CHANGES IN AVIFAUNAL ABUNDANCE IN A HEAVILY USED WINTERING AND MIGRATION SITE IN PUGET SOUND, WASHINGTON, DURING 1966–2007

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SUMMARY

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A critical first step in guiding protection efforts for marine birds is comprehensive evaluation of monitoring results. In a preliminary study designed to facilitate such a synthesis in Puget Sound, Washington, we identified five survey programs that spanned large fractions of this region during 1966–2007. We focused this initial review on Padilla Bay, one of the sites most heavily used by wintering and migrating birds on the Pacific Coast. Comparison for September to mid-May of Marine Ecosystems Analysis and Western Washington University shore-based surveys, two survey programs that used highly comparable methods, suggests that the combined density of all marine birds in Padilla Bay declined between 1978/79 and 2003–2006. These overall declines occurred mainly during early winter (November) and especially during spring migration (mid-March to mid-May). During spring migration, species assemblages were highly dissimilar between 1978/79 and 2003–2006. Of 27 species and species groups we considered, six increased and 13 declined. These declines occurred across foraging guilds and were large for many formerly abundant species. For example, typical maximum densities declined by about 75% (400/km^2 to 100/km^2) for Brant *Branta bernicla,* 80% (75/km^2 to 15/km^2) for scaup (mainly Greater Scaup *Aythya marila*) and 98% (>50/km^2 to <1/km^2) for Western Grebes *Aechmophorus occidentalis.* Results of aerial surveys during 1992–2007 by the Washington Department of Fish and Wildlife were consistent with most of the identified changes. Causes of decline are unclear for most species, but appear to be widespread. Padilla Bay habitats and the many thousands of birds that depend on them face multiple threats.

Key words: Marine birds, Padilla Bay, Puget Sound, surveys

INTRODUCTION

Human impacts on marine habitats, including effects of fisheries, contaminants, climate change and physical processes such as dredging and dike-building, are widespread (Thrush *et al.* 1998, Kennish 2002, Islam & Tanaka 2004, Harley *et al.* 2006). Such impacts threaten diverse species of marine animals and plants (Kappel 2005), and declines in marine birds in particular have occurred across taxonomic groupings and life history guilds (e.g. Irons *et al.* 2000, Dickson & Gilchrist 2002, Frederiksen *et al.* 2004). By signaling declines in local populations and establishing priorities for targeted studies and remediation, monitoring programs for marine species form a critical foundation for protection efforts. However, detection of declines is hindered by the duration of most monitoring programs and by inconsistency of protocols among programs.

The Washington Department of Fish and Wildlife (WDFW) has conducted an annual aerial survey of marine birds throughout Puget Sound since 1992. This survey program provides a rigorous foundation for evaluating recent changes in the mid-winter (late December to early February) abundance of marine birds. However, identifying changes that preceded the early 1990s is difficult. The most commonly used baseline for evaluating trends in the marine birds of Puget Sound is the Marine Ecosystems Analysis (MESA) survey program conducted during 1978/79 (Wahl *et al.* 1981). Comparison of WDFW aerial surveys with MESA results (Nysewander *et al.* 2005) indicates declines in many common species between the periods 1978/79 and 1992–1999, including Western Grebes *Aechmophorus occidentalis* (–95%), Horned Grebes *Podiceps auritus* (–82%), Brant *Branta bernicla* (–66%), scaup *Aythya spp.* (–72%), scoters *Melanitta* spp. (–57%), Long-tailed Ducks *Clangula hyemalis* (–91%) and Marbled Murrelets *Brachyramphus marmoratus* (–96%). However, methods used in those two survey programs may not yield results that are directly comparable. In particular, detectability of many species likely differed, because MESA observations were conducted mainly from shore. Also, budget limitations and the scale of WDFW surveys preclude their replication in seasons other than mid-winter. Thus, MESA and WDFW may not reveal changes in the abundance of species that rely on Puget Sound mainly at other times of year, such as Brant that stage in Puget Sound during March and April (Moore *et al.* 2004).

A comprehensive evaluation of monitoring results is needed to guide protection efforts for marine birds in Puget Sound. To facilitate such a regional synthesis, we identified key survey programs that targeted multiple species over large fractions of Puget Sound, and we considered differences in protocol between programs that may limit comparisons. We confine this initial review of survey results to Padilla Bay, one of the sites most heavily used by wintering and migrating birds on the Pacific Coast. Based mainly on the results of two survey programs that used highly comparable protocols, we evaluate changes in density over time for relatively common taxa and changes in species assemblages.

