 1000 feet in the regulations) within certain restricted areas, except for law enforcement or under permit. Under the federal Airborne Hunting Act, aircraft are prohibited from disturbing or molesting wildlife. Until recently, Castle–Hurricane and Devil's Slide occurred within the California Islands Wildlife Sanctuary and were managed by the California Department of Fish and Game. In early 2000, these colonies became part of the California Coastal National Monument and are now managed by the US Bureau of Land Management. The Point Reyes colony is managed within the Point Reyes National Seashore by the US National Park Service. Federal agencies do not allow disturbances of breeding seabirds under the Migratory Bird Treaty Act (1917) that prohibits "take" of migratory birds. Despite such protections, helicopters and small airplanes frequently traveled by Castle–Hurricane along the scenic Big Sur coastline, located south of the relatively populated Monterey Peninsula. Additionally, each April, a large number of low-altitude flyovers have occurred during patrolling and filming of the annual Big Sur Marathon (established in 1986). The course of the Marathon follows California Highway 1, which passes directly by Castle-Hurricane.

In this paper, we review recorded aircraft and vessel observations at three murre colonies in central California from April through August 1997–1999, with an emphasis on aircraft disturbance and the Castle–Hurricane Colony Complex (CHCC), in an effort to

- determine the extent of disturbance to murres from aerial flyovers and vessel approaches, and
- quantify behavioral responses to disturbance and related altitudes of aircraft (fixed-wing and helicopters) or approach distances of vessels.

METHODS

The CHCC (36°21′–22′N, 121°54′W) extends along 3.5 km of the Big Sur coast of Monterey County, California, just south of Monterey, occupying nearshore rocks and mainland cliffs (Fig. 1). The complex comprises three closely-associated murre colonies: Bench Mark-227X, Castle Rocks and Mainland, and Hurricane Point Rocks (Sowls *et al.* 1980, Carter *et al.* 2001). Ten subcolonies of Common Murres ranging in size from about 20 to 800 birds per count were monitored at CHCC. Devil's Slide Rock (DSR, 37°34′N, 122°31′W) has a recently restored murre colony (with only one murre subcolony) located off the coast of San Mateo County, south of Pacifica. However, for the DSR sample, two observations in 1998 were included from San Pedro Rock, located two kilometers north of DSR. San Pedro Rock was a restoration site for murres in 1998/99, but no breeding occurred. Breeding at DSR increased from nine pairs in 1997 to 70 pairs in

