CHANGES IN MARINE BIRD ABUNDANCE IN THE SALISH SEA: 1975 TO 2007

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SUMMARY

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Despite worldwide examples of marine bird declines, relatively little study of marine bird population changes in the Salish Sea has been undertaken. The 1978/79 Marine Ecosystems Analysis (MESA) Puget Sound Project provided baseline data for wintering marine bird abundance for the southern Strait of Georgia and northern Puget Sound. Subsequently, comprehensive census work has been limited to aerial surveys (1990–present) by the Puget Sound Ambient Monitoring Program (PSAMP), shore-based and ferry surveys by Western Washington University (WWU) of marine bird abundance (2003–present), and Christmas Bird Counts (CBCs, 1960s–present). I use these three surveys to evaluate changes in non-breeding-season marine bird abundance in the Salish Sea. Comparison of WWU data from 2003 to 2005 with 1970s MESA data from the same locations shows significant declines in 14 of the 37 most common overwintering Salish Sea species, including 10 species that declined by more than 50%; seven species showed significant increases over that time period. The order of species, from those showing the most declines to those showing the greatest increases, showed a significant correlation between the PSAMP and WWU studies. Western Grebe *Aechmophorus occidentalis,* scaup (primarily Greater Scaup *Aythya marila*), and Marbled Murrelet *Brachyramphus marmoratus* showed significant declines in all three studies. The Common Murre *Uria aalge,* not included in the PSAMP study, showed significant declines of more than 80% in the WWU and CBC studies. Significant declines occurred in species of four of the five feeding guilds, including piscivores, benthivores, omnivores and planktivores, and significant increases were seen in species of three feeding guilds, demonstrating that the factors affecting species abundance are complex and may be unique to each species. The WWU study largely corroborates declines documented by the PSAMP study, and analysis of 11 Salish Sea CBCs found the fewest species with significant declines. Long-term monitoring, including continuation and expansion of low-cost monitoring such as the WWU survey, and citizen-science efforts such as the BC Coastal Waterbird Survey (1999–present) and the Seattle Audubon Society's new Puget Sound Seabird Survey, will help to determine how future environmental changes in the Salish Sea marine ecosystem and beyond affect migratory and resident marine bird populations.

Key words: Marine birds, Salish Sea, Puget Sound, Strait of Georgia, surveys

INTRODUCTION

Marine birds have exhibited population declines throughout the world, including North America, over the last several hundred years (Boersma *et al.* 2001). For example, the five most common species of sea ducks have all declined in the Beaufort Sea (Dickson & Gilchrist 2002). The causes of these widespread declines are numerous and often complex, involving factors such as direct exploitation, habitat destruction, fishing bycatch, oil spills, other pollutants, introduced species and the effects of climate change on food resources (Boersma *et al.* 2001, Bertram *et al.* 2005, Lee *et al.* 2007). Indeed, marine birds have been used widely as indicator species for monitoring the health of both marine-feeding and terrestrial-breeding ecosystems (Piatt *et al.* 2007b).

Relatively few investigations of marine bird populations have been conducted in the Salish Sea, despite that location's recognized importance as a nesting and migration site for many marine bird species (Wahl *et al.* 1981). Accounts of pre-1970s Salish Sea marine bird abundance are mainly anecdotal, as collected and summarized by Jewitt *et al.* (1953). The first systematic surveys in the Salish Sea were Christmas Bird Counts (CBCs), the earliest of which took place in the 1960s. CBCs now occur in approximately 20 Salish Sea locations and provide a continuous series of censuses over a widespread geographic range that facilitates inferences about changes in winter marine bird abundance over time. The only published study using Salish Sea CBC data is by Wahl (2002), who analyzed CBC data (1969–1999) that he collected for urbanized Bellingham, Washington, using a standard protocol. He found that 12 of 20 species or species groups had shown significant declines over that period, while one species showed significant increases.

The most comprehensive marine bird census within the Salish Sea has been the Marine Ecosystems Analysis (MESA) Puget Sound Project conducted during 1978/79 (Wahl *et al.* 1981; Table 1). The study censused marine birds in 13 regions bordered by the mouth of the Strait of Juan de Fuca to the west, the Washington mainland to the east, the Canadian Gulf Islands to the north, and Port Townsend to the south. The study included only the southernmost Strait of Georgia and not Puget Sound itself. Within each region, MESA researchers used a variety of census techniques, including population counts from more than 100 shore-based sites, transect counts from ferries and small boats, breeding island counts, and aerial surveys. The study focused on a large variety of habitats, including bays and harbors, open shorelines, small islands and rocks, and open water, and included more than 7000 counts during all months over the two-year period.

The most comprehensive work on Salish Sea populations of marine birds in the non-breeding season since the MESA study has been the aerial surveys conducted from 1992 to 1999 as part of the Puget Sound Ambient Monitoring Program (PSAMP; Nysewander *et al.* 2005; Table 1). The PSAMP study is particularly important because it evaluated long-term abundance changes by repeating surveys of 54 aerial transects conducted during the MESA project (Fig. 1). Results of this analysis showed significant declines in 13 of the 20 species or groups of species studied, including declines for at least one species from all northwestern Washington marine bird families (Nysewander *et al.* 2005). For some species, such as Western Grebe *Aechmophorus occidentalis,* reported declines were as high as 95%. Reports of such large declines sparked concern for resident and nonresident marine bird populations. However, the PSAMP/MESA comparison has several potential drawbacks, including the fact that transects were flown only on one day during the winter, and aerial transects along coastal regions were limited to straight coastline, which overlooks much of the Salish Sea's complex topography. In addition, PSAMP researchers used a louder airplane than the MESA researchers did, thus possibly overestimating declines as a result of more birds diving or flying upon hearing the airplane's approach. Reliance on aerial surveys made it difficult to identify some birds (e.g. loons, cormorants and scoters) to the species level, forcing researchers to report results for taxonomic groups higher than species. Finally, aerial transects were a minor part of the MESA study, with only 2.4 flights made per transect, thus limiting the baseline data that could be used in the subsequent comparisons with PSAMP data.