STUDY AREA AND METHODS

Padilla Bay (48.5°N, 122.5°W) is located in northern Puget Sound, Washington (Fig. 1). The Padilla Bay National Estuarine Research Reserve was established in 1980 largely because of its perceived importance to marine birds. It was classified in the late 1970s as one of the most important and most vulnerable sites for marine birds in northern Puget Sound (Wahl *et al.* 1981). The National Oceanic and Atmospheric Administration and the Washington State Department of Ecology cooperatively manage the reserve, placing emphasis on research and education. Regulations have not been adopted to protect birds and their habitat in Padilla Bay, beyond applicable state and federal laws.

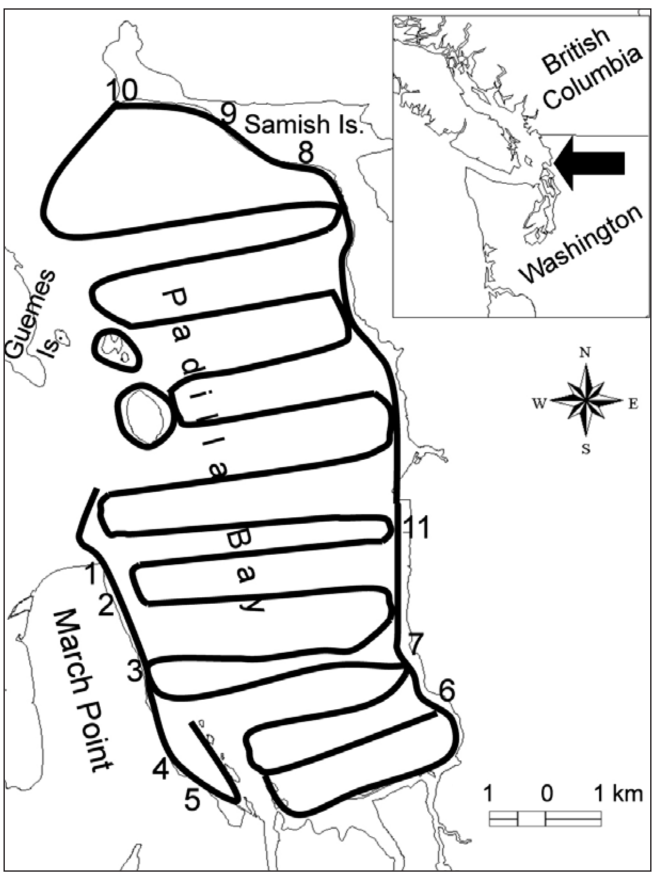

Fig. 1. Survey tracks and observation points for marine birds in Padilla Bay, Washington, including Marine Ecosystems Analysis Puget Sound Project and Western Washington University shore-based surveys (locations 1–11) and Washington Department of Fish and Wildlife aerial surveys (solid lines; transects shown for January 1997, but locations of transects varied among years). Details were not available for Washington Department of Game or US Fish and Wildlife Service aerial surveys of waterfowl (see "Study area" and "Methods" subsections).

Padilla Bay is mainly intertidal with mixed semidiurnal tides, and contains one of the largest contiguous eelgrass (*Zostera* spp.) beds on the Pacific Coast of North America (Bulthuis 1995). Eelgrass beds support diverse communities of fish and invertebrates, in many cases by providing resources critical to early life-history stages (Hemminga & Duarte 2000, Jackson *et al.* 2001). Thus, foods available in Padilla Bay support four main foraging guilds of marine birds:

- species that consume mainly eelgrass, including Brant and some dabbling ducks (Baldwin & Lovvorn 1994),
- ducks such as scaup and scoters that consume mainly invertebrates (Anderson *et al.* 2008),
- piscivorous species such as loons, grebes, cormorants and mergansers, and
- species of gulls, most of which are essentially omnivorous and opportunistic (e.g. Trapp 1979).

Scope of the present study

We identified five survey programs that documented bird abundance for multiple species, sites and years in Puget Sound. Only two of the five programs conducted counts during the breeding season (June–August), probably because abundance of most species of birds in Padilla Bay is greatest during the non-breeding season. We present results of surveys only for the non-breeding season. Survey programs did not distinguish among observations of birds on the water, on land or in flight. Thus, we restricted our focus to species that feed and rest mainly on the water, and we excluded species of shorebirds and waders that commonly feed on tidal flats—species not targeted in some survey programs. Below we briefly describe each of our main data sources.

Washington Department of Game surveys

The Washington Department of Game (WDG—now the WDFW) conducted aerial surveys of waterfowl in Padilla Bay and other sites in Puget Sound from 1953 until at least 1976. The only source we identified for WDG surveys was Jeffrey (1976), which did not include results from many early years of these surveys. Surveys of Brant were conducted irregularly in different months from October to April, with results available for 1970–1976 (48 surveys). The WDG conducted biweekly surveys of four species of dabbling ducks in Padilla Bay and other Puget Sound locations during fall and winter, with results for Padilla Bay available for 1966–1976 (71 surveys). We lack details of the methods used in surveys of Brant and dabbling ducks, including locations within Padilla Bay and the fraction of Padilla Bay surveyed. We assumed that the WDG surveys of Brant and dabbling ducks were conducted throughout the entire bay (about 72 km^2). We did not summarize results of the WDG surveys for diving ducks, because those surveys covered less than 10% of Padilla Bay and included shorelines rarely used by diving ducks (Jeffrey 1976).