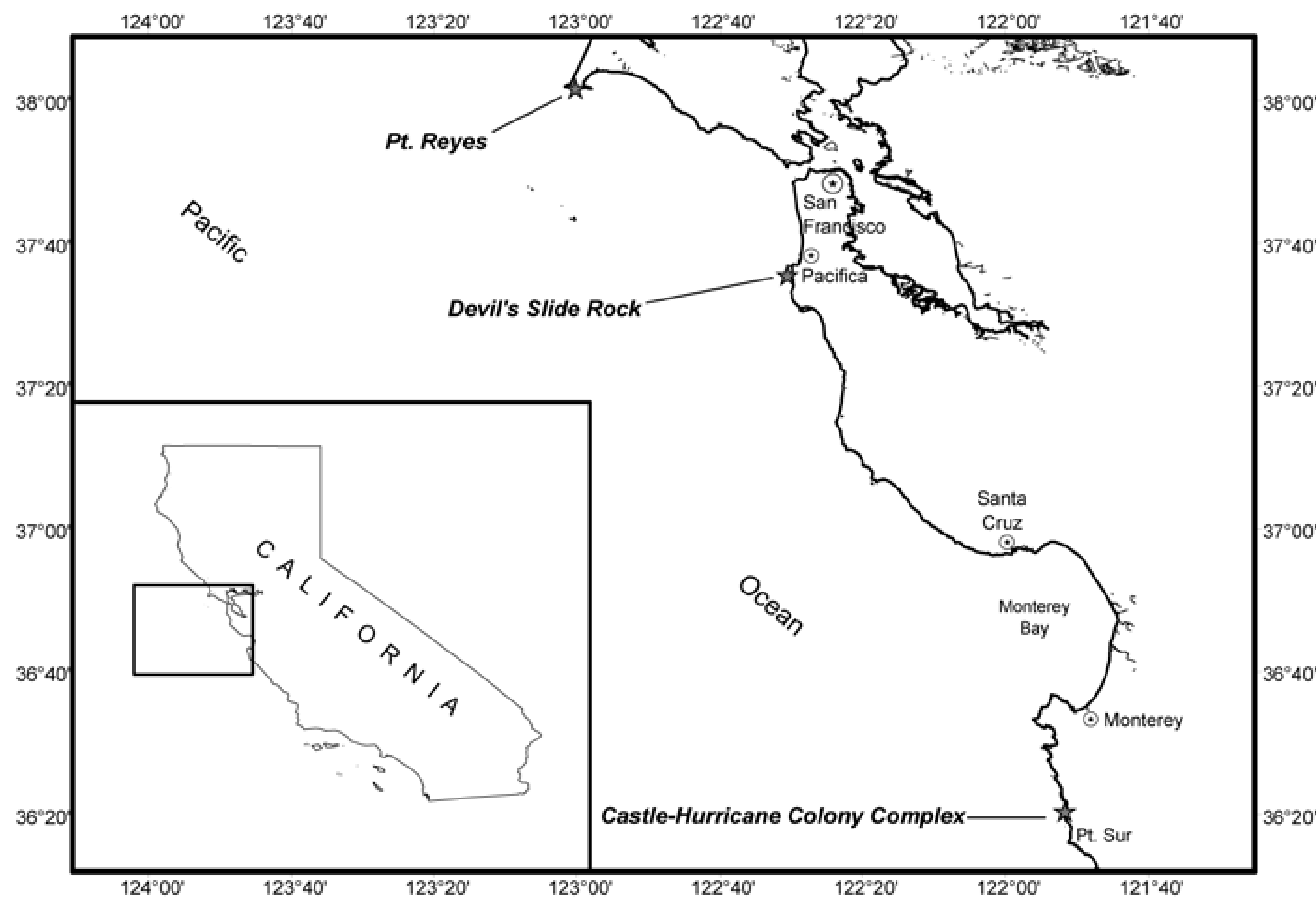

Fig. 1. Locations of Common Murre *Uria aalge* colonies studied: Castle–Hurricane Colony Complex, Devil's Slide Rock, and Point Reyes.

1999 (Parker *et al.* 2007). The Point Reyes colony (PR, 37°59′N, 123°59′W) occurs within the Point Reyes National Seashore, Marin County. Five subcolonies of murres were monitored at Point Reyes, ranging in size from <10 to 12 000 per count.

Monitoring of murre subcolonies was conducted from observation points on the adjacent mainland using binoculars (10×) and spotting scopes (20–65×). Data on aircraft, vessel and other disturbances were recorded from April through early August, 1997–1999.

