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**Restoration of Common Murre Colonies in the Copalis National Wildlife Refuge,
Washington—Phase I**

Draft Final Report to the *Tenyo Maru* Trustee Council

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INTRODUCTION

On 22 July 1991, the Chinese freighter *Tuo Hai* struck and sank the Japanese fishing vessel *Tenyo Maru* while entering the Strait of Juan de Fuca, approximately 20 miles northwest of Cape Flattery on the Washington coast (Figure 1). Oil from the *Tenyo Maru* quickly spread south across the mouth of the Strait, impacting the Washington shoreline and nearshore natural resources, including seabirds. In total, 100,000 gallons were estimated spilled (Neel et al. 1997). The heaviest oiling occurred along the northern outer coast of Washington, in the Makah Indian Reservation and the Olympic National Park (TMOSNRT 2000).

The spill occurred during the seabird breeding season, when gregarious nearshore species such as common murre, *Uria aalge*, and rhinoceros auklets, *Cerorhinca monocerata*, feed and congregate in proximity to breeding colonies (Parrish et al. 1998). In particular, murre regularly form large rafts (hundreds to thousands of individuals) within a kilometer of their breeding colonies (Parrish et al. 1998, Burger 1997). Diving seabirds, especially murre, are known to suffer oil spill related mortality in disproportionate numbers to their representation in the coastal seabird community (Burger 1992, Wiese 2002). In the northern hemisphere, in oiling events in both the Pacific and Atlantic, murre represent roughly three quarters of the total recovered kill (Burger and Fry 1993). The specific causes for this sensitivity are unknown, however there are several plausible explanations. Seabird species most at risk of oiling: (1) roost on the water surface, (2) escape by diving, (3) feed subsurface, (4) have small wintering areas, and (5) overlap with shipping lanes, the latter a general characteristic of coastal species (Camphuysen and Heubeck 2001, Camphuysen 1998, Burger 1991).

Within weeks of the sinking, 4,300 carcasses had been recovered (TMOSNRT 2000). Thirty species were affected; however the majority of the carcasses were murre (3,157 carcasses or 73%; Table 1). Because all oiled carcasses do not wash ashore, some may be buried by wave action or scavenged, and others may not be found by volunteers, it is generally accepted that carcass recovery represents 10-30% of total mortality (Burger

1993, Piatt and Ford 1996). Thus conservatively, 10,000 - 30,000 murres may have been killed by this event.

As is typical of many seabird species, murres display a long-lived, low fecundity life history strategy (Gaston and Jones 1998, Nettleship and Birkhead 1985, Tuck 1961). In these species, population growth (λ) is classically highly sensitive to minute changes in adult mortality (Nur and Sydeman 1999), although persistent exaggerated depression of reproductive output can also depress population growth (Parrish et al. 2001). In addition, murres are natally philopatric (Harris et al. 1996) - although straying does occur (Friesen et al. 1996) - a trait which would tend to accentuate the impacts of local mortality sources. Thus, small scale oil spills, or other mortality events, might be expected to differentially affect local colonies, especially during the breeding season when experienced adult breeders are most highly concentrated in the area.

Breeding populations of murres in the Pacific Northwest are variably sized. In Alaska, the species is well represented: Bering and Chukchi Seas ~1.4 million breeding nesting birds; Gulf of Alaska ~0.5 – 2 million nesting murres (Ainley et al. 2002). At the south end of their range in California and Oregon, murre numbers are in the same order of magnitude (~1 million; Carter et al. 2001, Ainley et al. 2002). The largest colony in the lower 48 states – Shag Rock in Three Arch Rocks complex (132,000 murres in 1988) – is located in northern Oregon (Carter et al. 2001). However, in Washington, British Columbia and southeast Alaska – the middle of the species' range – populations are quite low. Just prior to the spill, perhaps only 10,000 in WA (Carter et al. 2001, Parrish et al. 2001) with perhaps an additional 10,000 birds in British Columbia (Carter et al. 2001), and an additional ~15,000 in southeast Alaska (Ainley et al. 2002). Thus, depending on the actual numbers and origins of the murres killed in the spill, serious impacts may have occurred to local populations.

Multivariate morphometric analysis of recovered carcasses was used to determine likely population origin of murres killed in the *Tenyo Maru* spill (Warheit 1996). Although this study was not able to resolve individual colony signatures, several important results

emerged. First, 37% of examined carcasses were young-of-the-year. Second, 77% of adult carcasses were male. These data suggest that a significant portion of the murre kill were post-fledging chicks, usually accompanied by the male parent (Manuwal et al. 2001). These individuals were likely Oregon breeders, as Washington colonies fledge chicks in August-September (Parrish 1995) whereas Oregon colonies fledge chicks in June-July (Manuwal et al. 2001). Based on measurement differences resolved by principal components analysis relative to known-location reference specimens, combined with knowledge of breeding phenology of major West Coast murre colonies, Warheit (1996) concluded that 55-58% of murrees killed were Washington breeders. Total Washington kill was estimated at between 4,500 and 11,500 murrees. *Tenyo Maru* Trustees referred to the Washington murre kill as “a potentially sizable proportion of the total Washington state common murre population” (TMOSNRT 2000). What remains unclear is the degree to which any one colony was affected by the spill.

Because the number of murrees recovered after the spill was large, the majority of Washington colonies are small and many are unstable, murrees are subject to mortality from a variety of sources, and the murre population on Tatoosh Island (the colony closest to the spill) declined in the years following the spill (TMOSNRT 2000), a proposal was put forward to examine the potential of restoring the common murre population, using social attraction methods (Kress 1983, Kress 1998, Parker et al. 2001). The restoration project was broken into two phases. Phase I was a feasibility study to determine whether “(1) social attraction enhancement activities are warranted, and (2) project implementation would be impeded by physical or natural limitations” (TMOSNRT 2000). Phase II, contingent upon the results from Phase I, would “restore common murre colonies, using social attraction techniques, to locations in the Copalis National Wildlife Refuge,” and monitor the results (TMOSNRT 2000).

This document reports on Phase I of that restoration effort, specifically examining the logistical and biological feasibility of using decoys and playbacks to attract breeding murrees to the Copalis National Wildlife Refuge murre colonies, in order to rebuild the Washington murre population. In addition to data collected specifically under the

auspices of this two year study, we report on relevant data collected previously and contemporaneously under the auspices of Washington Sea Grant and National Oceanic and Atmospheric Administration Coastal Ocean Programs studies at Tatoosh Island, WA and at Yaquina Head, OR; at-sea data collected under the auspices of U.S. Fish and Wildlife Service Section 6 funding and Washington Department of Natural Resources funding for marbled murrelet data collection; and U. S. Fish and Wildlife Refuge funding for aerial surveys of coastal Refuge seabird populations.

REVIEW OF SOCIAL ATTRACTION TECHNIQUES

Social attraction techniques were pioneered in the restoration of seabird colonies by Steve Kress and co-workers (Kress 1983). Since that time, decoys and sound playback systems have been used to attract numerous species to nesting sites (Kress 1998 for review). With respect to common murre, decoys have been successful in attracting murre to recolonize Devil's Slide Rock, and start an actively reproducing colony (Parker *et al.* 2001). Thus, it is clear that social attraction works, and that social attraction can be used specifically to attract murre to colonize "new" breeding areas. On Tatoosh, a pilot study (Appendix A) indicated that the use of decoys on an extant colony could crystallize laying, and would perhaps enhance nesting synchrony. However, this study also showed that predators, principally bald eagles, *Haliaeetus leucocephalus*, were attracted to the decoys as potential prey. Disturbance caused by eagles was deleterious to nesting, causing egg and nest site abandonment, and perhaps even increased risk of death of those pairs nesting in the vicinity of decoys. Thus, it is apparent that caution must be used when placing decoys or other attraction devices in sites with avian predators. Finally, this study indicated that decoys placed in safe locations (defined as out of reach of eagles) did have a positive effect.

METHODS

Three types of data were collected during the course of this study by the participating agencies (Washington Department of Fish and Wildlife, WDFW; U.S. Fish and Wildlife

Service Washington Outer Coastal National Wildlife Refuge, the Refuge) and their contractor (University of Washington, UW). WDFW personnel collected at-sea data in the immediate area around various historic and current murre colonies including (1) Point Grenville, (2) Quilleute Needles (especially Huntingdon Island), (3) Carroll and Jagged Islands, and (4) Tatoosh Island, as well as more generally along the Washington outer coast. Refuge personnel collected aerial census data on all murre colonies within the Refuge. UW personnel collected on the ground data on the Point Grenville colonies, as well as on Tatoosh, the reference colony.

Study areas

Colony-based data collection was concentrated on two Washington outer-coast areas: Point Grenville, which houses a series of rocky outcroppings and islands as part of the Copalis National Wildlife Refuge (NWR), and Tatoosh Island, the northernmost murre colony in Washington located immediately south of the U.S. Canada border (Figure 1). Minimal observations were made of Split and Willoughby Islands, farther to the north (but also within the Copalis NWR). Despite the use of a Questar spotting scope (80x Birder), the islands were too distant to observe murres accurately. Therefore, these colonies were dropped immediately as realistic options for accurate data collection of murre attendance, reproductive success, or reproductive phenology, at least from ground-based positions.

The study focused on four colonies within the Copalis NWR in the immediate vicinity of Point Grenville (47°18'N, 124°16'W): Erin, Erin's Bride, Grenville Arch, and Grenville Pillar (Figure 2). These colonies comprise the current and historical murre nesting areas in this region (Speich and Wahl 1989). At present, murres nesting on the Point Point Grenville occupy ledges or crevices in vertical and sloping cliff face, as well as tops of rocky sea stacks and islands (e.g., Grenville Arch). Two of the colonies, Erin and Grenville Pillar, are totally or partially covered on the top with perennial grasses, and no murres nest in these areas. Erin's Bride and Grenville Pillar are not accessible from the water, whereas Erin and Grenville Arch can be climbed without ropes (Appendix B). In addition to murres, 7 other seabird species nest on the Point Grenville colonies (Speich

and Wahl 1989; Table 2). All observations during ground-based monitoring were conducted from observation points on the Point Grenville cliffs and Grenville Bay Beach. Permission to access these locations was granted by the Quinault Indian Nation.