US Fish and Wildlife Service surveys

The US Fish and Wildlife Service (USFWS) has conducted aerial surveys of marine birds in Grays Harbor and at 64 sites in Puget Sound. These surveys occurred irregularly in various months and years, with surveys conducted in Padilla Bay from October to March of 1977–1986 (22 surveys). These data were compiled by M.J. McMinn and W.H. Schaff of the Nisqually National Wildlife Refuge. We were unable to locate details of the methods used, and so as with WDG surveys of Brant and dabbling ducks (and consistent with Lovvorn & Baldwin 1996), we assumed that the entire bay was covered in each survey. These surveys focused mainly on waterfowl. Results for other taxa may be incomplete and are not considered here.

Marine Ecosystems Analysis Puget Sound Project surveys

MESA surveys were conducted one to three times per month from January 1978 to December 1979 in the Strait of Juan de Fuca and northern Puget Sound (Wahl *et al.* 1981). In Padilla Bay, census methods included shore-based, boat-based and aerial surveys. Boat-based and aerial surveys were conducted relatively infrequently, however, and included only small portions of Padilla Bay. We used shore-based surveys (n = 27) conducted from September through May, omitting additional MESA surveys from June through August. Observers conducted shore-based surveys from 11 designated points (Fig. 1) using binoculars and spotting scopes. Counts included birds on the water, on land near shorelines and in flight, although results did not distinguish among these three types of observations. Reference points were used to avoid sampling areas more than once. Each composite shore-based survey covered about 60% (43.1 km^2) of Padilla Bay.

Western Washington University surveys

To evaluate trends in abundance for marine birds in Puget Sound, one of us (JLB) replicated many of the MESA shore-based surveys in northern Puget Sound from September to mid-May during 2003–2006. Surveys were conducted by Western Washington University (WWU) students trained in methods the same as those used in MESA surveys. In Padilla Bay, the locations of 11 shoreline observation points were identical to MESA. However, some WWU surveys did not include all 11 observation points (eight of 21 surveys excluded one observation point and one survey excluded two observation points). To enable comparisons with complete surveys, we imputed missing observations using mean WWU results from the same stations and seasons. Specifically, we replaced each missing observation with the mean count for each species from surveys that were completed within ± 30 days (although possibly during different years) from the same observation point (two to five surveys were used to calculate each mean). For each observation point, counts for most species were similar across surveys conducted during comparable times of year, and all results were qualitatively robust to the multiple strategies we explored for handling missing observations. The frequency of surveys during September through May was lower for WWU (21 surveys over four winters) relative to MESA (27 surveys over three winters).

Washington Department of Fish and Wildlife

Since 1992, WDFW has conducted aerial surveys between December and February of all marine birds in Puget Sound (Nysewander *et al.* 2005). In each winter, all shorelines and a small sample of offshore waters (>20 m deep) were surveyed once. A Cessna 206 was used for surveys in 1992, and a DeHavilland Beaver was used for all subsequent surveys. Planes were flown at 80–90 kt and at an altitude of approximately 65 m. On each side of the plane, an observer recorded all birds within a transect 50 m wide (i.e. total transect width was 100 m). Survey routes in Padilla Bay varied from year to year, but typically included a flight path along the shoreline and multiple flight paths running parallel to one another across the bay (Fig. 1). Each survey covered between about nine and 13 square kilometers of Padilla Bay. We considered results of winter surveys from 1992 to 2007 (n = 15).

Data analyses

We present survey results as densities because the observed fraction of the bay varied between the survey programs. Among the five programs, protocols were most highly comparable between MESA and WWU. In particular, MESA and WWU conducted shore-based surveys from the same 11 observation points and included the same survey area. Moreover, the density of many species varied greatly between September and May in Padilla Bay, and only MESA and WWU documented such variation for all species by conducting surveys throughout the period. We therefore relied mainly on the MESA and WWU programs to evaluate changes in species densities over time. We evaluated trends for 27 species and species groups with mean densities of more than 0.13/km^2 across all MESA or all WWU surveys. Densities for most species were either much greater or lower than 0.13/km^2. We excluded species with densities below the threshold because the power to detect trends in such rarely-observed species was low.