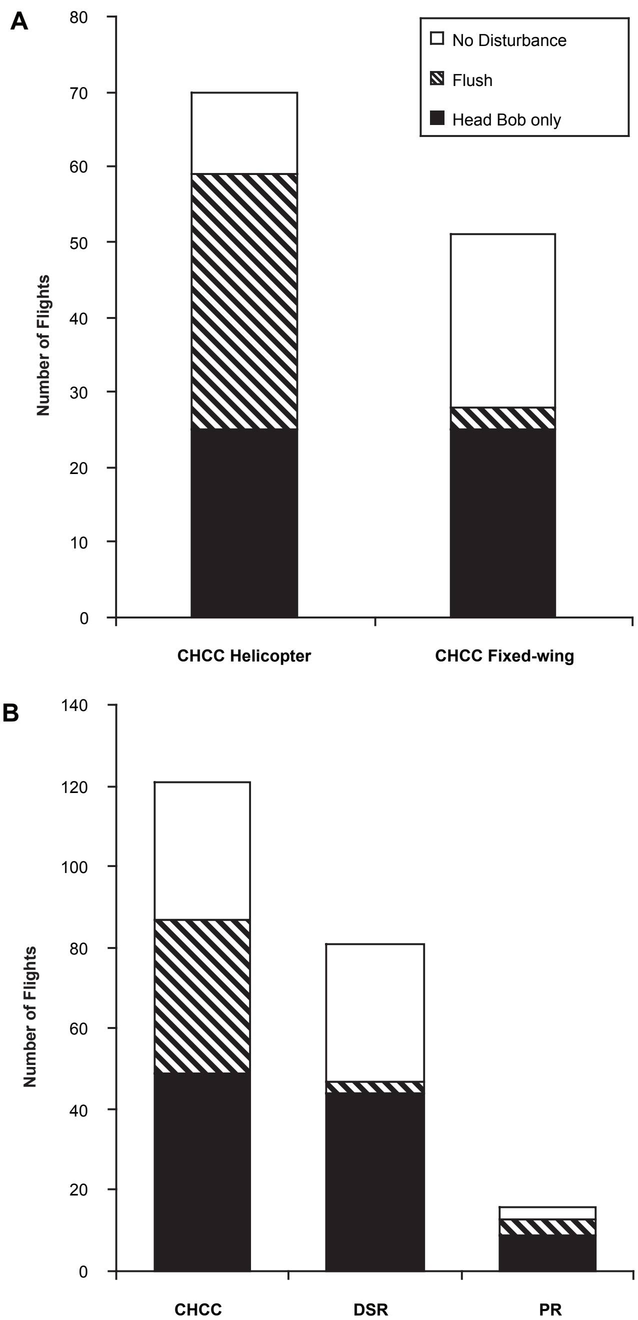

Fig. 2. (a) Number of low-flying (≤305 m altitude) helicopters and fixed-wing aircraft at the Castle–Hurricane Colony Complex (CHCC) and behavioral responses by Common Murres *Uria aalge* in April to August 1997–99. (b) Numbers of low-flying (≤305 m altitude) aircraft (helicopters and fixed-wing aircraft) and responses by Common Murres at the CHCC, Devil's Slide Rock (DSR) and Point Reyes (PR), April to August 1997–99.

Observations covered the late pre-laying and egg-laying periods (April to May) and the incubation, chick-rearing and colony departure periods (May to early August) for Common Murres. In early April, the subcolonies were monitored two days per week for about three hours per day. During Big Sur Marathon events (27 April 1997, 26 April 1998, 25 April 1999), the CHCC was monitored from sunrise until after all activities associated with the Marathon were completed (about 6–7 hours). After the first egg was laid, usually late April, subcolonies were monitored daily for 3–16 hours. Overall observer effort was similar between colonies.

Observations were recorded for any aircraft flying below 305 m altitude over a murre subcolony and for any aircraft causing a disturbance to seabirds. All boats that approached to within about 460 m of a murre subcolony or that caused a disturbance were recorded. We recorded date, time, estimated aircraft altitude (in 15-m increments using known elevations of observer location, nearby hilltops and other landmarks) or estimated nearest boat approach, approximate horizontal distance, aircraft or vessel type, direction of travel, and murre behavioral response. A disturbance was defined as causing either "head-bobbing" behavior (i.e. a moderate response to disturbance involving up and down jerking motions of the head, often done as a group response and often associated with warning and stress) or "flushing" (i.e. the maximal response to disturbance involving a partial or complete exodus of murres from the subcolony), or both.

Extensive head-bobbing alone could result in loss of eggs or chicks from breeding sites, but most birds appear to retain eggs and chicks if flushing does not occur. During flushing, eggs and chicks can be dislodged from nest sites, avian predators can gain access to them before murres return, and some eggs or chicks can be lost from exposure to heat or cold if left unattended for long periods. Return can occur within minutes, but may not occur within the same day depending on the time of day, the length of the disturbance or other factors. Return rates were more difficult to quantify, especially for extended or multiple disturbances, and were not summarized. We considered that each recorded disturbance event had a possible effect on reproductive success of murres, although the degree of effect could not be quantified, except by distinguishing between head-bobbing only (low effect) and flushing events (high effect). Head-bobbing often precedes flushing, and in most cases of observed flushing, head-bobbing was also noted to occur. In our analyses, however, we compared events of head-bobbing alone to flushing events (which may or may not have included head-bobbing).

We analyzed aircraft data using the NCSS2000 statistical software package, including several tests for contingency tables: chi-square, Fisher exact, and Kolmogorov–Smirnov (significance assumed when $P < 0.05$). For vessel data, sample sizes were too small for statistical analyses and summarized data only are presented.