Tatoosh Island (48°24'N, 124°44'W) is actually a complex of islands and rocky outcroppings (land area approximately 6 ha). The Island is owned by the Makah Indian Tribe, and has been uninhabited (except for researcher presence during the summer months) since the U.S. Coast Guard automated the light house in 1976. Permission to conduct research on the Island was granted by the Makah Tribe. Permission to use helicopters to access the Island was granted by the Olympic Coast National Marine Sanctuary. In addition to murre, Tatoosh is inhabited by 10 species of breeding seabirds (Paine et al. 1990, Table 2). Murre nest in two habitat types: crevices cut into vertical cliff wall and on the cliff-top at cliff's edge. Two predatory species, bald eagles, *Haliaeetus leucocephalus*, and peregrine falcons, *Falco peregrinus*, visit throughout the year and represent known mortality sources for the island's seabirds although neither predator currently breeds on the island (Parrish et al. 2001). Tatoosh has no resident rodents.

Yaquina Head (44°41'N, 124°05'W) is immediately north of Newport, OR. All observations are conducted from a lighthouse at the western tip of the headlands. Permission to conduct research at Yaquina Head was granted by the Bureau of Land Management, who manage access to the Yaquina Head Outstanding Natural Area. The U.S. Coast Guard gave us access to the lighthouse lantern room as a viewing platform. In addition to murre, four species of seabirds breed on the four islands and rocky outcroppings immediately offshore, as well as on the headland itself (Table 2). Occupied space on the upper portions of the rocks, plus the headland edges, is approximately 0.5 ha (D. Pitkin, Oregon Coastal National Wildlife Refuges, pers. comm. 2002). Seabirds, including murre, nesting on the headlands are subject to disturbance by a range of predators, including raccoons, river otters, opossums, feral cats, and rats. Bald eagles and peregrine falcons visit the site daily. Finally, over 500 tourists visit the lighthouse and surrounding platforms each day during the summer.

Ground-based Monitoring

Data collected at all colonies included: (1) annual attendance counts as a measure of population size, (2) daily attendance counts of reference subcolonies, to estimate intra-annual and diurnal variation, (3) reproductive success of reference pairs within reference subcolonies, (4) reproductive phenology of same, (5) foraging rate and chick diet within reference subcolonies, (6) sources of disturbance, including predators, space competitors, and human activities. In some locations, these data were modified due to logistical constraints. In addition, several observational experiments were conducted prior to and during the two year study period to augment the longitudinal dataset outlined above. These include a pilot decoy experiment on Tatoosh Island prior to the start of this study (Appendix A), and coordinated time-budget watches of reference pairs at Tatoosh, Point Grenville, and Yaquina Head to indirectly examine potential differences in food availability.

At Point Grenville, all ground-based observations were made with the aid of spotting scopes (20-60x Swarovski AT80HD; and 80x Questar Birder), with the exception of predator/disturbance observations, which were made with binoculars (10x42 Swarovski SLC). On Tatoosh, data were collected by observation, with the aid of spotting scopes (20-60x Swarovski AT80HD) and binoculars (8x30 Swarovski SLC) in the case of the crevice subcolonies. Cliff-top subcolonies were observed from blinds located at the edge of the nesting area. Most data can be collected from land; however, certain subcolonies could only be observed from boats. In these cases, counts were made from photographs (lens magnification at 300mm and 500mm) taken during calm afternoons, when the southwest-facing cliffs were well lit. For both locations, reference photographs were taken of each subcolony in each year, during the egg-chick period.

Data were also compiled from several remote sources, to augment on-colony data. Number of eagle eyries within 24 km of the Point Grenville and Tatoosh colonies were supplied by WDFW and the Quinault Indian Nation (Sally Butts, contact).

Oceanographic and atmospheric data were taken from a variety of government and postprocessing websites (URLs provided below).

We report the total number of days spent at observation points each season. To aid in analysis of eagle activity, we also report the total number of hours spent observing murre before and after July 20th, which approximates the date when eagle activity is known to decrease due to eaglet fledging along the Washington coast (Parrish et al. 2001). We refer to both the Tatoosh Island complex and Point Point Grenville as murre colonies, and isolated clusters of nesting murre within these areas as subcolonies.

Point Grenville

In 2001, Stephani Zador and Dan Nelson began regular observations in the Point Grenville area on June 6th (Table 3). Two earlier field trips took place accompanied by Sally Butts, the wildlife biologist for the Quinalt Indian Nation: (1) an introduction to Point Grenville on May 24 and (2) a trip to view Split and Willoughby Islands from an observation point near Hogsback on June 1st. Observations were restricted to rocks visible from Grenville Bay beach (Erin, Erin's Bride, and Grenville Arch) until July 13, when regular access to Point Grenville was granted the Quinalt Indian Nation. Fieldwork was conducted an average of six days per week until August 23. An additional day of observation occurred on August 27 to confirm fledging of the latest chicks. In 2002, Stephani Zador and Dan Davis began regular observations at the Point Grenville area on June 12 (Table 3). Fieldwork was conducted an average of 5 days per week until August 30. An additional day of observation occurred on September 4 to confirm fledging of the latest chicks.

On April 2, 2002, personnel associated with the *Tenyo Maru* murre restoration project surveyed the Point Grenville area by helicopter and boat (Appendix B). The goal of the trip was to assess access to current and potential murre nesting areas for the purpose of decoy deployment.

Tatoosh Island

On 23 May 2001, Julia Parrish, assisted by Brian Walker, made the first visit to Tatoosh to install blinds. Due to early season safety considerations, this trip was made by helicopter. A post-season trip to decommission the blinds was also made by helicopter on 21 to 24 September 2001. Regular data collection began on 10 June, continued through 17 August, and was conducted by Julia Parrish, and her graduate students and employees (Table 3). All regular season visits were made via boat. In 2002, regular data collection began on 10 June, continued through 16 August, and was conducted by Julia Parrish, and her graduate students and employees (Table 3). Because the island is shared as a research site with other scientists who focus on intertidal ecology during 3-5 day intervals surrounding the new and full moons, continuous observation throughout the breeding season is not possible.

Yaquina Head, Oregon

On April 21, 2001, Colin French and Erin Hagen made the first visit to Yaquina Head to begin colony observations from a temporary blind located on the hill behind the lighthouse. Access to the Yaquina Head lighthouse was granted on May 26. Data collection continued daily through July 24. Additional data were collected by Julia Parrish between May 26 and 28. In 2002, Colin French and Gillian Lichota commenced regular data collection from the lighthouse on April 29. Data were collected daily through July 25.

Murre Demography

Point Grenville

Opportunities for murre observations varied among colony rocks because of distances from the observation points (Appendix C). Accordingly, monitoring activities are summarized by rock/islets.

Erin and Erin's Bride

Murres on Erin and Erin's Bride were counted regularly from observation points (GBS, GBN, GBNNN) along Grenville Beach and occasionally from observation points on

Point Grenville (PGS, PGW). Most counts occurred in the morning and early afternoon before the rocks were backlit by sun. Murres that appeared to be nesting (assumed from continuous occupation of a site) were mapped and observed carefully for any sign of chicks. From the observation points, sightings of chicks occurred only when they were large enough to be seen standing independently of the parents. Therefore we assumed all chicks seen were at least 10-15 days old and subsequently fledged. Counting and nest monitoring ended when chicks had fledged and/or when nesting areas were vacant.

Grenville Arch

Murres on Grenville Arch were counted regularly from one observation point on Point Grenville (PGW SP viewing area) and occasionally from points along Grenville Bay Beach. Counts occurred throughout the day, visibility permitting. We made the same assumptions as above for the single continuously attended nest site and chick (in 2002). Observations continued throughout the season.

Grenville Pillar (a.k.a. Big Stack)

Murres on Grenville Pillar were counted regularly from 2 observation points on Point Grenville (PGW and PGW SP viewing area). Most counts occurred in the morning and early afternoon before the rocks were backlit by sun. In addition, sequential hourly counts were made at the CT sub-colony in 2002 to assess diurnal attendance patterns. The appearance and disappearance of observable eggs and chicks were recorded every 1-3 days to assess phenology and productivity.

Tatoosh Island

Cliff top colonies

Two cliff-top subcolonies (MCT-EXT; Petrified Colony) were monitored during the study period. Each had up to two blinds which faced non-overlapping regions within the murre nesting area. From each blind, 86 to 111 pairs were selected within a contiguous area (reproductive plot) which included the blind. All nesting murres within the plots were mapped and assigned numbers for identification purposes. Daily records of nest status for all mapped breeders were collected during each trip, where data included

reproductive status (egg, chick, fledged chick). Attendance of the entire nesting area was occasionally counted throughout the egg and chick period. During these counts, all visible murre were counted from all blinds on a subcolony, and murre numbers in areas not completely visible were extrapolated from areal and known nesting density measurements. Blind-based observations of cliff-top subcolonies were possible from dawn to dusk (from 0600 to 2200), in all but the most inclement weather. Observations ranged in time from 0530 to 2140, in a minimum of 1/2 hr blocks evenly spaced throughout the day (approximately 210 to 250 hrs in total among all blinds).

Crevice colonies

All data on monitored subcolonies were collected from Burning Barrel Point (BBPT), a promontory which affords a 270 degree view of ten spatially distinct crevice subcolonies (CC1-5, TC1-4, WBMCT), one cliff-top subcolony (Pole Island), and several eagle roosting areas (West Rocks, Strawberry Island). All ten crevice subcolonies were monitored for daily attendance. Four of these (CC1-4; 9 to 34 pairs) were specifically monitored for reproductive success, using the methods outlined above. Observations from BBPT ranged in time from 0630 to 2200, in a minimum of 1/2hr blocks evenly spaced throughout the day (approximately 30 to 45 hrs in total), restricted by wind (above 10 knots), rain, and fog. Additional data were collected on attendance, chick presence, and adult mortality from a variety of locations around the island, as well as from boats. No specific record of hours spent was kept in these situations, although all data was recorded as a specific function of when (both date and time of day) it was collected.

Attendance

Attendance, defined as the estimated number of adult murre on the colony or subcolony at the time of the count, was calculated at Point Grenville was determined by repeated counts of subcolonies of murre by both observers. Early in each breeding season, both observers counted each subcolony until counts were within 10%. Later in the breeding season, when each observer was more experienced, a single person would count repeatedly until successive counts were within 10%. Counts were made throughout daylight hours throughout the season as conditions permitted. Dense fog and

afternoon/early evening backlighting were the most common conditions that precluded counting. Data are reported as the mean and maximum count value per rock/islet. In addition, the minimum number of continuously attended sites are reported as an estimate of nesting attempts.