We used a one-way MANOVA to evaluate changes in density between two time periods: 1978/79 (MESA surveys) versus 2003–2006 (WWU surveys). The response variables were survey results within each of four periods of about two months (5 September–5 November, 6 November–27 January, 28 January–16 March, 17 March–18 May). We chose those seasonal periods for two reasons. First, MESA and WWU results indicated that densities of most species in Padilla Bay changed significantly between two or more of the bimonthly periods, which correspond approximately to fall migration, early winter, late winter and spring migration. Second, the monthly frequency of surveys was dissimilar for MESA and WWU, and the specific timing of our four seasonal periods yielded the most balanced design (i.e. six to seven MESA surveys per period, and five to six WWU surveys per period). Two MESA surveys conducted later in spring (23/24 May) were not included because significant numbers of most bird species depart Padilla Bay for breeding areas by late May, and because WWU did not conduct comparable surveys at that time of year. We used square-root transformations of data, which reduced, but did not eliminate deviations from the assumptions of multivariate normality and equality of covariances (Shapiro-Wilk test and Box's M test, respectively). However, MANOVA is generally robust to such deviations (Sheskin 2007).

For species showing significant changes in abundance between MESA and WWU surveys, we provide results graphically for each of the five survey programs (where available) as a secondary basis for evaluating trends in Padilla Bay. For these species, we present monthly or bimonthly results averaged over the respective years of each survey program. However, results of WDFW aerial surveys were available for a longer period of time than are other survey programs, and so we present mean results of WDFW surveys for each of three five-year periods. The single mid-winter WDFW surveys are probably inappropriate for evaluating site-specific trends in many species, and only MESA and WWU surveys used comparable methods (see the "Study Area and Methods" and "Discussion" subsections). Thus, we did not use inferential statistics to analyze trends in WDFW data, to compare results among WDFW and earlier aerial surveys, or to compare results of aerial and shore-based surveys.

Finally, we used the Morisita-Horn index (following Dobkin *et al.* 1998) to measure the similarity of bird assemblages in Padilla Bay between 1978/79 and 2003–2006. We evaluated the complement of this index, which ranges from 0 (no similarity) to 1 (complete similarity), for each of the four seasonal periods defined above. Detection of rare bird species is likely influenced by observer bias and survey conditions. To avoid influence of such species on the index, we included only the 27 most common taxa in MESA or WWU surveys (Table 1). We conducted statistical analyses using JMP 5.0.1 (SAS Institute 2002), set all significance levels at $\alpha = 0.05$ and report all means ± standard error. A spreadsheet file including all survey data referenced in this paper is available from the Padilla Bay National Estuarine Research Reserve.

RESULTS

During September through mid-May, the combined density of all marine birds (including loons, grebes, cormorants, waterfowl, gulls, terns and alcids) in Padilla Bay declined between 1978/79 and 2003–2006 [Table 1, Fig. 2(a)]. The change appears to be related mainly to declines in bird density during early winter (November) and especially during spring migration (mid-March to mid-May).

TABLE 1

Results of one-way MANOVA evaluating differences between 1978/79 [Marine Ecosystems Analysis (MESA) Puget Sound Project surveys] and 2003–2006 [Western Washington University (WWU) surveys] for the densities of marine birds combined and for 27 species and species groups during September to mid-May in Padilla Bay, Washington

Species or species group	Trend	$F_{1,9}$	P
All species	Decline	17.22	0.003
Red-throated Loon *Gavia stellata*	Decline	11.66	0.008
Pacific Loon *G. pacifica*	Increase	20.39	0.002
Common Loon *G. immer*	Increase	9.02	0.015
Horned Grebe *Podiceps auritus*	Decline	59.06	<0.001
Red-necked Grebe *Pod. grisegena*	Decline	33.39	<0.001
Western Grebe *Aechmophorus occidentalis*	Decline	82.58	<0.001
Double-crested Cormorant *Phalacrocorax auritus*	Not significant	3.67	0.088
Pelagic Cormorant *Phal. pelagicus*	Not significant	0.72	0.418
Canada Goose *Branta canadensis*	Increase	9.87	0.012
Brant *Br. bernicla*	Decline	44.71	<0.001
Mallard *Anas platyrhynchos*	Increase	18.6	0.002
Green-winged Teal *A. carolinensi*	Not significant	3.44	0.097
American Wigeon *A. americana*	Increase	6.07	0.036
Northern Pintail *A. acuta*	Not significant	3.76	0.085
Canvasback *Aythya valisineria*	Decline	44.41	<0.001
Scaup *Ay. marila, Ay. affinis*	Decline	93.34	<0.001
Scoters *Melanitta* spp.	Increase	13.99	0.005
Long-tailed Duck *Clangula hyemalis*	Not significant	2.25	0.168
Goldeneyes *Bucephala islandica, Buc. clangula*	Decline	10.64	0.01
Bufflehead *Buc. albeola*	Decline	10.86	0.009
Red-breasted Merganser *Mergus serrator*	Not significant	2.69	0.135
Ruddy Duck *Oxyura jamaicensis*	Decline	47.6	<0.001
Bonaparte's Gull *Larus philadelphia*	Decline	5.47	0.044
Ring-billed Gull *L. delawarensis*	Not significant	1.09	0.323
Mew Gull *L. canus*	Not significant	0.72	0.419
California Gull *L. californicus*	Not significant	0.02	0.892
Glaucous-winged Gull *L. glaucescens*	Decline	52.61	<0.001