RESULTS

Aircraft disturbances: CHCC

From April through early August 1997–1999, we recorded a total of 121 low overflights over CHCC: 70 (58%) by helicopters and 51 (42%) by fixed-wing aircraft. Overall, 87 flyovers (72%) caused a disturbance to one or more murre subcolonies. The proportion of flyovers that caused disturbances did not differ between years ($\chi^2_2 = 0.24$, $P = 0.9$). Multiple flyovers (n = 53, with 40 disturbances) during Big Sur Marathon events accounted for

46% of all aircraft disturbances recorded in 1997–1999. The level of Marathon disturbance was lower in 1998 (55% of flyovers caused disturbance, n = 11) as compared with 1997 (77%, n = 16) and 1999 (88%, n = 26), but a significant difference between years was not detected ($\chi^2_2 = 3.88$, $P = 0.1$).

Helicopter and fixed-wing aircraft accounted for 67% (n = 58) and 33% (n = 29) of all flyover disturbance in 1997–1999, respectively [Fig. 2(a)]. We noted a significant difference in the proportions of helicopters (83%) and fixed-wing (57%) aircraft flyovers that caused disturbance (Fisher exact test: $P = 0.002$). For disturbance events, head-bobbing alone occurred 56% of the time; 44% of events involved flushing. Also, for flyovers that caused disturbance, flushing occurred during a greater proportion of helicopter (60%) flyovers than of fixed-wing (10%) flyovers [Fisher exact test: $P < 0.0001$; Fig. 2(a)].

On average, flyover altitudes varied little between head-bobbing-only events ($\bar{\chi} = 232$ m) and flushing events ($\bar{\chi} = 226$ m, Table 1). In comparisons of helicopter and fixed-wing aircraft, no difference was detected in flight altitudes that caused head-bobbing (Kolmogorov–Smirnov test: $P = 0.09$). Flushing appeared to occur at higher helicopter altitudes, but the difference was not significant (Kolmogorov–Smirnov test: $P = 0.1$) given the small sample of fixed-wing aircraft flyovers. Flushing by fixed-wing aircraft occurred infrequently, but such aircraft, unlike many helicopters, were not observed below 152 m (500 feet).

TABLE 1
Flyover altitudes related to Common Murre *Uria aalge* behavioral response at the Castle–Hurricane Colony Complex, 1997–1999

Murre behavioral response	Aircraft type	Flyover altitude (m) $\bar{\chi}$	SD	n	Range
Flush	Helicopter	229	81	34	15–366
	Fixed-wing	193	16	3	183–213
	All aircraft	226	78	37	15–366
Head-bob only	Helicopter	232	96	25	15–457
	Fixed-wing	233	73	25	152–426
	All aircraft	232	87	50	15–457
No response	Helicopter	205	65	11	122–305
	Fixed-wing	246	70	23	91–305
	All aircraft	233	70	34	91–305
Total flyovers	Helicopter	226	84	70	15–457
	Fixed-wing	237	70	51	91–427
	All aircraft	231	78	121	15–457

SD = standard deviation.

Aircraft disturbances: comparisons among colonies

At DSR and PR, many fewer low overflights were recorded than at CHCC during the same period in 1997–1999: 81 at DSR and 16 at PR [Fig. 2(b)]. Although lower levels of disturbance tended to occur at DSR (58%) as compared with CHCC (72%) or PR (81%), the proportion of flyovers that resulted in disturbance was not significantly different between the three colonies ($\chi^2_2 = 5.76$, $P = 0.06$). If Big Sur Marathon days at CHCC are excluded (revised n = 68), more aircraft traveled over DSR than over the other two colonies. However, excluding Marathon days from the analyses resulted in little difference in the proportion of flyovers causing disturbance at CHCC (69%), and differences between the colonies were still nonsignificant ($\chi^2_2 = 4.09$, $P = 0.13$).

Comparable high-incidence events did not occur at the other two colonies. Largely because of much lower numbers of flyovers, the average number of observed disturbance events was lower at PR (four per season) than at DSR (16 per season) or CHCC (29 per season). Flushing was highest at CHCC (44% of all disturbances), lower at PR (31%), and especially low at DSR [6%; $\chi^2_2 = 20.0$; $P < 0.0001$; Fig. 2(b)].