At Tatoosh, attendance was calculated from averaged counts made after egg laying had begun but before chick fledging had begun (egg and chick periods) and reported annually as an afternoon count (operationally defined annually by statistical differences in counts as a function of time of day, and actually defined in 2001 and 2002 as after 1400H). Because some subcolonies were only counted once, there is no estimate of variation around annual islandwide attendance.

Direct counts of the smaller subcolonies (<300 birds), and extrapolated estimates from partial (~25-30%) counts of the larger subcolonies were combined to produce a value for total island attendance. Several correction factors were applied. Because some subcolonies could only be counted during the morning due to tidal constraints, a within year correction factor was applied to all morning-only counts, based on the difference between multiply-counted subcolonies from morning to afternoon. Morning-to-afternoon corrections ranged from 1.1 to 1.2. For subcolony attendance taken from photographs, a correction factor of 1.5 was applied, to account for individuals in the interior of ledges 2-4 birds deep which remained in shadow. Because several different personnel made counts during each season, inter-person corrections were used to delete select data from the final dataset as follows: concurrent counts were made with the most experienced datacollector (Parrish) early in the season, until junior counters independently came within 10% of the experienced count. At this point, data collected by the junior counters was included. Periodic checks insured continuing accuracy.

Phenology

Breeding phenology was defined as the timing of three reproductive events: egg laying, chick hatching, and chick fledging. Phenological information was collected from known or estimated dates for each event per observed pair. For egg laying and/or hatching, an

egg duration of 32 days was assumed (that is, hatching on the 32nd day). This value has been corroborated on Tatoosh (Parrish 1997) as well as at other common murre colonies (Ainley et al 2002). Therefore, if laying was observed and hatching was not, the latter could be calculated to the day, and vice versa. If neither laying nor hatching was observed, hatch date could still be estimated as follows. Chicks peck their way out of the egg, a process which usually takes several days. Based on data collected from Tatoosh prior to this study (Parrish unpub. data): pips (star-shaped cracks or very small holes) first appeared three days before hatch; holes (5-8mm) appeared the day prior to hatch; large holes or multiple holes appeared the day of hatch. In addition, eggshell fragments larger than 1cm in the immediate vicinity of the pair lasted only the day of the hatch; and chicks hatched wet, a condition which lasted several hours after hatch. Outside of these cases, hatch date could be placed within a time window bounded by observer presence. In these cases, known and estimated dates (as above) were used to construct an annual distribution, which was fit with a simple polynomial, allowing in-fill of pairs with uncalculated dates. In this latter case, specific hatch dates were not ascribed to individual pairs/chicks, but the inferred distribution was used to calculate quartiles of phenological event occurrence.

Phenology was used to divide the breeding season into four periods: prelaying – before the appearance of eggs; egg period – from first appearance of eggs to first appearance of chicks; chick period – from first appearance of chicks to first fledging; fledging – after first fledging until no chicks remained. Each period could be calculated per subcolony, as well as per colony. Phenological periods were used to bound attendance counts – for instance, only counts made during the egg and chick periods were used to assess colony size.

Date-specific phenological data were used to calculate: (1) median lay, hatch, and fledge dates (in cases where sample size was large and evenly distributed), (2) quartiles of lay and hatch, reported as date range over which the middle 50% of monitored pairs achieved a given stage, and (3) first to last range. Quartiles were used when continuous access was not possible.

Reproductive Success

Reproductive success was defined as successfully fledging a chick, or chicks per pair within subcolony or colony. Fledging was defined either by (1) actual event - the chick was observed in the day of the evening of fledging, may have been observed giving the chick fledging call (three short, shrill chirps) and/or leaving the subcolony in the company of a parent, and was never observed on subsequent days, nor were both parents ever observed together; or (2) the chick reached 18 days of age. The latter measure was used as fledging in this species occurs at 20-24 days (Ainley et al. 2002), and previous work on Tatoosh indicated that chicks older than 15 were extremely unlikely to die on-colony (Parrish unpub. data). For unsuccessful fledging, cause of loss was recorded, if known, as: egg lost (usually to predators – glaucous-winged gulls or Northwestern crows, and occasionally bald eagles), egg never hatched (dud egg), chick lost/died. In the case of egg loss, replacement eggs were often laid. Replacement eggs were confirmed, if possible, by matching egg color and spotting pattern, and replacement date (approximately 14 days after egg loss, Ainley et al. 2002). Replacement eggs did not alter fledging or reproductive success calculations, as these values are calculated per pair, regardless of the number of eggs (very occasionally three eggs) were laid.

We report all eggs and chicks seen at the Point Grenville subcolonies. At nests that could be monitored closely (plots CT and PC on Grenville Pillar), chicks last seen at 18 days or older were considered to have fledged successfully; at distant nests, chicks large enough to be observed were considered old enough to fledge successfully. Tatoosh murre reproductive success includes every nest in a subcolony in which an egg was laid. Successful nests are those which fledged a chick, plus those with chicks last seen at 18 days or older, except in cliff-top nesting areas.

Adult Murre Time-budgets

In 2002, we conducted an observational experiment to determine the degree to which local food availability might be affecting colony stability at the Point Grenville colonies. We reasoned that if food was scarce or of low quality, adults would have to spend more

time foraging, which would translate into longer foraging trips and shorter overlap periods when fisher and incubator/brooder switched roles. Several studies suggest that co-attendance declined with declining food conditions (Burger and Piatt 1990, Zador and Piatt 1999). Thus, co-attendance is a sensitive index of food availability, and by association, of oceanographic forcing of coastal productivity. To create viable comparisons, we collected data from two additional colonies: Tatoosh Island to the north, and Yaquina Head to the south.

We conducted five continuous watches of 7-16 hours duration at all three colonies to record and compare diurnal patterns of parental co-attendance, and, when chicks were present, chick-feeding rates and the durations of foraging trips. Watches were conducted for 8-9 hours at the CT subcolony on Grenville Pillar, for 7-16 hours at the PC2 study plot at Tatoosh, and for 8-14 at the CR1 at Yaquina. Variable watch lengths reflected differential exposure of observers (Point Grenville – exposed; Tatoosh and Yaquina – not exposed), low sun angle precluding observation (Pt Grenville, Yaquina), and partial days due to truncated trips (Tatoosh).

For 9 (Point Grenville) to 25 (Tatoosh) pairs within plots monitored for reproductive success, we recorded the time of day (to the minute) any parent left or returned. For returning parents, we recorded the species and size (length) of any fish brought back. Watches were scheduled to coincide with breeding stages (early incubation, late incubation, early, mid, and late chick-rearing), and therefore occurred on different days at each colony. All watches began 45 minutes after sunrise and continued for 8 hours. We report the data as the percent of time during the watches that both adults attended nest sites. Data are presented for the first and second 4 hour blocks, as well as the entire 8 hour period. The sample size is the number of nests watched.

Murre Chick Diets

All fish returned to reproductive plots (Point Grenville) or subplots (Tatoosh) were identified to the lowest possible taxonomic level and their lengths were estimated to the nearest quarter murre beak length (converted post-season to cm, using the standardization

1 beak length = 7.6cm, Parrish unpub. data). Fish were identified using a combination of species or higher taxon-specific characters from the dorsal fin back, as adult murre carry single fish head in – tail out. Unknown fish were drawn in field notes according to: number, placement, and shape of fins; presence of fin spines; shape of tail and caudal peduncle; body width-depth-length ratios; body, fin, and tail coloring; degree of countershading; degree of translucency; presence of photophores; for potential post-observation identification. All newly identified species were subsequently confirmed by additional observations. In each year at each colony, we attempted to collect 100 hours of “fish watch” observation or 1000 identified fish.

Chick-feeding rates at Point Grenville were monitored at the CT and PC (in 2001 only) subcolonies. Watches of 1 - 1.5 hours in duration were conducted at intervals spread evenly throughout observation days, which were later binned to compliment inter-colony comparisons. Separate watches focusing only on identifying fish were conducted at the SP sub-colony, where incoming murre with fish could be most readily observed, although delivery to specific nest sites could not. At Tatoosh, chick-feeding observations within monitored subplots (TPCT2#s 1 and 2, PC#s 1 and 2) occurred over one hour intervals beginning at 0600, 0900, 1200, 1500, and 1800. Feeding rate data are presented in 2 ways: as hourly rates during time-budget watches only and as hourly averages during 5 time periods (0600-0730; 0731-1030; 1031-1330; 1331-1630; 1631-1900) that include all watches.

Sources of Potential Demographic Impact

Oceanographic Indices

Changes as well as absolute differences in physical ocean properties have been well correlated with changes in local to regional biomass, from phytoplankton through seabirds (Roemmich and McGowan 1995, Veit 1997, Francis et al. 1998, Sydeman et al. 2001). This “bottom-up” forcing is thought to affect seabirds primarily through the abundance, predictability, and perhaps quality of fish resources (Veit 1997). However, it is also the case that local conditions may swamp larger-scale physical forcing, such that even well-documented events (e.g., El Niño-Southern Oscillation, ENSO) do not limit

prey availability (Parrish and Zador, *in press*). Because it is practically impossible to accurately quantify prey availability, we used several measures of oceanographic or atmospheric forcing developed and used by the oceanographic and fisheries community as proxies. We reasoned that patterns in this physical forcing may help to explain patterns in murre behaviors and reproductive success.

For a measure that represents physical change at the scale of the Pacific Ocean Basin, we chose the Multivariate ENSO Index (MEI). The MEI (<http://www.cdc.noaa.gov/~kew/MEI>) integrates six physical components (sea level pressure, zonal and meridional components of the surface wind, sea surface temperature, surface air temperature, and total cloudiness fraction of the sky) measured between 30°N and 30°S, Pacific-wide. To represent physical change at a regional (i.e. North Pacific) scale, we chose the Pacific Interdecadal Oscillation (PDO). The PDO (ftp://ftp.atmos.washington.edu/mantua/pnw_impacts/INDICES/PDO.latest) is the leading principal component of monthly sea surface temperature anomalies in the North Pacific Ocean, poleward of 20°N. Values are corrected for any global warming signal by the removal of monthly mean global average sea surface temperatures.

Eagles

As bald eagles have been shown to be a significant negative force in reproductive and population trends of murre nesting on Tatoosh (Parrish 1995, Parrish *et al.* 2001), we recorded eagle activity at both colonies in several ways. We recorded mortality as the number of direct kills of murre by eagles. Data are presented separated by phenological period (pre-lay, egg, chick, and fledging periods). We recorded eagle activity as the number of times an eagle (the same or different) flew past a standard observation location (BBPT on Tatoosh; over the water in the vicinity of Grenville Pillar and Grenville Arch at Point Grenville). Data are presented as hourly averages before July 20th and later. We recorded eagle presence in two ways: First, the number of active eagle eyries within a 24 km of the colonies. Second, the maximum number of individual eagles seen: for each observation day at Point Grenville, and per 3-5 day trip to Tatoosh (data collected by R.T.