From September through mid-May, numbers of all marine birds in Padilla Bay comprised mainly waterfowl (86% ± 2%, 86% ± 4%, and 98% ± 0.4% of all birds were waterfowl in the MESA, WWU and WDFW surveys respectively). For all species and all waterfowl, WDFW aerial surveys reported greater densities than did the MESA and WWU shore-based surveys, yet similarly suggest declines in density during 1992–2007 [Fig. 2(b)]. Of the 27 species and species groups for which we evaluated changes in density between 1978/79 and 2003–2006, six increased and 13 declined (Table 1).

Between 1978/79 and 2003–2006, species assemblages in Padilla Bay were relatively similar during the period 28 January–16 March (complement of the Morisita-Horn index = 0.73). However, species assemblages were somewhat dissimilar during fall migration and early winter (index = 0.54 during each of the periods 5 September–5 November and 6 November–27 January) and highly dissimilar during spring migration (17 March–18 May, index = 0.24).

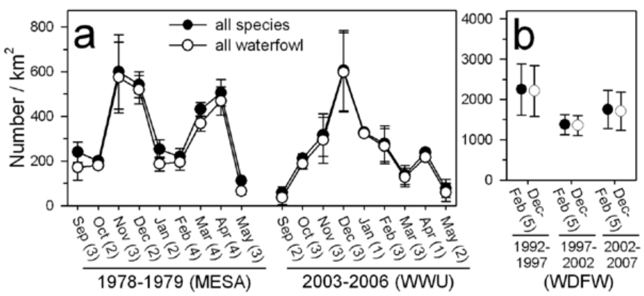

Fig. 2. Monthly mean densities [± standard error (SE)] of all marine birds (including loons, grebes, cormorants, waterfowl, gulls, terns and alcids) and of all waterfowl in Padilla Bay from (a) Marine Ecosystems Analysis (MESA) Puget Sound Project and Western Washington University (WWU) shore-based surveys, and from (b) Washington Department of Fish and Wildlife (WDFW) aerial surveys. WDFW surveys were conducted once each year between late December and mid-February, with most surveys occurring in mid-January; means of survey results for three periods are shown: 1992/93 to 1996/97, 1997/98 to 2001/02, and 2002/03 to 2006/07. Number of surveys for each data point shown in parentheses.

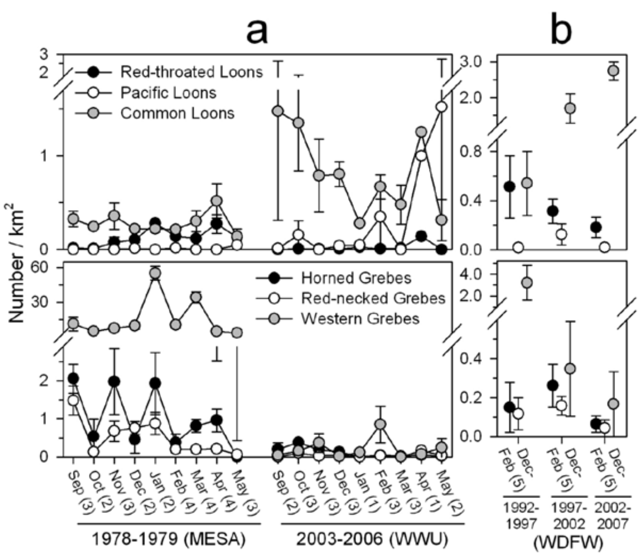

Fig. 3. Monthly mean densities [± standard error (SE)] of loons and grebes observed in Padilla Bay from (a) Marine Ecosystems Analysis (MESA) Puget Sound Project and Western Washington University (WWU) shore-based surveys, and from (b) Washington Department of Fish and Wildlife (WDFW) aerial surveys. Details as in Fig. 2.

Loons, grebes and cormorants

Between 1978/79 and 2003–2006, densities declined for Red-throated Loons *Gavia stellata* and three species of grebes, increased for Pacific Loons *Gavia pacifica* and Common Loons *Gavia immer,* and did not change for two species of cormorants [Table 1, Fig. 3(a)]. Notably, the typical maximum density of Western Grebes declined more than 98% (from >50/km^2 in 1978/79 to <1/km^2 in 2003–2006). These results for loons and grebes are generally supported by trends in WDFW aerial surveys during 1992–2007, although trends do not appear uniform across the three five-year periods for Pacific Loons, Horned Grebes, and Red-necked Grebes *Podiceps grisegena* [Fig. 3(b)].