To further test the results of the PSAMP/MESA comparison study (Nysewander *et al.* 2005) and to extend the time frame, I initiated a study—hereafter called the Western Washington University (WWU) or WWU/MESA comparison—replicating as closely as possible the substantial MESA data sets based upon shoreline and ferry counts (Bower 2003; Table 1). Participants focused on these aspects of the MESA study because they represented the bulk of the MESA dataset and thus facilitate a more robust comparison with historical information than does one relying solely upon aerial transect data (as for PSAMP and MESA). The shoreline and ferry counts were the largest and most reliable MESA data sets (T. Wahl pers. comm.) and could also be replicated with relatively little expense. The shoreline and ferry counts also permitted a high degree of geographic resolution for assessing changes in particular bays and regions (see, for example, Anderson *et al.* 2009 for use of the WWU/MESA comparison to detect trends in Padilla Bay, Washington). The present study, which relied on fieldwork by teams of trained WWU graduate and undergraduate students as well as on expert individual census work, was conducted monthly from September to May, in 2003/04 and again in 2004/05.

Here, I examine the PSAMP/MESA comparison results (Nysewander *et al.* 2005) in light of two additional sources of data:

- the WWU surveys, and
- Christmas Bird Counts from 11 sites within the Salish Sea.

Comparisons between these studies, which employed various methods, are used to evaluate the robustness of earlier reports about historical changes in Salish Sea marine bird abundance during fall, winter and spring, and to extend such comparisons over a longer time frame and broader spatial scale.

METHODS

To assess changes in Salish Sea marine bird abundance since the 1970s, I collated the published results of the PSAMP/MESA comparison (see Nysewander *et al.* 2005 for methods), results from our WWU/MESA comparison, and comparisons of recent and historical CBCs at 11 locations in the Salish Sea (Table 1). PSAMP data were obtained from Table 9 of Nysewander *et al.* (2005). WWU census work commenced in September 2003 after an eight-month training period and continued through May 2005, with the exception of June, July and August of 2004. We conducted shore-based point counts from 111 MESA census sites on 37 bodies of water (Fig. 2). We also conducted counts along 25 transects of varying length

TABLE 1
Comparison of methods and geographic areas covered in Marine Ecosystems Analysis (MESA) Puget Sound Project, Puget Sound Ambient Monitoring Program (PSAMP) study, Western Washington University (WWU) study, and Christmas Bird Count (CBC) studies of Salish Sea marine birds

Study	Geographic area	Methods	Data collection dates
MESA	Admiralty Inlet (S), Tsawwassen–Schwartz Bay BC Ferry (N), Neah Bay (W), and WA mainland (E)	Shore-based point counts, ferry and small boat transects, aerial transects	Jan 1978–Dec 1979
PSAMP	Straight coastline between Admiralty Inlet (S), Strait of Georgia (N), Neah Bay (W), and WA mainland (E)	Aerial transects compared with 1970s MESA aerial transects	Winter 1992–1999
WWU	Admiralty Inlet (S), Tsawwassen–Schwartz Bay BC Ferry (N), San Juan Islands (W), WA mainland (E)	Shore-based point counts and ferry transects compared with1970s MESA shore-based point counts and ferry transects	Sep–May 2003/04 and 2004/05
CBC	Salish Sea, including 8 BC and 3 WA CBCs	Standard CBC methods for 11 Salish Sea CBCs, data from 1975–1984 compared with data from 1998–2007	1975–1984 and 1998–2007

[mean ± standard deviation (SD) = 4.84 ± 3.44 km] on three ferry routes (Keystone–Port Townsend; Washington State ferries between Anacortes, Washington, Sidney, British Columbia, and the San Juan Islands; and BC ferries between Tsawwassen and Sidney). Ferry transects were chosen by MESA researchers with start and stop points corresponding to major geographic features (e.g. end of an island) or to changes in the body of water (e.g. mouth of a harbor). We used a paired design in which WWU censused the 37 bodies of water and 25 ferry transects on dates chosen to be within 10 calendar days of MESA census dates for the same locations. Total WWU effort included 1584 point counts and 211 ferry transects.

Shore-based point count and ferry census protocols were developed in consultation with historical observers to match MESA protocols as closely as possible (T. Wahl pers. comm.). Shore-based point counts were conducted using Eagle Optics Ranger 10×40 binoculars and 20-40× scopes (Eagle Optics, Middleton, WV, USA), with no time limit or distance restrictions; counts continued until all birds in the count area were censused. Maximum distances were typically about 1000 m, depending on the elevation of the observers. Birds were identified to species whenever possible.

Our one deviation from MESA protocol was that, although MESA typically relied on one observer, the WWU group typically used teams of four students, including two experienced students (or one student and JB) who were responsible for conducting the counts (see training details below) and two student interns who were learning identification and census protocol, but who were not responsible for actual counts. Because we were particularly interested in reliable detection of declines of marine bird species, we used two observers to err on the side of overcounting in contrast to the counts made by single observers in the MESA study. Ferry transect counts were also conducted according to the MESA protocol. Two experienced students (or one student and JB) used Eagle Optics Ranger 10×40 binoculars to identify and count birds from the bow of the ferry along the same transects used by MESA researchers, with no restrictions on distance from the boat (birds further out than about 300 m were not visible).

Before participation in census work, WWU students followed a rigorous training program, including instruction in identification and census protocol, computer-based identification quizzes and participation in field identification exercises. Students began participating in census counts when they were able consistently to score 95% or above on identification quizzes and had passed a final field evaluation of their identification skills. Most students who were responsible for counts entered the census program with previous bird identification experience. Students who started without prior skills received at least 20 weeks of training before participating in the counts.

A paired design was used to compare WWU census results with MESA census results occurring within 10 calendar days of each WWU census effort. For each species and each location (body of water or ferry transect), we calculated the mean count over the two-year period for both the WWU study (2003–2005) and matching MESA (1978–1979) censuses. To test for changes in marine bird abundance over time, Wilcoxon signed-rank tests (Lowry 2009) were conducted on differences in mean abundances between recent (WWU) and historical counts (MESA) for each paired body of water (n = 37) or ferry transect (n = 25). Thus, significant results meant that the changes in abundance of a species were consistent across the 62 bodies of water and ferry transects sampled. Feeding guilds were determined by inspection of feeding data from species accounts in the Birds of North America and other published sources.