Paine). We also present the average maximum number of eagles for 3-4 consecutive day intervals at Point Grenville for comparisons with values from Tatoosh.

Other Disturbances

At both colonies we recorded opportunistic observations of potential causes of disturbance to the murre. These were counts of aircraft over-flights and boat traffic, as well as other birds, such as gulls (*Larus glaucescens*), crows (*Corvus caurinus*), brown pelicans (*Pelecanus occidentalis*), and peregrine falcons (*Falco peregrinus*).

At Sea Surveys

As stated in the Final Work Plan, “It is the at-sea population portion of the population that will serve as the source of recruits” for rocks on which we may place decoys. Thus both small scale (grid surveys around Pt. Point Grenville, Quilleute Needles, and Carroll, Jagged and Tatoosh Islands) and large scale (entire outer coast of Washington) at-sea surveys of the outer coast of Washington document the distribution and abundance of murre in this area. Further, the relationship between these distribution and abundance patterns in relation to other physical parameters (sea surface temperature, water salinity, distance from shore, water depth) may help indicate whether murre attendance and reproduction on the Copalis Rocks is limited by physical factors or oceanographic conditions.

In 1998, the U.S. Fish and Wildlife Service hired a Module Lead who convened a “Population Team” to address population monitoring needs of the at-sea distribution and abundance of seabirds. Team members are as follows:

Naomi Bentivoglio, Module Lead, US Fish and Wildlife Service

Tim Max, Statistician, US Forest Service, Pacific Northwest Research Station

Jim Baldwin, Statistician, US Forest Service, Pacific Southwest Research Station

Ken Ostrom, GIS/Database Specialist, US Fish and Wildlife Service

Martin Raphael, Researcher, US Forest Service, Pacific Northwest Research Station

Chris Thompson, Researcher, Washington Department of Fish and Wildlife

Craig Strong, Researcher, Crescent Coastal Research

C.J. Ralph, Researcher, US Forest Service, Pacific Southwest Research Station

Sherri Miller, Researcher, US Forest Service, Pacific Southwest Research Station

Population Monitoring

At this point in our understanding of seabird biology, there is general consensus that populations of some seabirds are best assessed at sea. Funded by non-*Tenyo Maru* monies, members of the population team identified the target population as those birds in the near shore waters from the Canadian border to San Francisco Bay which is the area associated with the Northwest Forest Plan. We then subdivided the target population into the Conservation Zones identified in the Marbled Murrelet Recovery Plan (USFWS 1997). Certain methodological tests were conducted during the 1999 field season and the team reached consensus on the methods and sampling design for a pilot project in the 2000 field season (Bentivoglio et al. 2002).

Sampling Design

For the purposes of Phase 1 of this study, we were concerned only with Zone 2, the outer coast of Washington (Table 4). Within this area, we generally targeted the ‘near shore’ waters 8 km or less from shore. The inshore boundary close to land was defined by a distance safe for navigation away from the surf, rocks, or kelp. This distance from shore was roughly estimated for each zone and strata within zones. The offshore boundary varied from 5 to 8 km off shore (Table 4). Mid-May through mid-July is the time of year when murrelets on the water are most likely to represent locally breeding murrelets and not immigrants from Oregon or elsewhere. Sampling for the purposes of monitoring the population occurred during this time frame.

The outer coast of Washington (Zone 2) was divided into three geographic strata. Some level of sampling occurred within each geographic stratum. Lower density strata received less sampling effort. We defined a PSU as a roughly rectangular area about 20 km of coast line in length. The width of the PSU is the distance between the inshore and offshore boundaries. The width varies in different areas by zone and stratum. The PSUs

are configured to meet end to end without any gaps along shore. Each PSU represents a cluster consisting of two subunits, the inshore and the offshore (divided by the ‘center line’; Table 4).

The inshore boundary adjacent to the coast was influenced by the physical features of the shore line that affect navigation. In some instances, these physical features are permanent obstructions such as submerged rocks or islands. In other cases, these features are less permanent such as kelp beds which shrink or expand depending on various physical and biological factors, e.g., storms, time of year, and sea otter activities. Tidal fluctuations also affect navigation. Some areas that can be surveyed during high tides may be inaccessible during low tides.

We temporally defined a PSU as approximately one half of a day’s effort to avoid splitting a primary sampling unit over two days. In many areas the afternoon winds increase in intensity which makes it impossible to continue survey efforts. However, in some areas it was possible to complete more than one PSU in a day. PSUs were selected randomly without replacement and spread over the field season (time). On the north coast (Zone 1), PSUs were sampled twice during the field season. On the south coast (Zones 2), including Grays Harbor, Willapa Bay and the Columbia River estuary (Zone 3), PSUs were sampled only once. Over the long term, the PSUs that were selected during the pilot year will form the basis of the monitoring program. The same randomly selected PSUs will be sampled year after year to reduce variance in the annual population estimate each year. Parallel and zigzag transects were used to subsample the PSUs. Parallel transects were used in the inshore subunit and zigzag transects were used in the offshore subunit.

Within the inshore subunit, the entire length (~20km) of the PSU was divided into four 5-km transects (or rows) and divided into four bins parallel to shore. One transect was randomly placed within each bin (without replacement) ensuring that transects were spread out spatially from shore. These distances were chosen in 100 meter increments.

Within the offshore subunit, a zigzag transect traversed the entire width of the subunit (distance from shore) and a portion of the length of the PSU; in some cases the entire length of the PSU. The transect trajectory was determined from a random selection point. The length of the zigzag transect in each area was roughly calculated from a formula based on strata area and murrelet densities (from previous data) as follows: Each PSU consists of two subunits labeled inshore and offshore with areas (in km²) a_1 and a_2 , respectively. We assumed that the number of birds observed in each collection of subunit transects followed a Poisson distribution with mean densities λ_1 and λ_2 (in birds per km²). Therefore, the optimal ratio of near-shore to far-shore transect length is given by:

$$r = \frac{a_1}{a_2} \cdot \sqrt{\frac{\lambda_1}{\lambda_2}}$$

which is simply the product of the area ratio and the square-root of the density ratio.

Grid Transects

The abundance and distribution of common murre was measured along transects confined within a 5-km by 5-km rectangular area centered on each of the five sites (interrupted by land features, where present). Each rectangular area was divided into five adjacent 1-km by 5-km segments oriented in a east-west direction. Within each of these segments, a 200-meter by 5-km strip transect (100 meters on each side of vessel) was conducted, for a total of five transects within each rectangular area. The north-south starting point of each transect will be positioned randomly between 100 and 900 meters from the northern edge of each segment, thereby insuring that all points within the entire 5-km by 5-km area has an equal probability of being surveyed (except those points that are on-land). At each of the five localities a morning and afternoon set of surveys was conducted four times throughout the Common Murre nesting season (i.e., four replicate surveys conducted both in the morning and afternoon, for a total of eight surveys at each locality and 40 surveys overall; Appendix D). These methods are similar to those conducted by Drs. Julia Parrish and Chris Thompson as part a *Tenyo Maru*-funded pilot project (Thompson 1999).

Two observers surveyed 90° arcs on either side of the boat starting from the bow. Observers scanned continually, slowing their pace a little at the bow of the boat and speeding up a little abeam of the boat. A complete scan of 90° takes about 5-7 seconds. Binoculars were used for species verification but not for sighting birds. Observers relayed data via headsets to a person in the boat cabin who entered data directly onto a computer.

Description of Survey Area (Outer Coast of Washington)

The outer coast of Washington was divided into 3 strata. Stratum 1 (“north coast”) ranges from the northwest tip of Washington south to the mouth of Grays Harbor. This stratum is characterized by a rocky shoreline and ocean floor, and fairly steep increase in water depth with increasing distance from shore. Stratum 2 (“south coast”) ranges from the mouth of Grays Harbor south to the mouth of the Columbia River. This stratum is characterized by a sandy shoreline and ocean floor, and relatively shallow increase in water depth with increasing distance from shore. Stratum 3 (“rivers/bays”) includes Grays Harbor, Willapa Bay and the Columbia River.

Temporally distributed across the season from 15 May through 31 July, we sampled 25 PSUs: two replicates of all 8 PSUs in stratum 1 (north coast), one replicate of each of the six PSUs in stratum 2 (south coast), and one replicate of each of the three PSUs in stratum 3 (Appendix D).

We selected an average inshore boundary of 350 meters from shore. Although we can survey this close to shore in many places, there are many locations along the coast in which kelp, rocks, and/or surf extend to further distances from shore than 350 meters, thereby requiring that we extend our inshore boundary to a greater distance. The location of rocks is permanent, of course. In contrast, however, kelp abundance and distribution varies from year to year depending on many climatic and weather in the preceding year. Within years, abundance and distribution of kelp depends on the time of year (less kelp in May than in July) and tide (less kelp at high tide relative to low tide).

Previous empirical at-sea survey data from strata 1 and 2 indicate that the large majority of murre occur between the coast line and 5000 and 8000 meters from shore along the outer coast of Washington; thus, we chose these distances as the outer boundaries for these zones (Thompson 1997, 1999, unpubl. data)

Previous empirical at-sea survey data indicate that, along the outer coast of Washington, more murre occur within 1500 meters from shore than further off shore. Thus, 1500 meters was chosen as the center line boundary between the inner and outer subunits of PSUs.

As explained above, in the offshore subunit, a “zig-zag” transect traversed the entire width and most or all of the length of each PSU. The length of each transect to be surveyed was calculated from a formula based on stratum area and murre densities. In stratum 2, our offshore boundary was 8000 meters. Therefore, the areas of the offshore subunits of the PSUs in Zone 2 were rather large. In turn, the calculated transect length to survey in the outer subunit was longer, i.e., about 70 km. In addition to sampling the nearshore subunit, we often could not also survey the offshore subunit of the same PSU within a half day or so as required by our temporal definition of a PSU (see above). As a result, we reduced the transect length in our offshore subunits to between 20 and 30 km in most cases.

Some nearshore areas of the outer coast of Washington are not accessible because of kelp, rocks, islands or shallow water resulting in breaking waves. Specifically, on the north coast there are many islands, rocks, and kelp beds that occur within 1500 meters of shore that preclude surveying in proximity to these hazards. In the south coast, the mouths of Grays Harbor, Willapa Bay, and the Columbia River often have extremely treacherous boating conditions requiring that we survey at considerable distances offshore from their mouths. These distances vary considerably depending on tidal and weather conditions.