To examine behavioral responses between seasons (i.e. prebreeding and breeding), data were grouped as being before or after the first eggs of the season were laid, and before or after the mean egg-laying date at each colony in each year. Proportions of overflights that elicited flushing and all disturbance (flushing and head-bobbing) behaviors were compared between before and after groups. To increase the sample size, data were pooled for all colonies. Proportions of overflights that caused flushing differed significantly between samples taken before (28%) and after (11.3%) the mean egg-laying date. No difference was evident before and after the first egg (Table 2). In contrast, the comparisons for all disturbances revealed a difference between samples taken before (58.6%) and after (73.8%) the first egg, but no difference relative to mean egg date. These results suggest that a murre colony will react to aircraft overflights at any season, but that they are more prone to flushing in the pre-egg and early egg-laying periods than after egg-laying is well underway.

Vessel disturbances

At CHCC, a total of 23 vessels were recorded approaching within about 500 m of murre subcolonies. Of that total, eight approaches (33%) caused a disturbance to seabirds, with seven disturbances to murres. Four of those seven disturbances resulted in head-bobbing or walking movements of murres away from their sites (or both), and three (including one additional disturbance) resulted in flushing

TABLE 2
Percentages of low overflights resulting in flushing or any disturbance (flushing or head-bobbing) of Common Murres *Uria aalge* at all colonies, 1997–1999, relative to first egg date and mean egg-laying dates; results of *Z* tests of differences in proportions

	First egg				Mean egg-lay date			
	Before	After	*Z*	*P*	Before	After	*Z*	*P*
n[a]	70	145			118	97		
Flushed (%)	21.4	20.7	-0.053	0.96	28.0	11.3	2.85	0.004
Disturbed (%)	58.6	73.8	2.10	0.036	65.3	73.2	1.10	0.27

[a] Excludes two records at San Pedro Rock (Devil's Slide Rock area) in 1998 because no murres bred there.

of 5–100 murres (Fig. 3). One approach disturbed only the crèching chicks of Brandt's Cormorant. Six of the disturbances occurred in 1999, two in 1998, and none in 1997. Brandt's Cormorant adults and chicks were disturbed during all six events in 1999.

An increase in vessel activity near murre subcolonies at CHCC was observed during the chick-rearing period in late July 1999. Calm sea conditions resulted in fishing boats moving into nearshore kelp beds adjacent to subcolonies to set traps for catching rockfish *Sebastes* spp. Five incidents causing major disturbance at CHCC (subcolony CRM-03 East, where both murres and Brandt's Cormorants were nesting) were observed during a two-week period, culminating in no murres remaining on the rock. In each case, Brandt's Cormorants and their large chicks scurried to the top of the rock, displacing murre adults and chicks. Head-bobbing and flushing of murres occurred during this process.

On 21 July 1999, fishing activity by two boats at CHCC was observed for more than six hours. During that time, continual head-bobbing and flushing of breeding murres (including 100 murres flushing when the boats arrived) occurred. About 40 Brandt's Cormorants flushed and all their chicks moved to the top of the rock. Murres moved with their chicks from breeding sites to the edge of the rock. In the commotion, one Western Gull *Larus occidentalis* harassed a murre, resulting in its egg rolling off the rock; the same gull then harassed another murre with a chick. Also as a result of this disturbance, one 15-day-old murre chick, barely old enough to depart the colony, jumped off the rock and swam away with its parent at 10h30 (PDT). Murre chicks normally depart the colony in the evening or at night when avian predation is less likely. By the following day, three of the last four murre chicks remaining on the rock were missing. At least two of these were too young to depart the colony, and they were assumed to have died. The last remaining murre chick, only five days old, disappeared after further large-scale disturbances the following day.