Brant and dabbling ducks

Densities of Brant declined between 1978/79 and 2003–2006 [Table 1, Fig. 4(a)]. The density of Brant was greatest in Padilla Bay during spring migration in March–April (although USFWS surveys do not corroborate that pattern), and the typical maximum density in spring declined by about 75% (from about 400/km^2 in 1978/79 to 100/km^2 in 2003–2006). During April, Brant densities were similar in WDG aerial surveys from 1966 to 1976 and in MESA shore-based surveys during 1978/79, suggesting little decline between those periods [Fig. 4(b)]. WDFW aerial surveys suggest a slight decline in Brant densities during 1992–2007, yet USFWS and WDFW surveys occurred each year before the typical period of greatest Brant densities in Padilla Bay.

Dabbling ducks consituted the most abundant group of birds in Padilla Bay throughout most winter months, with combined densities of Mallards *Anas platyrhynchos,* Green-winged Teal *A. carolinensis,* American Wigeon *A. americana* and Northern Pintails *A. acuta* exceeding 1200/km^2 during 2002–2007 (mean for WDFW aerial surveys). Mallards and American Wigeon increased between 1978/79 and 2003–2006 [Table 1, Fig. 4(a)], and during 1992–2007 (Fig. 4b). However, densities of dabbling ducks in

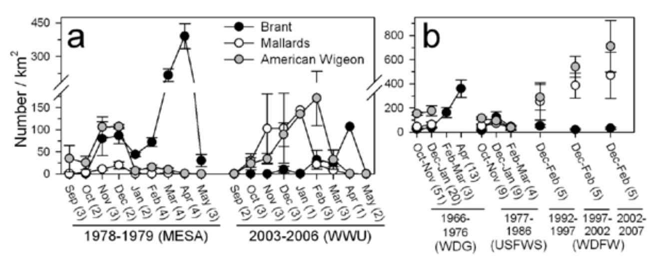

Fig. 4. Monthly mean densities [± standard error (SE)] of Brant *Branta bernicla,* Mallards *Anas platyrhynchos,* and American Wigeon *Anas americana* in Padilla Bay from (a) Marine Ecosystems Analysis (MESA) Puget Sound Project and Western Washington University (WWU) shore-based surveys, and from (b) Washington Department of Game (WDG), US Fish and Wildlife Service (USFWS), and Washington Department of Fish and Wildlife (WDFW) aerial surveys. For Brant, WDG surveys were conducted during 1970–1976, with 21 and 11 surveys occurring during October/November and December/January respectively. Details as in Fig. 2.

Padilla Bay were often highly variable both within and among years. Relative to shore-based surveys (MESA, WWU), aerial surveys (WDG, USFWS, WDFW) consistently reported higher densities of the four abundant species of dabbling ducks.

Diving ducks

Densities of scaup (mainly Greater Scaup), Buffleheads *Bucephala albeola,* Canvasbacks *Aythya valisineria,* goldeneyes (mainly Common Goldeneyes *B. clangula*), and Ruddy Ducks *Oxyura jamaicensis* declined between 1978/79 and 2003–2006 [Table 1, Fig. 5(a)]. Notably, the density of scaup was greatest in early winter, and the typical maximum density during that period declined by about 80% (from about 75/km^2 in 1978/79 to 15/km^2 in 2003–2006). Densities of Long-tailed Ducks and Red-breasted Mergansers *Mergus serrator* did not change, and only scoters (mainly Surf Scoters *Melanitta perspicillata*) increased in density. WDFW aerial surveys suggest increasing trends in scaup during 1997–2007 and in scoters during 1992–2007 [Fig. 5(b)]. However, WDFW surveys were conducted during winter rather than during fall and spring migration, when the densities of most species of diving ducks are greatest in Padilla Bay [Fig. 5(a)].

Gulls

MESA, WWU and WDFW survey results indicate that most larids in Padilla Bay during September–May were Glaucous-winged Gulls *Larus glaucescens.* However, 29% ± 5%, 49% ± 7% and 69% ± 6% of all gulls observed were not identified to species in the MESA, WWU and WDFW surveys respectively. The densities of Bonaparte's *L. philadelphia* and Glaucous-winged Gulls declined between 1978/79 and 2003–2006 (Table 1), mainly because of declines during September–November in Bonaparte's Gulls and during February–May in Glaucous-winged Gulls [Fig. 6(a)]. Results of WDFW aerial surveys suggest no trend for either species during 1992–2007 [Fig. 6(b)], but occurred each year in December–February, when densities of both species were relatively low. Densities of three other gull species did not change between 1978/79 and 2003–2006 (Table 1).