To collect data during at-sea surveys, Washington Department of Fish and Wildlife (WDFW) uses a software program called DLOG (for datalog, developed by R.G. Ford Consulting, Portland, OR.) loaded onto a laptop computer. DLOG interfaces with a GPS, and GIS overlays of the Washington shoreline and adjacent bathymetry, and uses these to record GPS coordinates, perpendicular distance to shore, and water depth at operator-defined time intervals (e.g. every 30 seconds). Transect survey length is calculated from the GPS trackline recorded in DLOG. Other data such as weather and sea conditions, on/off effort, and names of observers are also recorded manually in DLOG. One of our survey crew manually entered bird observation data (species, number, and behavior [flying, on water, diving, etc.] in real time into the laptop as relayed from both the port and starboard observers through audio-headphones. In summer 2000, 2001, and 2002 all murrelets observed within a strip of 100 meters on either side of the boat (trackline) were recorded. Since 1995, WDFW has used many boats to conduct at-sea surveys for murrelets. Boats have varied from 26 to 56 feet in length, inboard to outboard, and single to twin engine. In 2000, we used two vessels, a twin-outboard 26' WDFW vessel, *Harlequin*, and a 36' twin inboard commercial fishing vessel, *Seasport*. In 2001 and 2002, we used a twin-outboard 26' WDFW vessel, *Research 4*.

All observers had extensive at-sea seabird survey experience prior to 2000, 2001, and 2002. Despite this, we spent a week training observers in seabird species identification and use of our software program (DLOG) that we used for real-time data collection.

Aerial Surveys

Aerial helicopter surveys for murrelets and cormorants nesting on Refuge islands have been conducted annually during the breeding season since 1979, by Ulrich Wilson (Wilson 1991, Wilson unpub. data). Since 1995, up to four surveys per annum have been made. Since 1979, photographs of nesting colonies have been made (Carter et al. 2001). Except for 1994-1996, Tatoosh – located outside the Refuge – has not been surveyed. During the two years of this study, aerial surveys and photographs were made. These results and the specific methods used are reported under separate cover. However, aggregate data (over the entire Refuge) as well as data specific to the Point Grenville area are presented.

These data come from previous published work and unpublished reports to the *Tenyo Maru* Trustees Council. It should be noted here that any analyses and conclusions drawn from these data do not necessarily reflect the opinion of the Refuge biologist, but rather of the authors of this report. Aerial survey data collected specifically under the auspices of this study, as well as analyses and conclusions of the Refuge biologist are reported under separate cover.

RESULTS AND DISCUSSION

We present an integrated Results and Discussion section, so that summary interpretation can be presented at the conclusion of each minor section, where appropriate. The entire section is divided into two overall sections: logistical feasibility and biological feasibility. The former simply deals with whether it is physically possible to place decoys on the Point Grenville colonies, and secondarily what types of restrictions any Phase II activity would have to adhere to, as the proposed site is within a National Wildlife Refuge. The latter details the data collected over the last two years which inform our interpretation about the stability of the Point Grenville colonies, the likely sources of disturbance or impact to those colonies, and the degree to which the Washington colonies interact.

Logistical Feasibility

A significant aspect of any restoration project is an analysis of whether it is possible, safe, and biologically responsible, to access colonies for the installation and retrieval of decoys and sound systems (Appendix B). To assess logistic feasibility, we took the following steps:

- Assessment of water and wave conditions in the immediate vicinity of the colonies (observation – Year 1)
- Conversations with decoy installation experts on methods they most preferred and most likely to succeed at Point Grenville (Years 1 and 2)
- Site visit to the colonies to attempt landings and climbing of all four colonies (early Year 2).

A detailed summary of these activities is provided in Appendix B, and much of this information has been submitted in previous reports.

In brief, we conclude that deploying decoys would be possible on Grenville Arch, Erin, and Grenville Pillar, but not on Erin's Bride. Most of Grenville Arch can be safely climbed when very calm ocean conditions allow boat access. The flat surfaces of Erin can be safely climbed; accessing cliff faces would require setting appropriate rope systems from which to descend to nesting ledges. The flat surfaces at the top of Grenville Pillar look to be accessible with appropriate rope systems to enable ascent. Erin's Bride was ruled out due to the steep cliffs on all sides and little flat surface area at the top.

Wilderness Constraints

Because the proposed restoration sites are in a National Wildlife Refuge with a Wilderness designation, there are additional constraints on the types of activities which can be conducted, and materials which can be used, for restoration, or any other proposed work on the Point Grenville. Boat access to the islands is permitted, but helicopter access, including dropping sling-loads of gear, is not. Climbing is permitted; however, installation of permanent anchors or bolts is not. These restrictions limit our ability to safely access Grenville Pillar, as the climbing report (Appendix B) clearly indicates the need for installation of a bolted safety line if Grenville Pillar is accessed from below. Thus, restoration on Grenville Pillar is not possible.

Additional constraints are relevant to the installation of decoys and other restoration equipment. Decoy installation is permitted, with the caveat that the installation technique would have to be temporary and removable (e.g., cementing decoys into place would not be permitted). We believe that this restriction would not compromise the installation of decoys. However, sound playback systems, routinely used to attract potential breeders to a decoy site, would not be permitted. This restriction may slow the pace of social attraction, although pilot experiments on Tatoosh indicated that decoys are attractive without sound (Appendix A). Since the Point Grenville complex already has a recruited population, we feel that this limitation would not compromise a restoration project.

Finally, all man-made materials would have to be removed at the conclusion of the work, leaving the site in pristine condition.

In summary, logistical and wilderness constraints preclude the use of two of the four proposed sites: Erin's Bride and Grenville Pillar. Erin and Grenville Arch are possible sites. One additional caveat to this conclusion - because Grenville Arch is the most distant of the four colonies, accurate viewing and detailed recording of reproductive effort and chick diet is not possible from the mainland. Thus, some type of camera system would have to be installed to monitor any restoration project. Such systems (timelapse movie cameras driven by solar-powered batteries) have been used on the Barren Islands in the Alaska Maritime National Wildlife Refuge to monitor common murre reproductive phenology and success. Thus, we believe this avenue is also open to us at Point Grenville.

Biological Feasibility

This section, much longer than the former, reports on the demographic and source of potential impact data collected over the two years of the study, as supplemented by additional data from outside of the study (e.g., comparative data from Yaquina Head) as well as that collected prior to the study (e.g., Refuge annual surveys, prior work on Tatoosh).

Murre Population Estimates

U.S. Fish and Wildlife Service Washington Outer Coast Refuge personnel have conducted multiple aerial censuses annually of the number of murrens attending outer coast colonies. These data, reported in Wilson (1991) and subsequent reports, indicate that the number of murrens nesting in Washington dropped dramatically in the early 1980s (Figure 3). At the same time, murre numbers on Tatoosh Island appeared to rise (Figure 4), although systematic annual counts were not available for this colony until 1991. Parrish et al. (2001) have speculated that this population must have been supplemented by substantial immigration during the 1980s, as apparent population growth ($\lambda =$

1.289, or almost 30% annual population growth) was not possible in a closed system. On the Point Grenville colonies, attendance estimates echoed the pattern apparent in the Refuge (Figure 5) – a steep decline in the early 1980s followed by no substantial recovery. Thus, at the point in time of the *Tenyo Maru* spill, the majority of colonies within the Refuge housed relatively low numbers of murres (versus 1979-1980 counts) whereas the Tatoosh population was in an expansion phase.

Post-spill - during the 1990s - murre numbers in the Refuge appeared to stay low, despite a brief resurgence during the late 1990s (Figure 3). At the same time, murre numbers on Tatoosh Island were dropping at approximately 3% annually (Figure 4; Parrish et al. 2001). At the Point Grenville colonies, the continued depression apparent in the 1990s was actually due principally to numbers at Grenville Arch. Murres recruiting to Erin, Erin's Bride, and Grenville Pillar actually increased to a peak in 1998 which, while still substantially lower than 1979-1980 numbers, could possibly be indicative of a recovery (Figure 6). However, a more in-depth analysis of these data indicate that whereas annualized numbers appeared to increase, within-year variation was quite high. Due in part to necessarily low sample sizes (as repeated helicopter counts are simply not possible) and in part to the range between counts, pairwise t-tests with appropriate correction for experiment-wise error (reducing significance level to $p = 0.003$) shows that there is actually no difference among values reported from the 1990s (with the exception of 1995 versus 1998, $p=0.002$). One interpretation of these results is that there is no recovery and that the apparent variability in intra-annual counts indicates instability within these colonies. A competing interpretation is that the first counts of the season were made before the murres settled for the season, and thus are less reliable. If only peak counts are used, numbers do appear higher, although (obviously) actual variability measures are lost.

The time series of population size estimates collected during this study are too short to provide insight into whether these populations are recovering or not. However, they can be placed in the context of the earlier numbers, and – more importantly – they can provide insight into intra-annual patterns of variability, itself a potential measure of

colony stability. There are two lines of evidence: ground-based counts and at-sea estimates. Ground-based counts are extremely restricted, both by the inherent logistics in making these counts, but also by the fact that a majority of murrens attending the Point Grenville colonies are either non-breeders, or nest in locations not visible from land (Zador, pers. obs.). Nevertheless, counts of plots visible from land on all four colonies show relatively high variability both within and between years (Table 5). High sample size, and a restricted sample (to only those counts made during the egg and chick period, only those counts made during good visibility, and only those counts made before abandonment) contribute to apparently low variance (standard error at 8-15% of the mean); however, it is instructive to compare mean to maximum counts (as in the aerial survey data). Maximum counts are 1.5 to 5 times mean counts. Thus, either these plots have a substantial number of non-breeders which obscure patterns in the breeding population, or the breeding population is unstable and likely to abandon. In either case, the data point to instability.

Comparison with similar counts taken at Tatoosh further this interpretation. At subcolonies on Tatoosh counted throughout the season, where the murrens are nesting in similar habitat (rocky ledges or crevices in cliff-face), mean and maximum counts are usually within 10% and standard errors are usually less than 5% of the mean, except in cases of very low sample size (Table 6). It should be noted that this pattern occurred during a period when the entire colony appears to be stable (e.g., Figure 4), although these latter island-wide estimates are unbounded.