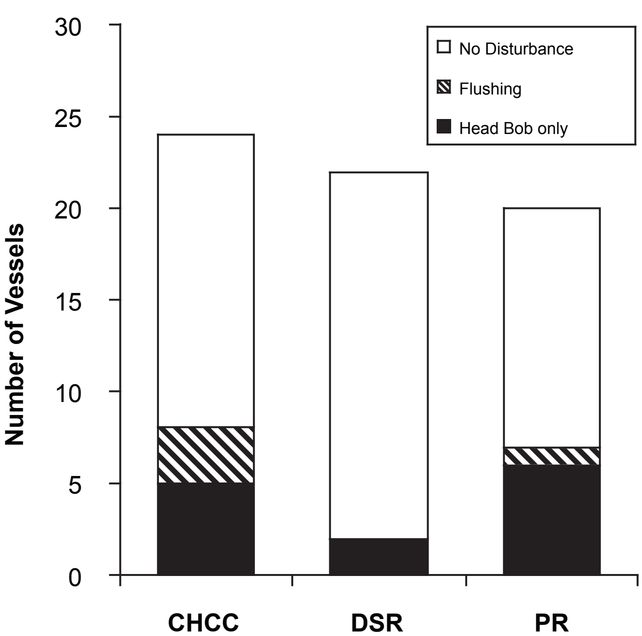

Fig. 3. Number of vessels approaching to ≤1000 m and behavioral responses by Common Murres Uria aalge at the Castle–Hurricane Colony Complex (CHCC), Devil's Slide Rock (DSR), and Point Reyes (PR), April to August 1997–99.

In 1997–1999, similar numbers of vessels were observed approaching murre subcolonies at PR: 23 total for the three seasons, with seven causing disturbance (five in 1999, one in 1998, and one in 1997; Fig. 3). Only one of these disturbances resulted in flushing of one murre, 15 Brandt's Cormorants, and 50 Brown Pelicans *Pelecanus occidentalis.* At DSR, 30 vessels were observed, but only one in 1998 caused a disturbance, causing murres to head-bob and move from their sites.

At all colonies, 78% of recorded disturbances occurred when boats approached to within 50 m of an active murre subcolony, and all flushing events occurred when boats were within 75 m. On two occasions at PR, murre head-bobbing occurred when boats approached to within 200 m, and a vessel with a loud engine elicited head-bobbing when about 800 m away.

DISCUSSION

Disturbances by low-flying aircraft, especially helicopters, have potential to seriously affect breeding by Common Murres. Although a relatively low level of disturbance was observed during the present study, single or infrequent disturbances can result in long-term impacts. Helicopters caused more disturbances and flushing than fixed-wing aircraft did, partly because of their low-altitude capabilities. For search-and-rescue missions, US Coast Guard helicopters often need to fly at low altitudes.

Helicopters also appeared to cause disturbance at altitudes higher than those of planes, probably because of their typically louder engines and rotor vibration (which was evident to us when they passed overhead). Although our sample size of flushing by fixed-wing aircraft was low at CHCC (n = 3), mean flushing altitude by helicopters was higher (229 m) than the highest flushing altitude by a fixed-winged aircraft (213 m, Table 1). Other studies have found that helicopters are or appear to be more disturbing to seabirds (Dunnet 1977, Wanless 1983) and waterfowl (Boothroyd 1986, Ward *et al.* 1987) than fixed-wing aircraft are. Studies have also documented that louder aircraft elicit greater behavioral responses by murres (Curry 1995) and other species (Brown 1990, Ward *et al.* 1999, Ward *et al.* 2001, Goudie & Jones 2004, Goudie 2006).

Flushing during incubation or chick-rearing periods can lead to egg or chick loss because of displacement from the breeding site, egg breakage or depredation by avian predators such as Western Gulls or Common Ravens *Corvus corax.* Such losses were documented during vessel disturbances at CHCC. Murres can replace lost eggs, depending on the time within the breeding season that the first egg is lost, but the hatching success of replacement eggs is lower than that of first eggs (Carter & Manuwal 2001) and reproductive success tends to decline with later laying date (Gaston & Nettleship 1981, Birkhead & Nettleship 1982, Wanless & Harris 1988, Hatchwell 1991).

Effects of flushing on birds that are not attending eggs or chicks are difficult to assess, but may exist. For example, disturbance during the pre-incubation period has the potential to disrupt courtship, nest site defense and prospecting activities. Despite such consequences, low-flying aircraft disturbed murres at our study colonies, whether in violation of federal and state regulations, with a valid permit, or through emergency or other exemptions. Our data support current NOAA overflight restrictions of 1000 feet (305 m) above ground level, because aircraft flying at or above that height are unlikely to cause disturbance to breeding seabirds. (A small number of disturbances still occurred during overflights at higher altitudes.) Thus, if more aircraft were to follow NOAA regulations, fewer and less severe disturbances should occur at CHCC murre colonies. Lacking earlier data, it is impossible to determine if aircraft activities prior to the designation of the Monterey Bay National Marine Sanctuary in 1992 resulted in higher numbers of disturbances at CHCC. However, many older military and US Coast Guard helicopters were louder than those in use during our study. This study reconfirms that helicopter disturbance probably has been a significant factor affecting certain murre colonies in California, such as CHCC, over past decades (Carter *et al.* 2001).