I used estimated changes in winter marine bird abundance of 37 species based on CBCs (http://www.audubon.org/Bird/cbc/) from 11 locations in the Salish Sea that have been consistently reported since the 1970s: Anacortes–Sidney Ferry (started 1972),

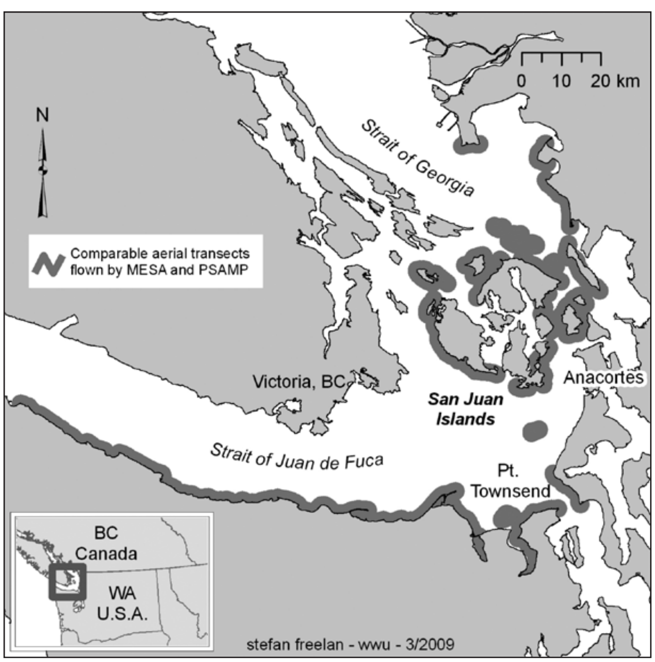

Fig. 1. Map of coastline censused during Marine Ecosystems Analysis (MESA) and Puget Sound Ambient Monitoring Program (PSAMP) aerial survey work. Gray lines show aerial transects. Modified from Nysewander *et al.* (2005).

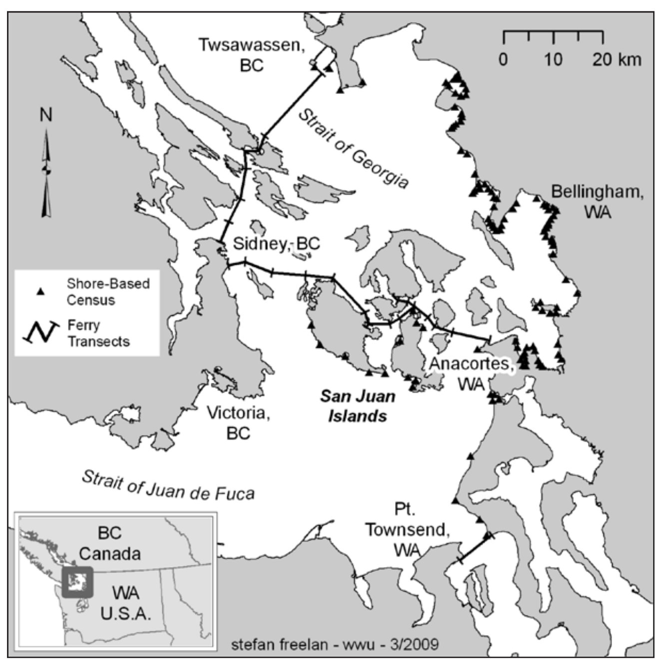

Fig. 2. Shore-based point-count locations (filled triangles, n = 111) and ferry transects (line segments, n = 25) censused by the Western Washington University (WWU) survey for comparison with the historic Marine Ecosystems Analysis (MESA) surveys.

Bellingham (1967), Campbell River (1972), Comox (1961), Deep Bay (1975), Kitsap County (1974), Ladner (1957), Nanaimo (1972), Vancouver (1958), Victoria (1958) and White Rock (1971). Three CBCs were excluded from the analysis because major changes in protocol occurred over the study period, including inconsistent use of boats (Seattle and Tacoma) and a move of the count center by eight kilometres (Everett). Changes in marine bird abundance were calculated for each CBC by comparing the mean number of birds per party–hour between 1998 and 2007, with the mean number of birds per party–hour between 1975 and 1984. This comparison was used because it was closest to the methods used in the PSAMP/MESA and WWU/MESA comparison studies. Three CBCs were missing one year of data (Anacortes–Sidney Ferry, 1984; Kitsap County, 1998; and Comox, 2007). For these three CBCs, data from the closest year not already being used was substituted for the missing years (1985, 1996, and 1997 respectively). Wilcoxon signed-rank tests (Lowry 2009) were used to test CBC data for the consistency of abundance changes across the 11 CBCs.

To test for the consistency with which the various studies identified abundance changes in particular species, I conducted Spearman rank correlations (Lowry 2009) of the ranking of species' abundance changes, from greatest declines to greatest increases, across the three studies being compared: PSAMP/MESA, WWU/MESA and 11 Salish Sea CBCs. I used a Bonferroni correction to adjust the significant P value for three pair-wise comparisons (adjusted $\alpha = 0.05/3$).

RESULTS

Results of the WWU/MESA comparison showed a significant decrease of 28.9% in the total number of birds observed at 62 bodies of water and ferry transects between 1978/79 and 2003–2005 (Wilcoxon signed-rank test: $Z = -2.82$; n = 62; $P = 0.005$; Table 2). Of the 37 most common overwintering Salish Sea species, 14 showed significant decreases, including decreases of more than 50% for 11 species (mean decline ± SD: 67.1% ± 18.9%), and six species showed significant increases (Table 2). The largest declines were spread across taxonomic groups, including Common Murre *Uria aalge* (–92.4%; Wilcoxon signed-rank test: $Z = -2.82$; n = 62; $P = 0.005$), Western Grebe (–81.3%; $Z = -4.91$; n = 56; $P < 0.001$), Red-Throated Loon *Gavia stellata* (–73.9%; $Z = -4.77$; n = 44; $P < 0.001$) and Bonaparte's Gull *Larus philadelphia* (–72.3%; $Z = -4.10$; n = 61; $P < 0.001$).