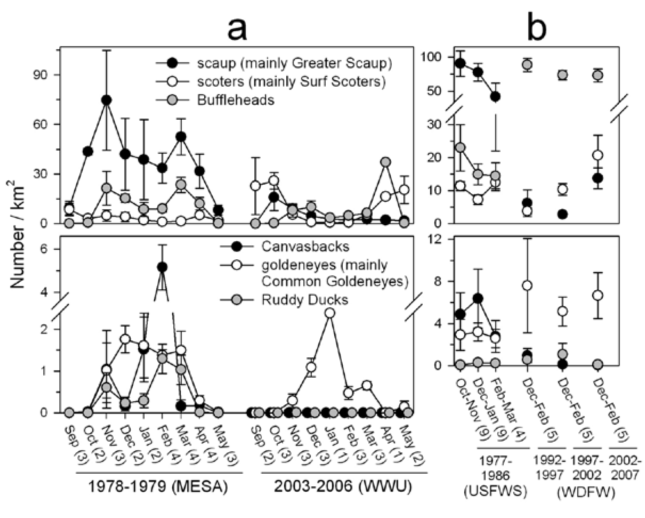

Fig. 5. Monthly mean densities [± standard error (SE)] of diving ducks in Padilla Bay from (a) Marine Ecosystems Analysis (MESA) Puget Sound Project and Western Washington University (WWU) shore-based surveys, and from (b) US Fish and Wildlife Service (USFWS) and Washington Department of Fish and Wildlife (WDFW) aerial surveys. Scaup, scoters, and goldeneyes often were not identified to species; observations within each of those genera are combined. Details as in Fig. 2.

DISCUSSION

We identified five survey programs for marine birds in Puget Sound that together spanned the years 1966–2007. Although a range of species use Padilla Bay, waterfowl constitute at least 85% of total numbers of birds during September to mid-May. Comparison between MESA and WWU shore-based surveys (two surveys that used highly comparable methods) for that time of year suggests that the combined density of all marine birds declined between 1978/79 and 2003–2006. Declines occurred mainly during early winter (November) and especially during spring migration (mid-March to mid-May). During spring migration, species assemblages were highly dissimilar between 1978/79 and 2003–2006 (complement of the Morisita-Horn index = 0.24). Of 27 species and species groups we considered, six increased and nearly half (13 taxa) declined. Declines occurred across foraging and life-history guilds, and were often large for many formerly abundant species. For instance, in Padilla Bay, typical maximum densities of Brant declined by 75%; of scaup, by 80%; and of Western Grebes, by 98%. Results of WDFW aerial surveys during 1992–2007 were consistent with most changes identified through comparison of MESA and WWU surveys; where inconsistencies occurred, they were likely, in part, a result of differences between programs in

- survey technique (i.e. aerial versus shore-based observations),
- seasonal timing and frequency of surveys, and
- locations observed within Padilla Bay (see next subsection).

Factors limiting comparisons among survey programs

At least three general factors must be considered when interpreting and comparing results of survey programs. First, the seasonal timing of observations affects the questions that can reasonably be addressed. The local abundance of many bird species changes seasonally during the non-breeding period, as in Brant that stage during spring migration in Padilla Bay (Moore *et al.* 2004). Seasonal movements among non-breeding sites can also vary,

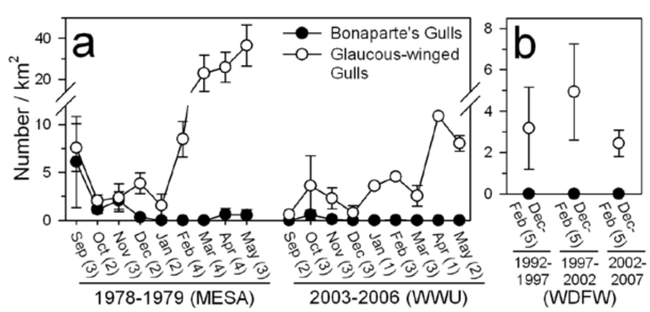

Fig. 6. Monthly mean densities [± standard error (SE)] of Bonaparte's Gulls *Larus philadelphia* and Glaucous-winged Gulls *L. glaucescens* in Padilla Bay from (a) Marine Ecosystems Analysis (MESA) Puget Sound Project and Western Washington University (WWU) shore-based surveys, and from (b) Washington Department of Fish and Wildlife (WDFW) aerial surveys. Details as in Fig. 2.

less predictably, because of proximate environmental factors. For instance, variation in the abundance of dabbling ducks in Padilla Bay likely results from changes in the relative attractiveness of wintering sites in terms of food availability and weather (Lovvorn & Baldwin 1996). Thus, surveys conducted once annually throughout Puget Sound (i.e. WDFW aerial surveys) are appropriate for evaluating regional trends of species that remain in Puget Sound throughout the non-breeding period. However, species that move among regions require repeated sampling or timing of surveys to correspond with the main periods of use.