A large number (46%) of recorded aircraft disturbances at CHCC occurred on Big Sur Marathon event days, which typically coincide with initiation of murre egg-laying at that colony. In 1997, the first murre egg of the season was laid two days after the Marathon (29 April), and in 1999, the first egg was sighted on Marathon day (25 April). Because of El Niño conditions, murre breeding was delayed in 1998, with the first egg laid on 22 May. Low numbers of murres attending subcolonies in April 1998 accounted for fewer observed disturbances on Marathon day that year.

Our observations showed that disturbances before the peak of the egg-laying period resulted in a greater proportion of flushing events than after that time. During the former period, little reproductive investment has been made, and birds likely choose to take flight for their own safety. Later in the season, when most birds are attending to eggs or chicks, the choice is between protecting the investment in breeding and protecting themselves, and they are more reluctant to leave the nest site (Kury & Gochfeld 1975, Manuwal 1978, Anderson & Keith 1980, Parrish 1995, Schauer & Murphy 1996). We observed that most birds that flushed during the breeding season were roosting on the periphery of the colony or were mates of birds incubating eggs or brooding chicks; they were not directly guarding nest sites. However, frequent disturbances could affect continued use of breeding sites by site-holding, pairing, mating, or prospecting birds, leading to site abandonment or no egg-laying in a given year. Other species have been documented to be more liable to abandon nesting when disturbed early in incubation as opposed to later (Bunnell *et al.* 1981, Pierce & Simons 1986). If birds are more likely to flush during the pre-breeding period, impacts may be greater if prospecting birds deem the area to be unsafe for breeding. Major changes in numbers of murres attending colonies each year were not noted, but breeding success was lower on average at CHCC than at PR in 1997–1999. Lower breeding success at CHCC was probably associated with aircraft disturbances, predation and local prey availability (Parker 2005).

Compared with aircraft, vessels caused fewer disturbance events at all of the colonies. This finding was at least partly attributable to fewer vessels than aircraft approaching the colonies. However, certain vessel events at CHCC caused more severe impacts, resulting in the observed loss of both eggs and chicks when boats spent extended periods of time close to nesting areas. All of these events were associated with commercial vessels fishing for live rockfish. Fortunately, birds were typically not affected by vessels passing by at extended distances, but vessels approaching closely elicited disturbance responses. Nearly all vessel disturbances to murres and cormorants occurred at distances <100 m, with most of the disturbances occurring within 20 m. Fishing boats did not ordinarily approach the nearshore areas except during periods of calm sea conditions, which occur more frequently in late summer. Thus the effects to murre colonies occurred later in the breeding season, when chicks were present. Severe or frequent disturbance could result in chicks fledging at lower than normal body weight, as documented in a disturbance study by Harris & Wanless (1984), possibly affecting at-sea survival rates.

Aircraft were observed to travel more frequently over CHCC colonies and to cause more disturbance than at DSR and PR colonies [Fig. 2(b)]. Higher aircraft traffic at CHCC was largely attributable to high volume during the Big Sur Marathon (44% of total flyovers) but also likely resulted from frequent flights along the Big Sur Coast because of its high scenic value. Excluding Marathon days, more aircraft traveled over DSR than over the other two colonies, but the level of disturbance was still higher at CHCC (69%) than at DSR (58%). Some low-flying aircraft were involved in resource monitoring and other non-recreational purposes. At PR, few aircraft flew directly over the colonies [Fig. 2(b)], because aircraft traffic near this isolated point within the Point Reyes National Seashore is scant. The site also has frequent low fog and turbulent air during windy conditions. The greatest proportion of flyovers (44%) and disturbances (54%) at PR occurred as a result of emergency or other US Coast Guard helicopter operations, which have affected this colony before (McChesney *et al.* 1998, Thayer *et al.* 1999). US Coast Guard helicopters accounted for 30% and 12% of overflights, and for 12% and 11% of disturbance events at CHCC and DSR respectively. During search-and-rescue operations, and sometimes during transit, these helicopters often flew at altitudes of 180 m or less. Behavioral responses by murres to low-flying aircraft at PR were similar to those at CHCC [Fig. 2(b)].