Four of the five feeding guilds included species showing significant decreases (Table 2), including benthic feeders (three of nine species decreasing), omnivores (three of four), piscivores (six of 14) and planktivores (two of two). There were no significant declines amongst herbivores. Two feeding guilds included species showing significant increases: herbivores (one of six) and piscivores (four of 16).

CBC data showed seven species with significant declines, including Western Grebe (–85.9%; Wilcoxon signed-rank test: $Z = 2.20$; n = 11; $P = 0.03$), Common Murre (–83.7%; $Z = 2.11$; n = 11; $P = 0.04$), Marbled Murrelet (–68.5%; $Z = -2.38$; n = 11; $P = 0.02$) and all scaup (primarily Greater Scaup *Aythya marila*; -50.8; $Z = 2.38$, n = 11, $P = 0.02$; Table 3). Three species showed significant increases (Table 3).

Declines in the WWU/MESA comparison and CBC dataset were compared with those documented in the PSAMP/MESA comparison for species or species groups for which PSAMP/MESA data were available (Table 4). For these species or species groups, the PSAMP/MESA comparison showed more species with significant declines (14 of 17) than did either the WWU/MESA comparison (six of 17) or the CBC study (three of 17).

In each of the three comparisons, several species were showing significant increases as well. Although the PSAMP/MESA comparison revealed only one of 17 species or species groups with a significant increase, the WWU/MESA and CBC results for the same species respectively included four of 17 and two of 17 species with significant increases (Table 4). Considering all species in the latest studies, significant increases were revealed for six of 37 species in the WWU/MESA comparison (Table 2) and three of 37 species in the CBC analysis (Table 3). No species showed significant increases in all three comparisons. The number of species declining exceeded the number of species increasing by at least a factor of two in all three comparisons.

Spearman rank correlation tests showed congruence among the three comparisons (PSAMP/MESA, WWU/MESA and CBC) in the ordering of species from those showing the most declines to those showing the greatest increases. A significant correlation was observed between the ordering of species and species groups from those showing the greatest declines to those showing the greatest increases for the PSAMP/MESA comparison and the WWU/MESA comparison ($r_s = 0.76$, $t = 4.48$, n = 17, $P < 0.001$).

DISCUSSION

The PSAMP/MESA, WWU/MESA and CBC studies all showed declines in the abundance of a number of overwintering marine bird species between 1978/79 and the 1990s (PSAMP) and 2003–2005 (WWU). These results, coupled with the earlier PSAMP/MESA comparison, demonstrate important and widespread changes in the abundance of marine birds during the non-breeding season over the last 30 years in the Salish Sea. It is important to note that data from the 1970s is used here as a baseline only because that period is when the first reliable abundance data were collected. We do not know, aside from anecdotal information, how much Salish Sea marine bird populations have changed since the beginning of Euro-American/Canadian colonization of the Salish Sea coast. However, given the early transformations of the landscape, particularly in estuarine and riparian areas associated with the Fraser, Nooksack, Skagit and other major rivers, it is likely that marine bird numbers were higher before the 1970s.

The correlation of the ordered magnitudes of abundance changes (from greatest decline to greatest increase—PSAMP/MESA and WWU/MESA) provides evidence that the two independent comparisons correctly identified species that have undergone the greatest abundance changes. Similarly, all seven species showing significant declines in the CBC study showed significant declines in the WWU/MESA comparison as well. Species showing significant declines in all three comparisons included Western Grebe, all scaup and Marbled Murrelet.

Differences in the rates of change in abundance between the PSAMP/MESA, WWU/MESA and CBC comparisons could have been caused by several factors. It is also conceivable that the populations of birds may have increased overall since the PSAMP surveys were conducted. The PSAMP survey's use of a louder airplane (to meet safety regulations) than that used in the MESA

TABLE 2
Mean abundances [± standard error (SE)] and percentage change between Marine Ecosystems Analysis (MESA) Puget Sound Project surveys (1978–1980) and Western Washington University (WWU) surveys (2003–2005)[a] for 37 common overwintering Salish Sea species