In sum, aerial and ground-based data appears to indicate that the Point Grenville colonies are unstable in annual as well as intra-annual attendance, relative to the Tatoosh Island colony. This relatively high variance makes any determination of pattern within the attendance data problematic, given necessarily low sample sizes of the whole colony counts (i.e., aerial surveys).

At-sea data provide a complimentary picture of instability in the Refuge colonies. Here, stability refers to three states along a continuum: (1) colonies with stable attendance over

the season and active breeding, (2) colonies with unstable attendance over the season and indications of breeding, and (3) colonies with unstable attendance over the season and no indications of breeding. We conducted grid transects (approximately 5 km by 5 km, see methods for more details) around four historic and/or current murre breeding colonies on the outer coast of Washington (Tatoosh Island, Carroll and Jagged Islands, Quilleute Needles, and Point Grenville). Four replicates were conducted at each site (1) in 2001 and 2002, and (2) in the morning and in the afternoon. Using Tatoosh as a reference colony, and assuming that despite the steady decline in population size experienced through the mid 1990s that this colony is essentially stable, we compared patterns of rafting attendance in the vicinity of several colonies. To test for potential differences in murre distribution around each of these sites in relation to time of day and year, we conducted a two-way ANCOVA for each site using year and time of day as factors, and distance from each colony as a covariate. Because we conducted four ANCOVAs, we reduced our significance level of $P \leq 0.05$ to an experiment-wise level of $P \leq 0.0127$ using the Dunn-Sidak correction (Sokal and Rohlf 1995). Year was not a significant influence on the patterns within colonies ($df = 1$, $F \leq 1.495$, $P \geq 0.229$). Time of day also was not a significant factor ($df = 1$, $F \leq 2.809$, $P \geq 0.009$) except at Tatoosh Island where murre densities in the morning than in the afternoon (Figure 7; $df = 1$, $F = 9.08$, $P = 0.003$). However, the spatial pattern was different among colonies. Last, murre density decreased with distance from Tatoosh, the Quilleute Needles (centered on Huntington Island), and Carroll and Jagged Islands ($df = 1$, $F \geq 11.797$, $P < 0.001$), but not from the Point Grenville (Figure 7; $df = 1$, $F = 0.001$, $P = 0.981$).

The pattern displayed at Tatoosh, of a peak in numbers close to the island followed by a steep decline – essentially a halo – was also apparent in earlier studies (Thompson 1999, Parrish et al. 1998), and can be interpreted as a further indication of a stable reproductively active colony. The halo is composed of rafting birds – most probably breeders (Burger 1997) – which consistently occur during the pre-breeding and breeding season.

Two of the three Refuge colonies display a similar pattern to Tatoosh – Quilleute Needles, and Carroll and Jagged Islands whereas the Point Grenville colonies have a fairly uniform coverage of murre across a wide area. One potential interpretation of this pattern is that rafting murre are associating with individual colonies (e.g., Erin versus Grenville Pillar, etc.) such that at-sea counts incorporate several rafts resulting in a uniform distribution. However, the total distance between the colonies is much smaller than 4km, making this hypothesis only partially explanatory. A second potential explanation is that murre which have abandoned for the season, or who returned to the area but never settled, may remain in the general area for the season, not faithful to any one colony. Over the four kilometers surveyed, an even distribution of approximately 25 murre/km² is over 1250 birds, or half again as large as the peak Refuge aerial survey numbers in 2001 (925). At the very least, these data point to a potential difference between the colonies at Point Grenville and the Tatoosh murre colony.

In addition to assessing population size in the immediate vicinity of known or suspected colonies, we also censused the broader outer coast region out to 8km. Earlier work has shown that the majority of murre on the water occur within this strip of coastal ocean (Thompson 1997, 1999, Parrish et al. 1998). To obtain an index of murre numbers, we used the same sampling methods and data analyses that are used to estimate population size of marbled murrelets, *Brachyramphus marmoratus*, in the same geographic area each summer (Bentivoglio et al. 2002, Jodice et al. 2002). Over the two years of the study, estimated numbers were both high and constant – 72,840 in 2001 and 74,011 in 2002 (Table 7). Statistically, these values are indistinguishable (two-sample t-test, df = 48, t = 0.058, P > 0.9). An earlier coast-wide aerial survey in 1989 (Briggs et al. 1992) estimated 21,939 (raw counts x 1.67 after Takekawa *et al.* 1990) murre in late June. Although these data may be incomparable due to methodological differences (i.e., boat versus aerial surveys), they do point to either substantial increases in the number of murre inhabiting the Washington coastal colonies, or to the potential for much additional recruit to Washington colonies.

Relative to total colony counts (a combination of aerial counts in the Refuge and ground-based counts on Tatoosh), these values are extremely high. Total on-colony numbers in 2001 were only 7,800 (peak 2001 Refuge count + Tatoosh attendance in 2002; 2002 Refuge numbers are unavailable). Even assuming a correction factor for foraging mates of 1.67 (Takekawa et al. 1990) to estimate breeding population, and an additional correction factor of approximately 2 to incorporate pre-breeders (assumes no skipping in the breeding population; Parrish et al. 2001), the total estimated Washington murre population would only be 26,000, only a third of the at-sea values. One interpretation of this discrepancy is that there is a substantial nascent breeding pool in Washington waters, which has either elected not to breed, or has failed at breeding. These birds might likely be the candidates for breeding population restoration via social attraction. It is also possible that a fraction of these at-sea birds are Oregon breeders which have moved north following the end of the breeding season. Thompson (1999) has shown that the Oregon “dad-chick wave” passes the Columbia River in early July, Point Grenville by 15 July, reaching Tatoosh around 1-7 August. Our surveys occurred before this time.

In sum, the grid survey data appear to substantiate the pattern of instability at the Point Grenville colonies established by the aerial and ground-based work. At the same time, at-sea surveys indicate a substantial pool of murre – coastwide – available for restoration via social attraction.

Reproductive Timing and Effort

Timing of initial breeding events differed little between years at Point Grenville (Table 8). However, the chick period in the CT subcolony on Grenville Pillar in 2002 was delayed 3 weeks due to egg loss from predation and the subsequent time it took the murre to replace those eggs. Chick hatching and fledging at the SP subcolony on Grenville Pillar was asynchronous in both years due to the loss and subsequent replacement of some of the eggs. At Tatoosh, breeding phenology was essentially identical to Point Grenville (Table 9). Thus, it is probably the case that the Washington murre colonies all breed on the same schedule. Oregon colonies, as assessed by Yaquina Head, breed substantially earlier (first eggs in the beginning of May; last fledge at the end

of July). One interpretation of this pattern is that breeding phenology may be set by oceanographic conditions, and that the Columbia River acts as a hydrologic barrier between successive coastal regions (Hickey 1998).

Reproductive effort at the Point Grenville colonies – at least as assessed from ground-based locations – was low and variable. No murrelets nested on Grenville Arch in either year, with the exception of one isolated pair in a very small ledge (the NK subcolony) that raised a chick in 2002. Murrelets on Erin, Erin’s Bride, and Grenville Pillar did reproduce successfully in 2002; however, only pairs nesting on two subcolonies (SP and PC) on Grenville Pillar were successful and synchronous in 2001 (Table 10).

A detailed accounting of the fate of chicks produced on Erin and Erin’s Bride (Table 11) indicates an extremely wide range in reproductive success (0 to 88% per subcolony). Across these two colonies, plot-based average success was only 53%, and pair-based success was 61%. These values, especially considering the general reproductive failure in 2001, are unusually low (Nur and Sydeman 1999) and are not enough to sustain the population (Parrish et al. 2001).

By contrast, reproductive success on monitored subcolonies on Tatoosh was substantially higher (Table 12). In both years, average plot-based success was 80-81% and pair-based success was slightly lower at 73-79%. On this colony, islandwide reproductive success is estimated annually by assuming consistent habitat-based success (that is, crevices versus cliff-tops; with the exception of a single cliff-top subcolony, Pole Island, where success is independently monitored), and standardizing by habitat-based attendance (cliff-top versus crevice; Appendix E). Both 2001 and 2002 were relatively successful years (Table 12), especially in reference to earlier years in the mid-to-late 1990s (Parrish et al. 2001).

In sum, reproductive success on the Point Grenville colonies is variable and low; too low to sustain the population were the system closed (i.e., no immigration). By contrast, the most recent Tatoosh reproductive success is much higher, and much less variable.

However, in the recent past, the Tatoosh colony has also experienced significantly degraded reproductive success (Parrish et al. 2001).

Adult Foraging and Chick Diet

At Point Grenville, fish observations were conducted on Grenville Pillar subcolonies, mostly at the SP subcolony, where incoming murre with fish can be seen briefly at an angle which allows fish identification. Fish carried by murre landing at CT or PC are rarely visible as incoming murre are facing away from the observers. On Tatoosh, chick diet was assessed at cliff-top subcolonies (MCT-EXT, PC).

Smelt, likely surf smelt *Hypomesus pretiosus* comprised the biggest proportion of identified fish fed to chicks on Grenville Pillar subcolonies in both years, accounting for approximately half of all fish fed to chicks (Table 13). Pacific herring *Clupea pallasii* and salmon *Oncorhynchus* spp. accounted for an additional 40% of the diet in 2001. In 2002, sandlance *Ammodytes hexapterus* was more prominent, accounting for nearly one third of the diet. In general, broad dietary patterns were similar between Point Grenville and Tatoosh foragers. Major prey species, defined as those accounting for 5% or greater of the total chick diet, were nearly identical – smelt (most likely surf smelt and eulachon *Thaleichthys pacificus*), Pacific herring, sandlance, and salmonids (based on body coloration and markings, most likely chinook salmon *O.tshawytscha*, coho salmon *O. kisutch*, or steelhead, *Salmo gairdnerii*). It is notable that adult murre breeding on Tatoosh brought back lanternfish (Myctophids) in significant numbers in both years, whereas this group of fish was absent from the Point Grenville diet. Myctophids are generally regarded as a deepwater fish, which vertically migrate to the surface at night (Paxton 1967, Frost and McCrone 1979, Watanabe *et al.* 1999). The presence of these fish in the Tatoosh diet may reflect unique oceanographic conditions in the area immediately surrounding this colony (Parrish and Zador in press). All major prey species, including myctophids, are high energy content fish (Figure 8) suggesting that at both colonies, adults have a range of high-quality prey choice.