A second consideration when interpreting survey results is variation between programs in survey locations within Padilla Bay. Density estimates may be biased and dissimilar among surveys where the proportions of habitats surveyed are not representative of those available. For instance, MESA and WWU shore-based surveys were limited to areas relatively close to shorelines (i.e. such surveys excluded about 29 of 72 km^2 in Padilla Bay). Thus, MESA and WWU surveys probably underestimated the density of species such as scoters and Long-tailed Ducks that occur mainly in deeper-water habitats (Savard *et al.* 1998, Robertson & Savard 2002).

A final factor affecting interpretations of survey results concerns the quality of species detections and identifications. Results of shore-based and aerial surveys may be similar for conspicuous species such as Western Grebes, and especially for those that also do not dive, such as Brant. Indeed, densities of those two species were similar in most aerial and shore-based surveys conducted during comparable years and seasons. Results from aerial and shore-based surveys may be less similar for species that tend to dive or fly in response to low-flying aircraft. Aerial surveys may be more appropriate for species such as dabbling ducks, which often occur in dense flocks that are difficult to survey accurately from shore. For instance, results of WDFW aerial surveys indicated much greater densities of dabbling ducks than did either the MESA or WWU shore-based surveys. On the other hand, distinctions among species of similar appearance may be more difficult during aerial surveys, which afford only a brief period of observation. For example, compared with surveys from shorelines, aerial surveys by WDFW reported a larger fraction of gulls unidentified to species.

Conservation implications

Monitoring programs should be conducted and evaluated at regional and larger scales to identify population trends, but also at local scales to identify critical habitats. For instance, North American populations of scoters declined by about 60% over the past 30–50 years (Hodges *et al.* 1996, Dickson & Gilchrist 2002, Nysewander *et al.* 2005). Numbers of scoters in Padilla Bay increased during the same period, possibly suggesting that the relative value of Padilla Bay to scoters has increased (e.g. Stillman *et al.* 2005). Once identified, sites that are heavily used by declining species can be targeted in protection efforts. For example, marine birds benefit from restrictions on activities such as hunting, boating and harvest of important fish and invertebrate foods (Fox & Madsen 1997, Rodgers & Schwikert 2002, Beukema & Dekker 2006). Areas that support resources of predictably high value may be designated marine protected areas (MPAs; Hooker & Gerber 2004). Sites such as Padilla Bay that support substantial numbers of marine birds should be considered candidates for MPA designation under Executive Order 13158, which promotes a scientifically-based system of MPAs to enhance ecological and economic sustainability of marine environments (Federal Register 2000).

Identifying causes of population decline is especially difficult for species that migrate substantial distances among distinct habitats used over an annual cycle. In particular, it is unclear how changes in resources within Padilla Bay versus non-local factors have contributed to declines of many bird species in Padilla Bay. Most species that declined in Padilla Bay have also declined throughout northern Puget Sound and other portions of their ranges, suggesting that the causes are widespread (Barr *et al.* 2000, Afton & Anderson 2001, Dickson & Gilchrist 2002, Nysewander *et al.* 2005, Ward *et al.* 2005, ASRD/ACA 2006). Similarly, continent-wide increases in Canada Geese *Branta canadensis* and Common Loons suggest that the contributing factors are not restricted to Padilla Bay (Cooper & Keefe 1997, McIntyre & Barr 1997).

Nonetheless, Padilla Bay habitats and the many thousands of birds that may depend on them face multiple threats. For example, the importance of Padilla Bay to marine birds likely relates to a high availability of food, including eelgrass and diverse fish and invertebrate communities supported by eelgrass. Although significant loss of eelgrass has not been reported for Padilla Bay, eelgrass habitats have declined worldwide and often lack effective protections (Hemminga & Duarte 2000). Oil spills from two refineries on the western shore of Padilla Bay occur infrequently, but have at times been substantial (Chia 1971). Vessel traffic and hunting are common in Padilla Bay: these factors directly reduce survivorship, but also increase the rate of energetically costly movements and reduce energy intake for marine birds during nutritionally challenging times of year (Béchet *et al.* 2004). Many species of marine birds are vulnerable to fisheries bycatch, although this source of mortality appears to affect mainly seabirds feeding in pelagic habitats (Melvin & Parrish 2001).

Effective protection efforts for birds will combine continued monitoring of their abundance and habitat conditions, protections for habitats of particular value and studies to evaluate both local environmental factors (e.g. Beukema & Dekker 2006) and processes that occur at broader scales (e.g. Frederiksen *et al.* 2004).

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