Species	Feeding guild	MESA surveys (1978–1980)	WWU surveys (2003–2005)	Change (%)
All birds	—	1235.2±357.0	878.0±272.8	–28.9[b]
Red-throated Loon *Gavia stellata*	Piscivore	2.4±0.7	0.6±0.3	–73.9[b]
Pacific Loon *Gavia pacifica*	Piscivore	16.3±8.8	8.7±2.6	–47
Common Loon *Gavia immer*	Piscivore	2.7±0.8	4.0±1.0	+48.8[b]
Red-necked Grebe *Podiceps grisegena*	Piscivore	4.0±0.9	2.2±0.5	–45.9[b]
Horned Grebe *Podiceps auritus*	Piscivore	9.7±2.1	2.8±0.7	–71.6[b]
Western Grebe *Aechmophorus occidentalis*	Piscivore	97.3±40.5	18.2±8.3	–81.3[b]
Double-crested Cormorant *Phalacrocorax auritus*	Piscivore	7.8±2.5	15.4±4.7	+97.7[b]
Pelagic Cormorant *Phalacrocorax pelagicus*	Piscivore	2.2±0.5	4.2±0.7	+87.7[b]
Brandt's Cormorant *Phalacrocorax penicillatus*	Piscivore	14.4±11.6	1.5±0.5	–89.6
Great Blue Heron *Ardea herodias*		3.1±1.1	4.7±1.6	50.7
Canada Goose *Branta canadensis*	Herbivore	0.0±0.0	3.8±1.2	+10 801.9[b]
Brant *Branta bernicla*	Herbivore	148.6±97.2	39.9±16.7	–73.2
Mallard *Anas platyrhynchos*	Herbivore	21.2±9.1	10.2±3.9	–52.1
Northern Pintail *Anas acuta*	Herbivore	41.4±18.3	81.8±44.7	97.7
American Widgeon *Anas americana*	Herbivore	86.9±39.9	115.0±69.6	32.3
Green-winged Teal *Anas crecca*	Herbivore	7.0±3.7	5.5±2.9	–21.6
Canvasback *Aythya valisineria*	Omnivore	2.2±1.4	0.0±0.0	–98.4[b]
All scaup *Aythya* spp.	Omnivore	121.3±45.8	42.7±19.2	–64.8[b]
Harlequin Duck *Histrionicus histrionicus*	Benthivore	1.3±0.4	1.6±0.4	19.8
Long-tailed Duck *Clangula hyemalis*	Benthivore	3.2±0.8	1.8±0.4	–44
Surf Scoter *Melanitta perspicillata*	Benthivore	141.2±54.9	56.8±16.6	–59.8
Black Scoter *Melanitta nigra*	Benthivore	1.8±0.7	0.6±0.3	–65.7[b]
White-winged Scoter *Melanitta fusca*	Benthivore	13.8±4.8	19.5±8.7	41.3
Common Goldeneye *Bucephala clangula*	Benthivore	6.7±1.9	3.5±1.0	–47.8[b]
Barrow's Goldeneye *Bucephala islandica*	Benthivore	1.2±0.8	0.9±0.4	–23.1
Bufflehead *Bucephala albeola*	Benthivore	41.4±12.0	36.9±11.7	–10.8
Common Merganser *Mergus merganser*	Piscivore	1.0±0.6	1.8±0.9	80.7
Red-breasted Merganser *Mergus serrator*	Piscivore	5.5±1.3	5.2±1.3	–6.6
Ruddy Duck *Oxyura jamaicensis*	Benthivore	16.8±11.2	6.8±6.4	–59.7[b]
Bald Eagle *Haliaeetus leucocephalus*		0.4±0.1	1.1±0.3	+187.0[b]
Bonaparte's Gull *Larus philadelphia*	Planktivore	32.0±10.5	8.9±3.2	–72.3[b]
Mew Gull *Larus canus*	Omnivore	28.7±8.5	20.2±5.8	–29.5
Glaucous-winged Gull *Larus glaucescens*	Omnivore	59.2±11.0	44.6±12.4	–24.8[b]
Common Murre *Uria aalge*	Piscivore	22.6±6.9	1.7±0.7	–92.4[b]
Pigeon Guillemot *Cepphus columba*	Piscivore	2.3±0.4	4.9±1.3	+108.9[b]
Ancient Murrelet *Synthliboramphus antiquus*	Planktivore	0.6±0.3	0.2±0.1	–69.1[b]
Marbled Murrelet *Brachyramphus marmoratus*	Piscivore	2.6±0.7	0.8±0.3	–71.0[b]

[a] MESA data paired with WWU censuses by date (see the "Methods" subsection for details). Shown are the abundances of birds from 37 bodies of water or 25 ferry transects (Fig. 2). Wilcoxon signed-rank tests were used to test for abundance changes across the 62 locations.
[b] Statistically significant ($P < 0.05$).

TABLE 3
Birds per party–hour [mean ± standard error (SE)] and percentage change between 1975–1984 and 1998–2007 for 11 Salish Sea Christmas Bird Counts (CBCs) of 37 common overwintering Salish Sea species

Species	Birds per CBC per year		Change (%)
	(1976–1985)	(1998–2007)	
All birds	278.6±74.2	209.0±38.2	–25
Red-throated Loon *Gavia stellata*	0.48±0.27	0.16±0.5	–66.5
Pacific Loon *Gavia pacifica*	4.66±3.08	2.33±1.01	–50
Common Loon *Gavia immer*	0.74±0.19	0.84±0.26	12.6
Red-necked Grebe *Podiceps grisegena*	1.24±0.78	0.81±0.31	–34.6
Horned Grebe *Podiceps auritus*	1.71±0.43	1.20±0.45	–29.9
Western Grebe *Aechmophorus occidentalis*	27.70±11.5	3.9±2.59	–85.9[a]
Double-crested Cormorant *Phalacrocorax auritus*	1.64±0.54	4.46±2.36	+171.1[a]
Pelagic Cormorant *Phalacrocorax pelagicus*	1.71±0.63	1.77±0.64	3.3
Brandt's Cormorant *Phalacrocorax penicillatus*	7.03±6.65	4.00±3.50	–43.1
Great Blue Heron *Ardea herodias*	0.71±0.16	0.60±0.08	–16.4
Canada Goose *Branta canadensis*	1.85±0.69	3.96±0.65	+114.4[a]
Brant *Branta bernicla*	0.08±0.04	0.88±0.47	+1027.3[a]
Mallard *Anas platyrhynchos*	20.90±8.25	25.82±7.65	23.6
Northern Pintail *Anas acuta*	18.85±11.93	15.13±8.93	–19.7
American Widgeon *Anas americana*	32.11±14.89	36.89±13.67	14.9
Green-winged Teal *Anas crecca*	3.76±1.85	4.02±1.51	7
Canvasback *Aythya valisineria*	0.24±0.1	0.09±0.03	–63.3[a]
All scaup *Aythya* spp.	10.41±2.4	5.12±1.71	–50.8[a]
Harlequin Duck *Histrionicus histrionicus*	1.61±0.79	1.73±1.00	7.3
Long-tailed Duck *Clangula hyemalis*	1.25±0.5	1.87±1.08	49
Surf Scoter *Melanitta perspicillata*	9.87±2.27	11.5±3.37	16.5
Black Scoter *Melanitta nigra*	2.97±1.24	1.57±0.78	–47.0[a]
White-winged Scoter *Melanitta fusca*	8.09±3.55	6.46±2.70	–20.1
Common Goldeneye *Bucephala clangula*	3.61±0.83	3.44±1.30	–4.9
Barrow's Goldeneye *Bucephala islandica*	1.54±0.74	1.64±0.62	6.2
Bufflehead *Bucephala albeola*	4.70±0.82	4.92±1.06	4.5
Common Merganser *Mergus merganser*	2.59±1.21	1.52±0.32	–41.5
Red-breasted Merganser *Mergus serrator*	1.96±0.90	1.60±0.41	–18.6
Ruddy Duck *Oxyura jamaicensis*	1.84±1.49	0.25±0.13	–86.5
Bald Eagle *Haliaeetus leucocephalus*	1.00±0.45	1.28±0.28	27.7
Bonaparte's Gull *Larus philadelphia*	1.81±1.37	0.19±0.11	–89.5
Mew Gull *Larus canus*	11.01±3.51	11.08±5.63	0.6
Glaucous-winged Gull *Larus glaucescens*	43.17±11.06	27.18±7.26	–37.0[a]
Common Murre *Uria aalge*	21.61±17.33	3.51±2.14	–83.7[a]
Pigeon Guillemot *Cepphus columba*	0.93±0.82	1.07±0.91	14.5
Ancient Murrelet *Synthliboramphus antiquus*	0.65±0.52	0.62±0.50	–4.7
Marbled Murrelet *Brachyramphus marmoratus*	1.02±0.82	0.32±0.24	–68.5[a]