Higher levels of disturbance at CHCC as compared with PR reflect greater activity by aircraft—and possibly greater responses by murres—within small CHCC subcolonies (see Birkhead 1977). However, the recently restored murre colony at DSR was smaller than that at most CHCC subcolonies, yet flushing rarely occurred even during multiple overflights. Social attraction equipment (including decoys, vocal playback, and mirrors) used for restoration purposes at DSR (Parker *et al.* 2007) may somehow reduce flushing by simulating conditions of larger colony size and densities. For example, immobile decoys and constant colony sounds do not change when aircraft or boats approach, dispelling disturbance responses to some degree. Substantial flight traffic above DSR results partly from its location near the north approach to the Half Moon Bay airport. Potential future expansion of this airport could lead to a major increase in overflights at DSR, possibly leading to higher levels of disturbance to this restoration site. Whether some habituation to overflights will or has already occurred is unknown.

Because of extensive mortality from gillnet fishing and oil spills, the CHCC declined by 13% per annum over the period 1979–1989 (Carter *et al.* 2001). CHCC apparently was affected by the 1986 *Apex Houston* oil spill, and murre numbers declined for three to four years following that spill, reaching its lowest level in 1988/89 (McChesney *et al.* 1999; Carter *et al.* 2001, 2003a). Although murre numbers at CHCC increased at a rate of 7% per annum from 1989 to 1995 (Carter *et al.* 2001), the complex had recovered to only about 50%–60% of pre-decline numbers by 1997 (McChesney *et al.* 1999).

Aircraft disturbances are one of many impacts that cumulatively contributed to slow recovery of murre breeding population size and breeding success at CHCC in the 1997–1999 period. Vessel disturbances also occurred from a live rockfish fishery since 1998 in the Monterey Bay area. Vessels close to subcolonies were observed in 1999 and 2000, and disturbances to Common Murres and Brandt's

Cormorants were observed, resulting in loss of murre eggs and chicks (Parker *et al.* 2000, 2001). In 1999, the colony was also affected by a juvenile Brown Pelican that landed in subcolonies and disturbed breeding murres (Parker *et al.* 2000). Although gillnet fishing off the central California coast was reduced to a great degree during 1987–1990 (Takekawa *et al.* 1990, Carter *et al.* 2001), estimated mortality from the remaining set gillnet fishery for California Halibut *Paralichthys californicus* in Monterey Bay and Morro Bay averaged about 1000 to 2000 murres annually during 1990–1998 (Forney *et al.* 2001) and reached 5000 murres in 1999/2000 (NOAA, National Marine Fisheries Service, unpubl. data) before the fishery was more severely restricted in 2002. This fishery likely killed many adults and juveniles from CHCC, the nearest colony to principal fishing areas. Additional mortalities also occur from other sources (e.g. oil pollution, die-offs), but murres at CHCC may have been spared from other recent oil spills that mainly affected murres further north [e.g. 1997/98 Point Reyes Tarball Incidents (Carter *et al.* 2003b)].

Cumulative impacts on the CHCC since 1979 have affected population size, distribution, breeding densities and recruitment, which could lead to colony extirpation in the future (McChesney *et al.* 1999). In 1997–1999, the DSR colony was in the early stages of recolonization following extirpation in the 1980s from human impacts (Takekawa *et al.* 1990, Carter *et al.* 2003a). Although restoration efforts have been successful thus far (Parker *et al.* 2007), future increases in disturbance could jeopardize the long-term viability of this colony. Efforts to reduce human disturbances at these colonies have met with some success, but need to be continued and expanded to better assure full recovery of all central California murre colonies. Such efforts may include reducing the level of aerial activity near colonies, enforcement of the 305-m NOAA National Marine Sanctuaries overflight restriction zones and expansion of restriction zones where needed, creation of buffer zones against boat traffic around sensitive colonies, and outreach to aircraft pilots, fishermen, and other boat users regarding the effects of disturbance and what they can do to avoid it.

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