There was an apparent difference in prey diversity between the Point Grenville colonies and Tatoosh, 5 (2001) and 6 (2002) prey species were returned by Point Grenville murrelets, whereas nearly three times that diversity were returned by Tatoosh foragers (16 species – 2001; 14 species – 2002; Table 13). However, this comparison is somewhat misleading. Due to low numbers of actively reproducing pairs visible on the Point Grenville colonies, total fish sample size in both years was over an order of magnitude smaller than the Tatoosh diet sample. Thus, rare prey species would be expected in lower numbers. Furthermore, observations at Point Grenville are conducted from mainland sites using spotting scopes, whereas on Tatoosh observations are made from blinds within 2 m of all monitored pairs. Thus, prey identification is inherently easier at Tatoosh. For instance, on Tatoosh most smelt were identified to species, whereas at Point Grenville most smelt were lumped at the family level (Table 13).

Chick feeding rates (fish per hour) were assessed using two datasets. First, for both years, hourly fishwatch data collected across a broad range of pairs within identified plots were used. These watches were planned to cover specific periods across the range of lighted hours over the entire chick-rearing period, to control for time of day and date effects. Data are not binned by pair, but instead by individual watch - that is, total fish returned to a plot with a known total of chicks. Data were then aggregated within time of day category, and finally across time of day categories. This dataset allows for interannual comparisons, and broad comparisons between colonies. The second dataset involves a much more detailed examination of individual pairs conducted in 2002. Chosen pairs were watched continuously for at least 8 hours, during single days in two phenological periods: mid-chick (median chick age 12 days) and late-chick (median chick age 17 days). The latter dataset allowed much more individualized comparisons across single days, but could not integrate across the season. In addition, the latter dataset included pairs followed at Yaquina Head, the Oregon colony.

Fishwatch data suggest that there was little difference between years in the result of foraging efforts of adults at both Point Grenville and Tatoosh (Table 14). However, in both years, adults at Point Grenville returned slightly more often, such that the estimated

daily delivery rate at Point Grenville was more than a fish higher than at Tatoosh (5.8 versus 4.5 fish/day in 2001, $t = -2.39$, $df = 8$, $p = 0.04$; 5.9 versus 3.8 fish/day in 2002, $t = -2.28$, $df = 8$, $p = 0.05$; assuming 16 hours of foraging time per day). Of course, this difference does not necessarily translate into a poorer chick diet on Tatoosh, as both fish size and fish energy content play a role in determining relative chick diet. However, given the fact that major prey diversity was similar and predominated by high caloric content species (Table 13), these data certainly suggest that adults foraging in the Point Grenville area are not at a disadvantage.

Pair-based fish watches show a slightly different inter-colony pattern (Table 15). Here, the range of foraging rates are much closer, with the exception of mid-chick at Yaquina, where daily delivery rate dropped to 1.7 fish/day. Although rates at Point Grenville were slightly lower than at Tatoosh, in contrast to the seasonally averaged fish watch data above, this difference only amounted to a maximum of half a fish difference over the day and was not significantly different from the other colonies (repeated measures ANOVA $F = 0.223$, $df = 2,28$, $p = 0.801$). In general, delivery rates were higher in the morning than in the afternoon (with the exception of Yaquina mid-chick). Rates were also fairly comparable across phenological time, again with the exception of Yaquina. If the mid-chick data at Yaquina is discounted, the general pattern displayed appears to be: (1) foraging rate peaks in the morning, when both chicks and adults are presumably most hungry, having just spent the night without eating, (2) foraging rates are comparable across time, with the potential exception of Yaquina, where rates may have risen from mid to late chick, and (3) foraging rates are fairly comparable among colonies, although Point Grenville appears slightly lower.

Taken together, these data clearly indicate that parents foraging for their chicks at Point Grenville do not appear to be hampered relative to murre nesting either within the Washington coastal population (i.e., Tatoosh), or to the south in the much larger Oregon population. Thus, although the Point Grenville colonies appear unstable from an attendance and reproductive success point of view, pairs making it through to the chick stage have no trouble feeding their chick.

Potential Sources of Instability

There are several sources of instability we considered during the course of this study. Most are too variable, and occasionally too infrequent, to merit a thorough investigation within a two year period. However, we used data from other colonies collected prior to this study, as well as data collected outside the strict bounds of this study, to supplement our results. We present potential sources of instability in three sections: oceanographic forcing, predator forcing, and other disturbance. It should be noted that we also did not address potential interactions between these sources, or between these sources and the *Tenyo Maru* oil spill, although these interactions certainly occurred.

Oceanographic Forcing

Two regional indices of climate impact known to be correlated with a range of biological response variables (Sydeman *et al.* 2001, Bograd *et al.* 2000, Parrish and Zador, *in press*) were used as surrogates for remote oceanographic effect: the multivariate ENSO index (MEI; Figure 9) and the Pacific decadal index (PDO; Figure 10). We assumed that should such forcing be present, it would most likely manifest itself through a change in coastal productivity, which would translate into a change in forage fish availability and perhaps species diversity. All of the above would then affect murre demography parameters, including chick production (which we measured as reproductive success) and possibly adult attendance (if environmental conditions reduced adult body condition below that needed to breed). Because we are only looking at two years of data, long-term correlations usually needed for such a “bottom-up” finding were not available to us. Therefore, we rely on prior data collected within the Refuge and on Tatoosh to support our conclusions. Within the two year time frame, we also explicitly compared the response of Point Grenville murre versus Tatoosh murre to forcing factors at the regional level.

The PDO switches from warm (predominantly positive values) to cool (predominantly negative values). These regime shifts signal a change in many physical parameters (Francis *et al.* 1998), and generally have the result of flipping the relative coastal

productivity between the California Coastal Current and the Alaska Current systems (Hare et al. 1999). In the lower 48, warm phase PDO (1977-1997) is relatively worse (McGowan et al. 1998). The MEI spikes positive during El Niño events, which are generally associated with a lessening of coastal upwelling. Particularly strong events occurred in 1983, 1987, and 1998, and a weaker but more sustained event occurred from 1992 through 1994. Thus, if the murre populations were responding to oceanographic forcing, we might expect declines in attendance and/or reproductive success during the PDO warm phase, on or after a particularly strong MEI signal.

Murre population estimates from Tatoosh (i.e., Figure 4) and peak numbers from the Refuge (i.e., Figure 3) show little concordance with oceanographic conditions as expressed in the MEI and PDO indices (PDO - Pearson correlation coefficient (R) = -0.004, $p=0.98$, $N=23$; MEI - $R=-0.028$, $p=0.90$, $N=23$), with the exception of the dramatic decline in attendance in the Refuge in 1983 (Figure 11; Figure 12). Murre attendance in the Refuge did decline following the ENSOs of 1987 and 1998. The signal during 1992-1994 is more confusing. Within the Point Grenville colonies, any obvious concordance between PDO, MEI, and attendance is even less clear (Figure 5; Figure 6). It is possible that after the steep decline experienced in the early 1980s, attendance on these colonies has remained so low that further drops corresponding with oceanographic conditions are difficult to discern. Scatterplots of the data clearly indicate two groups of points, those prior to 1983 which are correlated with PDO, and those following, which are not (Figure 12).

On Tatoosh, data were not routinely collected until 1991. The ENSO of 1998 is associated with the nadir in attendance; however the prolonged event from 1992 to 1994 produced no discernable effect. Furthermore, although the decline through the 1990s is in the PDO cool phase, so is the dramatic increase which must have happened throughout the 1980s. There is some indication that the most recent change in the PDO, in 1998, is correlated with a stabilization followed by an increase in attendance; however, this association is weak and several more years of data will be needed to confirm or refute this correlation (PDO - $R=-0.302$, $p=0.09$, $N=11$; MEI - $R=-0.532$, $p=0.09$, $N=11$).

Earlier work on possible regional scale oceanographic forcing on murre colonies in the Pacific Northwest (Parrish and Zador *in press*) indicated that the Tatoosh population experiences relatively little regional forcing, whereas the much larger colony at Yaquina Head is significantly forced by regional measures. This is expressed both in attendance and in measures of reproduction.

In sum, we believe that oceanographic forcing has affected Pacific Northwest murre populations, particularly in places – and times – when the local populations were/are quite large, as was the case in the Refuge in the late 1970s and early 1980s, and is the case currently in Oregon. Parrish and Zador (*in press*) argue that colonies closer to carrying capacity (K) may be more sensitive to oceanographic forcing, as even small changes in coastal productivity may translate into a re-thresholding of K below current population size. At present, the Point Grenville colonies are substantially below their historic values, thus they are unlikely to be affected by oceanographic forcing.

Further evidence to bolster this hypothesis comes from the amount of time monitored pairs spent together on-colony during the chick-rearing period. In colonies which are food-stressed, brooding murrens spend a minimum amount of time together on the colony (Zador and Piatt 1999) – just enough to maintain pair bonds. The majority of time is spent in foraging. As food conditions become richer, time paired on the colony increases (Zador and Piatt 1999), presumably because the time needed to find food decreases. We hypothesized that if the Point Grenville colonies were food-stressed (oceanographically forced), parents would spend significantly less time paired during our 8 hour watches. In fact, the mean number of minutes both parents attended nest sites did not vary by colony (repeated measures ANOVA $F = 0.193$, $df = 2,28$, $p = 0.825$; Figure 13).

Finally, our chick diet and adult foraging rate data clearly show that the Point Grenville colonies are not suffering relative to Tatoosh, or to Yaquina. In sum, there is no evidence that the Point Grenville colonies are currently forced by oceanographic conditions limiting prey base or otherwise affecting demographic parameters.

Predators

Avian predators, principally bald eagles, have had a significant effect on the demographics of the Tatoosh murre population (Parrish 1995, Parrish et al. 2001), and were considered here as a potential source of instability. Because detailed demographic and predator-prey data were not available for the Point Grenville population prior to this study, it is difficult to discern the degree to which eagles may have played a role in the past. However, eagle presence on the outer Olympic Peninsula has been steadily increasing (Figure 14).

Within the two years of this study, we witnessed only a single eagle attack at Point Grenville resulting in a murre being killed in 2001. However, witnessed predator kills are rare in this system, because observers are distant to the site (compare to blinds on Tatoosh), a significant fraction of the murre nests on the west side of the colonies out of sight of observers, and – unlike Tatoosh – we do not have the opportunity to inspect carcasses left by eagles.