[a] Statistically significant ($P < 0.05$).

surveys may have led to more birds diving and avoiding detection by PSAMP researchers (Nysewander *et al.* 2005). Furthermore, although the geographic areas covered by the three studies had some overlap, there were also important geographic differences. Although the WWU/MESA comparison included much of the shoreline between Whidbey Island, Washington, and Tsawwassen, as well as San Juan and Lopez islands, no work was done in the Strait of Juan de Fuca and north of Tsawwassen (Fig. 2). The PSAMP and MESA aerial flights extended out to the shoreline of the Strait of Juan de Fuca (Fig. 1), but more than half the CBC counts were from British Columbia locations not covered by the other studies (Fig. 3). Finally, there were differences in the habitats censused in the various studies, with the PSAMP and MESA aerial flights being restricted to straight coastline and thus excluding the small bays counted in the WWU/MESA study and the CBCs. These differences in methodology, geographic coverage and habitats assessed in the various studies underscore the importance of consistent species declines documented in these studies.

The PSAMP/MESA comparison and the WWU/MESA comparison both showed declines across the feeding guilds. Although piscivores accounted for most of the declines, all the major feeding guilds represented in the winter marine bird assemblage included some declining species. In each guild except planktivores, there were also species that increased over the same period. These findings point to the likelihood that many factors beyond changes in the abundance

TABLE 4
Comparison of percentage changes detected by various studies[a] in non-breeding-season marine bird abundance (Sep–May) for 17 species or species groups reported in the Puget Sound Ambient Monitoring Program (PSAMP)/Marine Ecosystems Analysis (MESA) study

Species	MESA/ PSAMP	WWU/ MESA	Historic/ recent CBCs	Other studies
Common Loon *Gavia immer*	–64[b]	+49[b]	13	–7[c]
All loons	–79[b]	–33	–47	
Red-necked Grebe *Podiceps grisegena*	–89[b]	–46[b]	–35	+3[c]
Horned Grebe *Podiceps auritus*	–82[b]	–72[b]	–30	–2[c]
Western Grebe *Aechmophorus occidentalis*	–95[b]	–81[b]	–86b	Widespread declines in AB (ASRDACA 2006)
Double-crested Cormorant *Phalacrocorax auritus*	–62[b]	+98[b]	+171b	Increases across North America (Wires & Cuthbert 2006)
All cormorants	–53[b]	–8.3[b]	–25	
Great Blue Heron *Ardea herodias*	–19	51	–16	
Brant *Branta bernicla*	–66[b]	–73	+1027b	Pacific population declines since 1961 (Sedinger *et al.*1994, Ward *et al.* 2005)
All scaup	–72[b]	–65[b]	–51b	Declines in North America (Austin *et al.* 2000)
Harlequin Duck *Histrionicus histrionicus*	+189[b]	20	7	Probably stable in NW (Goudie *et al.* 1994)
Long-tailed Duck *Clangula hyemalis*	–91[b]	–44	49	–5.5% in western AK (USFWS 1999)
All scoters	–57[b]	–33[b]	–8	Possible declines, all species (Savard *et al.* 1998)
Bufflehead *Bucephala albeola*	20	–11	5	Stable in AK (USFWS 1999)
Bald Eagle *Haliaeetus leucocephalus*	35	+187[b]	28	Increases in North America since 1970s (Wires & Cuthbert 2006)
Pigeon Guillemot *Cepphus columba*	–55[b]	+109[b]	15	
Marbled Murrelet *Brachyramphus marmoratus*	–96[b]	–71[b]	–69b	Widespread declines in WA, OR, and CA (e.g. Piatt & Naslund 1995, Piatt *et al.* 2007a)

[a] PSAMP/MESA data from Nysewander *et al.* (2005), WWU/MESA results drawn from Table 2, and Christmas Bird Count (CBC) results drawn from Table 3.
[b] Statistically significant ($P < 0.05$).
[c] Western Breeding Bird Survey region, 1966–1998 (Sauer *et al.* 2008).

of various types of prey produced the decreases and increases of Salish Sea marine bird abundance.

Detailed examination of the causes of changing species abundances is beyond the scope of the present study, but inclusion of three examples of how such studies may be useful in better understanding changes in Salish Sea marine bird abundance is instructive. Scoters showed significant declines in both the PSAMP/MESA (–57%) and WWU/MESA (–33%) comparisons. In the WWU/MESA comparison, Surf Scoters *Melanitta perspicillata* declined by 60%. However, much of the decline in Surf Scoters in the WWU/MESA comparison resulted from greatly decreased numbers of Surf Scoters congregating at the collapsed Cherry Point herring spawn event (Stout *et al.* 2001). On 30 April 1978, MESA researchers counted 40 100 Surf Scoters at Cherry Point. In 2004 and 2005, counts from the Cherry Point area at the end of April were less than a thousand. When data from the spring Cherry Point spawn event is removed from the WWU/MESA dataset, the census-wide decline in Surf Scoters is halved. In that case, the temporal and geographic resolution of the WWU/MESA comparison offers evidence that much of the apparent decline in Surf Scoters is tied to the collapse of the herring spawn in the Cherry Point area.

Like Surf Scoters, Brant *Branta bernicla* showed abundance changes that varied widely over the study area. Brant showed declines in the PSAMP/MESA (–66%) and WWU/MESU (–73.2%) comparisons, but increased by more than 10 000% in CBC data. The large decline in the WWU/MESA comparison was largely driven by a decrease from 7851 birds per census to 1087 birds per census (–86.2%) in the primary Salish Sea wintering grounds for Brant: Padilla Bay and Samish Bay. Outside those two locations, the summed number of birds per census for the 21 other bodies of water and ferry transects in which Brant were counted showed a 1.9% increase (1362 birds per census in 1978/79 to 1388 birds per census in 2003–2005), indicating that Brant numbers were stable outside their historical primary wintering grounds. CBC data showed increases in Brant in most count locations, including an increase in the Ladner, British Columbia, CBC from 0.1 birds per party–hour (10.4 birds per CBC) in the 1975–1984 time period to 3.9 birds per party–hour (833.7 birds per CBC) in 1998–2007. Overall, these data probably indicate a decline in Salish Sea Brant numbers, but may also reflect a change in the wintering location of Brant.

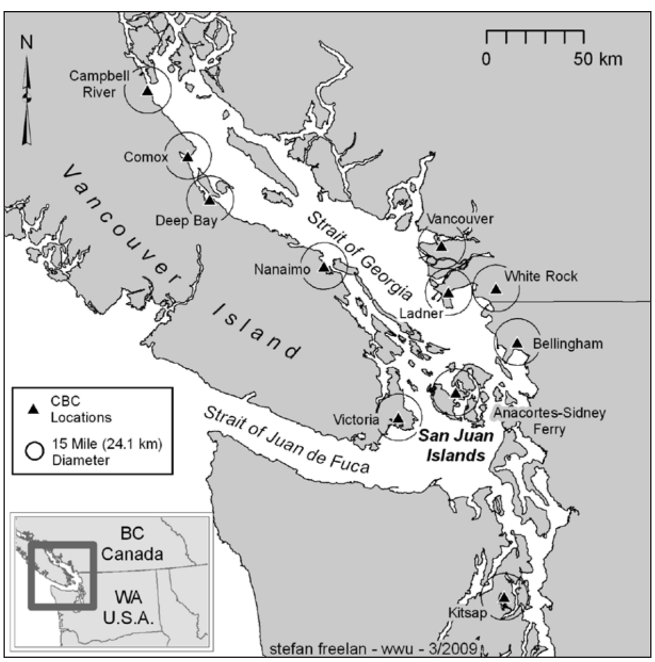

Fig. 3. Locations of 11 Christmas Bird Count (CBC) sites used for comparisons of recent and historical information.

Western Grebes showed a markedly different pattern from Surf Scoters or Brant, declining in all three studies across many Salish Sea locations and in every month of the WWU/MESA surveys. Although the role of Salish Sea environmental degradation in Western Grebe declines is not known, Western Grebes wintering in industrial areas have been shown to contain high levels of industrial contaminants that approach levels needed to disrupt endocrine function in other birds (Henny *et al.* 1990). Western Grebes have also been killed in large and small west coast oil spills, including spills in the Puget Sound area (Speich & Thompson 1987). It is likely, though, that degradation of lakes through wetland draining, pollution and human disturbance (especially motorboat use) in western provinces and states, where Western Grebe breeding colonies are located, has played an important role in reducing Western Grebe reproductive success, resulting in reduced numbers of breeding grebes on many lakes (ASRDACA 2006). For instance, ASRDACA (2006) found that Western Grebe populations have declined rapidly in almost every northeastern and central Alberta lake where they were censused, with at least six lakes having lost entire breeding colonies since the 1970s. The reported declines at breeding colonies are consistent with the declines seen across the Salish Sea wintering grounds. This example demonstrates that focused efforts will be required to attribute relative effects of environmental degradation on breeding grounds and of degradation of the Salish Sea marine ecosystem on the populations of species showing widespread non-breeding-season declines in the Salish Sea.

Stabilization and recovery of marine bird populations wintering in the Salish Sea will likely require restoration of degraded local landscapes, protection and restoration of the diverse breeding sites these birds use, research into the environmental factors affecting bird numbers today and continued monitoring to track future changes in marine bird abundance. Low-cost monitoring, such as the WWU/MESA comparison, and citizen-science efforts such as the BC Coastal Waterbird Survey (1999–present; Bird Studies Canada 2005) and Seattle Audubon Society's new Puget Sound Seabird Survey (Seattle Audubon Society 2008), will be valuable in future for determining how changes in the Salish Sea marine ecosystem are affecting the abundance of migratory and resident marine bird species.

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REFERENCES

ANDERSON, E.M., BOWER, J.L., NYSEWANDER, D.R., EVENSON, J.R. & LOVVORN, J.R. 2009. Changes in avifaunal abundance in a heavily-used wintering and migration site in Puget Sound, Washington during 1966–2007. *Marine Ornithology* 37: 19–27.

ASRDACA (ALBERTA SUSTAINABLE RESOURCE DEVELOPMENT AND ALBERTA CONSERVATION ASSOCIATION). 2006. Status of the Western Grebe (*Aechmophorus occidentalis*) in Alberta. Wildlife status report no. 60. Edmonton, AB: ASRDACA. 42 pp.

AUSTIN, J.E., AFTON, A.D., ANDERSON, M.G., CLARK, R.G., CUSTER, C.M., LAWRENCE, J.S., POLLARD, J.B. & RINGELMAN, J.K. 2000. Declining scaup populations: issues, hypotheses, and research needs. *Wildlife Society Bulletin* 28: 254–263.

BERTRAM, D.F., HARFENIST, A. & SMITH, B.D. 2005. Ocean climate and El Niño impacts on survival of Cassin's Aukets from upwelling and downwelling domains of British Columbia. *Canadian Journal of Fisheries and Aquatic Sciences* 62: 2841–2853.

BIRD STUDIES CANADA. 2005. Monitoring coastal bird populations in BC: the first five years of the coastal waterbird survey (1999–2004) [Unpublished report]. Delta, BC: Birds Studies Canada, BC Program. 36 pp.

BOERSMA, P.D., CLARK, J.A. & HILLGARTH, N. 2001. Seabird conservation. In: Schreiber, E.A. & Burger, J. (Eds). Biology of marine birds. Baton Rouge, FL: CRC Press. pp. 559–580.