Despite the paucity of kills, we believe eagles to be a major influence on the Point Grenville murre population for several reasons. Eagle fly-bys routinely caused murre to get agitated, and in some cases flush. Eagles occasionally roosted on Grenville Arch itself. In 2002, we witnessed nine eagles at one time on Grenville Arch, one attempting to eat a murre egg. Eagle activity early in the 2002 nesting season had a dramatic impact on the first murre eggs laid at Grenville Arch and Grenville Pillar. We believe that all of the first eggs laid on these rocks were lost due to eagle-induced gull predation. All measures of eagle activity were higher in 2002, including maximum number of eagles seen per day before and after July 20 (the approximate date of eaglet fledging in coastal Washington; Parrish et al. 2001), and maximum number of eagles per trip (Table 16). In both years, the numbers of eagles seen per day was three times higher before July 20th than after. Although eagle activity declined later in the season, we believe that the cycle of disturbance and abandonment had already begun. In 2002, replacement eggs were laid and lost at PC and SP (Table 10). Some replacement eggs at SP produced chicks. All

chicks at CT were produced from replacement eggs. Finally, the colonies at Point Grenville offer little secure habitat from eagles. The majority of space available for expansion of these colonies is on the top of unvegetated or grassy islets (Appendix C). Ledges and crevices in the vertical cliff walls are limited. Thus, when eagles attack, they are likely to provoke evacuation. Over the long term, increasing predator pressure is also likely to prevent recruitment to these exposed upper areas.

Over the past decade, eagle pressure, defined by both the count of eagles on the colony and the relative activity of those eagles, has fluctuated (Figure 15). What is interesting to note is while eagle numbers have been fairly constant, even slightly increasing, eagle activity has not followed this pattern (maximum eagles versus eagle flybys; Pearson correlation, $R=0.261$, $p=0.439$). Eagle activity, defined as average flights past our observation point per hour before 20 July, peaked in 1999 and 2000, but has since dropped off significantly. When these measures of eagle pressure are regressed against islandwide reproductive success, only eagle flybys are a significant predictor of murre chick fledging, albeit barely ($T=-2.23$, $p=0.05$, $N=11$, $R^2=0.284$; Figure 16).

On Tatoosh, eagle visitation rates were higher than at Point Grenville (Table 16). However, the effect of their visitation appears to be lower – at least as assessed by reproductive success (Table 12). We believe there are several reasons for this. First, eagle activity over the past two years is actually lower than in most of the previous years (Figure 15). Second, murre nesting in particularly vulnerable habitats have either vacated that habitat (Parrish 1995, Parrish and Paine 1996, Parrish et al. 2001) or have altered their response to eagle attack (Parrish unpub. data). Cliff-top nesting murre which used to evacuate to the water during an eagle attack now retreat into the salmonberry cover. This “new” strategy on the part of the prey has significantly reduced the chance of successful eagle attack, as salmonberry density prevents eagle entry. Finally, in 2002, a pair of adult eagles conducted courtship activities around Tatoosh daily, including chasing other eagles, including juveniles, from the main island. As a result, eagle activity dropped substantially.

In sum, we believe that eagle effects can be a significant force affecting murre population stability in the Pacific Northwest. At Point Grenville, although actual kills witnessed are low, we suspect eagles are the main predator responsible for the loss of early eggs, and the abandonment of nesting subcolonies in 2001. Thus, unless eagle numbers can be controlled, or safe habitat can be constructed, eagles will likely continue to play a major role in shaping the Point Grenville colonies.

Other Disturbance

Pelicans

In 2001, we infrequently observed 1-9 brown pelicans flying past or roosting on Grenville Arch. Most observations were during the month of August. However, in 2002, we observed brown pelicans throughout the field season (Figure 17). Pelicans were occasionally present from mid-June to mid-July, but were consistently present from mid-July through early September. Peak numbers were recorded from mid-July to late August, with a maximum count of 938 on August 18. In addition, the pelicans appeared to displace murres from the top of Erin beginning July 24. No murres were seen in the DC subcolony at the top of Erin after the pelicans appeared. A similar pattern occurred at Grenville Arch at the TR subcolony. Pelicans began to occupy the area in early August, after this time we did not see murres in the TR area until the pelican numbers dropped in late August. Pelicans began to occupy the lower reaches of subcolony B on Erin's Bride in late July. By July 23 murres remained absent from this area. We have never observed pelicans landing on Tatoosh, although we have recorded them flying by in flocks of 2-30 since 1995.

Planes

At Point Grenville, we noted little disturbance from airplanes and helicopters during our observations. We observed some head-bobbing of murres when planes were in the area, but could not attribute the cause of the behavior to the airplanes or to gull alarm calls. In one instance in 2001, an airplane flew <100 meters above Grenville Pillar. Half of the murres in the PC colony head-bobbed, but neither the murres, gulls, nor cormorants

flushed. Similarly, no response to planes or helicopters was observed which directly affected breeding success of murres at Tatoosh in either year.

Summary of Biological Feasibility

Two years of ground-based data collection on the demographics of, and potential sources of impact to, the Point Grenville common murre colonies, with reference data from Tatoosh and secondarily from Yaquina Head, and supplemented by aerial and at-sea survey work, have lead us to believe that the Point Grenville colonies are currently instable. This instability is manifest in attendance and in reproductive success, and is aggravated to the degree where the population – were it closed – could not sustain itself. We believe the most likely source of the initial decline was abrupt changes in ocean conditions during the 1983 ENSO, which may have affected adult body condition, elevated adult mortality, and seriously depressed breeding in that year. We feel that it is highly likely that murres nesting in the Refuge at that time were not all killed, but more likely the population experienced a combination of increased instantaneous annual mortality and a major reshuffling of breeders among colonies. It is at this point that the Tatoosh colony dramatically increased in size, most likely as a result of this within-Washington migration. When combined with the similarity in breeding phenology, and the similarity in morphology (Warheit 1996), these data all suggest that the Washington colonies may act as a metapopulation, where individual colonies become sources – or sinks – depending on local circumstances. Finally, we suggest that the current conditions preventing self-induced restoration at the Point Grenville colonies is most likely eagle activity – including both predation and disturbance. Because eagle numbers appear to be increasing, this source of disturbance is not likely to fade, unless mitigated or actively controlled. In part, this is because the opportunities for shelter on the Point Grenville colonies are extremely limited.

CONCLUSIONS AND RECOMMENDATIONS

The overall purpose of this project “is to restore Common Murre colonies, using social attraction techniques, to locations in the Copalis NWR” (TMOSNRT 2000). The

workplan for Phase I of this project stated two general objectives: (1) determine if “social attraction enhancement activities are warranted”, and (2) determine if “project implementation would be impeded by physical or natural limitations.” Specifically, Phase II of the project should be implemented only if:

- (1) findings of Phase I indicate that Common Murres are not self-sustaining within the colony identified for restoration;
- (2) social attraction methods are deemed to have a reasonable likelihood of success based on Phase I findings;
- (3) social attraction devices can be deployed in a manner safe for humans and all necessary access permission is obtained;
- (4) rock(s) in which social attraction devices are to be deployed allows adequate monitoring of Common Murres and other seabirds for attendance, breeding behavior, and reproductive success, and;
- (5) it is compatible with Refuge purposes at Copalis NWR and surrounding Refuges (i.e., it will not materially impair the management of migratory birds, including Common Murres and other migratory species).

In other words, Phase II should be implemented if the results from Phase I suggest that;

- (1) social attraction techniques are a viable option at these sites, (2) the sites can be adequately monitored for behavioral interactions with the attraction devices and, (3) the sites can be adequately monitored for reproductive success.

Our results indicate that food is not a limiting factor to the stability or growth of the colony of murres at the Point Grenville. Despite this, our aerial, at-sea and ground-based data all indicate that the murre colony at the Point Grenville is not stable or self-sustaining, and that it also can not support many more murres than currently attempt to breed there. The reasons for this are two-fold. First, and most importantly, eagles cause direct mortality of adults and chicks, and reduction in reproductive success through (a) egg breakage when adults flee the colony in response to eagle presence, (b) predation on eggs by gulls when adult murres flee the colony, and (c) reduced fitness of chicks

resulting from subsequent relaying attempts. Second, murre nesting habitat is limited on the Point Grenville; most of the suitable ledges and crevices in the walls of the Point Grenville are already being utilized by murre. Most of the cliff-top areas that were used for nesting by murre many years ago are now covered with tall grass in which murre will not nest. This grass can not be removed because the Point Grenville are designated as Wilderness areas by the Copalis NWR which prohibits such activities. Further, even if the grass could be removed, continued eagle predation would likely prevent murre from nesting on cliff-top sites. The Tatoosh pilot decoy study clearly indicates that eagles are attracted to decoys in unprotected areas, such as would be available at the tops of Grenville Arch and Erin.

Given these conclusions, we do not think that deploying decoys on the Point Grenville would be likely to significantly enhance the number of murre that breed successfully at that colony because (1) most suitable crevice sites are already being used for nesting by murre, and (2) deploying decoys on cliff-top sites would likely result in eagle predation of murre attracted to those decoys. Indeed, such activities may act as a population sink by increasing adult, chick and egg mortality. Therefore, we recommend that Phase II should not be implemented at the Point Grenville.

Instead, as co-Principal Investigators of this project (Chris Thompson - WDFW and Kevin Ryan - Refuge) we propose to move all Phase II activities to Tatoosh Island (Appendix F). We have documented above that murre in Washington appear to be a morphometrically panmictic population, i.e., there is nothing different about murre at the Point Grenville as compared to murre at other colonies in Washington. Furthermore, we have documented that the breeding schedule of the Point Grenville colonies and the Tatoosh colony is identical. Finally, we have presented indirect evidence that the increase in the Tatoosh murre population in the 1980s likely came from the Refuge colonies.

Because the goal of this project is to increase the size of breeding population of murre in Washington, an increase in murre at any colony within Washington will benefit the

“Washington” murre population and fulfill the objective of Phase II. Of all other murre colonies in Washington, Tatoosh Island is the logical choice for conducting Phase II for many reasons: (1) there is extensive crevice/ledge and cliff-top habitat that is not currently used by murre, but could be utilized by murre in the future as the Tatoosh colony expands; (2) decoys can be deployed safely in both crevice/ledge sites and cliff-top sites given the knowledge gained in the decoy pilot experiment; (3) eagles currently cause less disturbance at Tatoosh than at the Point Grenville despite increased presence at Tatoosh. We believe this is due to a combination of learning on the part of the Tatoosh murre, availability of safe habitat on Tatoosh, and recent nesting activity on the part of a single eagle pair; (4) murre activities (e.g., response to decoys, foraging activity, reproductive success, etc.) can be monitored much more easily and accurately than at the Point Grenville (or any other murre colony in Washington); and (5) we have agreement from the Makah Tribe, who own Tatoosh Island, work on Tatoosh Island.

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