BOWER, J.L. 2003. Assessing southern Strait of Georgia marine bird populations changes since 1980: what we know and what we need to know. In: Droscher, T. & Fraser, D.A. (Eds). 2003 Georgia Basin/Puget Sound research conference proceedings; March 31–April 3, 2003; Vancouver, British Columbia. Olympia, WA: State of Washington.

DICKSON, D.L. & GILCHRIST, H.G. 2002. Status of marine birds of the southeastern Beaufort Sea. *Arctic* 55: 46–58.

GOUDIE, R.I., KONDRATYEV, A.V., BRAULT, S., PETERSEN, M.R., CONANT, B. & VERMEER, K. 1994. The status of sea ducks in the North Pacific Rim: toward their conservation and management. *Transactions of the North American Wildlife and Natural Resource Conference* 59: 27–49.

HENNY, C.J., BLUS, L.J. & GROVE, R.A. 1990. Western Grebe, *Aechmophorus occidentalis,* wintering biology and contaminant accumulation in Commencement Bay, Puget Sound, Washington. *Canadian Field-Naturalist* 104: 460–472.

JEWITT, S.G., TAYLOR, W.P., SHAW, W.T. & ALDRICH, J.W. 1953. Birds of Washington State. Seattle, WA: University of Washington Press. 767 pp.

LEE, D.E., NUR, N. & SYDEMAN, W. 2007. Climate and demography of the planktivorous Cassin's Auklet *Ptychoramphus aleuticus* off northern California: implications for population change. *Journal of Animal Ecology* 76: 337–347.

LOWRY, R. 2009. Vassar stats: web site for statistical computation {Web resource]. Poughkeepsie, NY: Vassar College. [Available at: http://faculty.vassar.edu/lowry/VassarStats.html; accessed 14 March 2009]

NYSEWANDER, D.R., EVENSON, J.R., MURPHIE, B.L. & CYRA, T.A. 2005. Report of marine bird and marine mammal component, Puget Sound Ambient Monitoring Program, for July 1992 to December 1999 period. Olympia, WA: Washington Department of Fish and Wildlife. 181 pp.

PIATT, J.F. & NASLUND, N.L. 1995. Abundance, distribution and population status of Marbled Murrelets in Alaska. In: Ralph, C.J., Hunt, G.L. Jr, Raphael, M. & Piatt, J.F. (Eds). Ecology and conservation of the Marbled Murrelet. General Technical Report PSW-GTR-152. Albany, CA: Pacific Southwest Research Station, Forest Service, US Department of Agriculture. pp. 285–294.

PIATT, J.F., KULETZ, K.J., BURGER, A.E., HATCH, S.A., FRIESEN, V.L., BIRT, T.P., ARIMITSU, M.L., DREW, G.S., HARDING, A.M.A. & BIXLER, K.S. 2007a. Status review of the Marbled Murrelet (*Brachyramphus marmoratus*) in Alaska and British Columbia. Open-File Report 2006-1387. Reston, VA: US Geological Survey. 258 pp.

PIATT, J.F., SYDEMAN, W.J. & WIESE, F. 2007b. Introduction: a modern role for seabirds as indicators. *Marine Ecology Progress Series* 352: 199–204.

SAUER, J.R., HINES, J.E. & FALLON, J. 2008. The North American breeding bird survey, results and analysis 1966–2007 [Web resource]. Version 5.15.2008. Laurel, MD: USGS Patuxent Wildlife Research Center. [Available at: http://www.mbr-pwrc.usgs.gov/bbs/trend/trend98.html; accessed 14 March 2009]

SAVARD, J.L., BORDAGE, D. & REED, A. 1998. Surf Scoter (Melanitta perspicillata). In: Poole, A. The Birds of North America. Ithaca, NY: Cornell Lab of Ornithology [Available at: http.//bna.birds.cornell.edu.bnaproxy.birds.cornell.edu/bna/species/363; accessed 14 March 2009]

SEATTLE AUDUBON SOCIETY (SAS). 2008. Puget Sound seabird survey [Web resource]. Seattle, WA: SAS. [Available online at: http://www.seattleaudubon.org/sas/WhatWeDo/Science/CitizenScience/PugetSoundSeabirdSurvey.aspx; accessed 14 March 2009]

SEDINGER, J.S., WARD, D.H., ANTHONY, R.M., DERKSEN, D.V., LENSINK, C.J., BOLLINGER, K.S. & DAWE, N.K. 1994. Management of Pacific Brant: population structure and conservation issues. *Transactions of the North American Wildlife and Natural Resource Conference* 59: 50–62.

SPEICH, S.M. & THOMPSON, S.P. 1987. Impacts on waterbirds from the 1984 Columbia River and Whidbey Island, Washington, oil spills. *Western Birds* 18:109–116.

STOUT, H.A., GUSTAFSON, R.G., LENARZ, W.H., MCCAIN, B.B., VANDOORMIK, D.M., BUILDER, T.L. & METHOT, R.D. 2001. Status review of Pacific Herring in Puget Sound, Washington. NOAA Technical Memorandum NMFS-NWFSC-45. Springfield, VA: US Department of Commerce. 175 pp.

USFWS (US FISH AND WILDLIFE SERVICE). 1999. Population status and trends of sea ducks in Alaska [Unpublished report]. Anchorage, AK: US Fish and Wildlife Service, Migratory Bird Management.

WAHL, T.R. 2002. Trends in numbers of marine birds wintering on Bellingham Bay. *Washington Birds* 8: 29–40.

WAHL, T.R., SPEICH, S.M., MANUWAL, D.A., HIRSCH, C.V. & MILLER, C. 1981. Marine bird populations of the Strait of Juan De Fuca, Strait of Georgia, and adjacent waters in 1978 and 1979. Washington, DC: Environmental Protection Agency. 384 pp.

WARD, D.H., REED, A., SEDINGER, J.S., BLACK, J.M., DERKSEN, D.V. & CASTELLI, P.M. 2005. North American Brant: effects of changes in habitat and climate on population dynamics. *Global Change Biology* 11: 869–880.

WIRES, R.W. & CUTHBERT, F.J. 2006. Historic populations of the Double-crested Cormorant (*Phalacrocorax auritus*): implications for conservation and management in the 21st century. *Waterbirds* 29: 9–37.