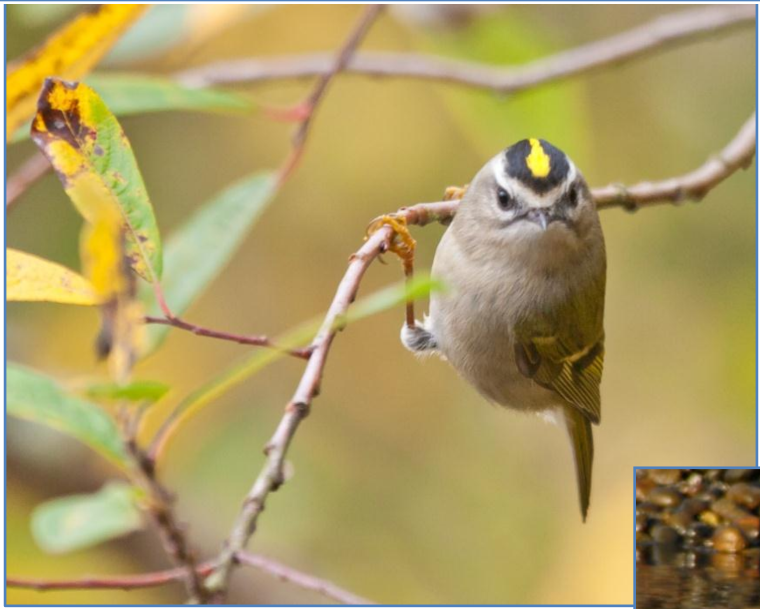
Marine and Terrestrial Bird Indicators for Puget Sound



Washington Department of Fish and Wildlife
& Puget Sound Partnership
12/31/2013

Cover Photographs: Pigeon guillemots by Peter J. Hodum and golden-crowned kinglet by Kevin D. Mack. Used with permission.

Recommended citation: Pearson, S.F. and N.J. Hamel. 2013. Marine and terrestrial bird indicators for Puget Sound. Washington Department of Fish and Wildlife and Puget Sound Partnership, Olympia, WA, 55 pp.

EXECUTIVE SUMMARY

The Puget Sound Partnership (Partnership) was created in 2007 with a mandate to restore the health of Puget Sound by 2020. To assess progress towards an ecologically healthy Puget Sound and spur recovery actions, the Partnership adopted a suite of ecosystem indicators and associated ecosystem recovery targets collectively referred to as the Puget Sound Vital Signs. The portfolio of indicators for the species and food web goal included a Vital Sign for birds. However, the description of the bird Vital Sign, which included marine and terrestrial birds, was ambiguous and in need of refinement. Consequently, we were tasked by the Partnership with developing terrestrial and marine bird indicators for the bird Vital Sign.

We used existing compilations of indicators and screening criteria to rank and refine lists of potential indicators and to provide recommendations for specific indicators and their reporting strategy. We define the geographic scope for our work as the U.S. portion of the Salish Sea (Puget Sound, including the Strait of Juan de Fuca) and associated watersheds (this includes the upland habitats in these watersheds). We emphasize that the bird indicators that we recommend are intended to be coarse-grained, i.e., aimed at the general public and policy makers and easily understood, and are not intended to provide the detailed information necessary to diagnose specific problems, monitor responses of the ecosystem to management actions or assess the causes for the patterns in the data. They are intended to indicate status and trends of marine and terrestrial bird populations that depend on the Puget Sound region, and also provide an integrative and long-term view of the health of Puget Sound. They are not intended as diagnostic indicators of habitat, contaminants or prey, or to track the effectiveness of specific conservation actions.

Because the selection process excluded those species for which there were little or no data, only indicators that met specific criteria (e.g., ongoing monitoring programs, existing trend data) were considered here. Subsequent efforts by the Puget Sound Ecosystem Monitoring Program will assess the need for additional indicators regardless of the historic information associated with them.

We recommend the following marine bird indicators:

1. Spring/summer at-sea density trends of pigeon guillemot, rhinoceros auklet, and marbled murrelet. These species are highly dependent on the marine environment of, and breed in, Puget Sound and Strait of Juan de Fuca.

2. At-sea abundance trends of scoter species that overwinter in Puget Sound and Strait of Juan de Fuca. These species are highly dependent on the marine environment of Puget Sound and the Strait of Juan de Fuca, but do not breed there.

We recommend the following terrestrial bird indicators:

1. Breeding abundance trends of resident species associated with interior conifer forests, namely golden-crowned kinglet, varied thrush and brown creeper.
2. Breeding abundance trends of resident synanthropic (human-associated) species, namely American crow, rock pigeon, house sparrow, house finch and European starling.

In addition we recommend methods for reporting annual results and trends.

Table of Contents

INTRODUCTION

Background

In 2007, the Washington State Legislature enacted Engrossed Substitute House Bill 5372 creating the Puget Sound Partnership (Partnership) with a mandate to restore the health of Puget Sound by 2020. Restored health was defined as: 1) a healthy human population supported by a healthy Puget Sound that is not threatened by changes in the ecosystem, 2) a quality of human life that is sustained by a functioning Puget Sound ecosystem, 3) healthy and sustaining populations of native species in Puget Sound, including a robust food web, 4) a healthy Puget Sound where freshwater, estuary, near shore, marine, and upland habitats are protected, restored, and sustained, 5) an ecosystem that is supported by ground water levels as well as river and stream flow levels sufficient to sustain people, fish, and wildlife, and the natural functions of the environment, and 6) fresh and marine waters and sediments of a sufficient quality so that the waters in the region are safe for drinking, swimming, shellfish harvest and consumption, and other human uses and enjoyment, and are not harmful to the native marine mammals, fish, birds, and shellfish of the region.

Hundreds of actions are underway in Puget Sound to protect and restore the ecosystem's ecological health (Puget Sound Partnership 2008, Puget Sound Partnership 2012). Recovery efforts are, in part, organized around two fundamental questions: "What is the status of Puget Sound?" and "What does a healthy Puget Sound look like (and how do we know if we are moving toward one)?" (Puget Sound Partnership 2008). To assess progress towards a healthy Puget Sound and spur recovery actions, the Partnership approved a suite of ecosystem indicators and associated ecosystem recovery targets in a "Dashboard of Vital Signs" (Leadership Council 2010).

Indicators on the Dashboard are meant to serve as "high-level, outcome type measures of the health of Puget Sound and of the health and well-being of the people of Puget Sound" (Puget Sound Partnership's Indicator Action Team 2010). Indicators are associated with each of the ecosystem recovery goals (Puget Sound Partnership 2008). By design, the Dashboard is a "relatively small, representative collection of interconnected natural, human and program dimension indicators that reflect both short- and long-term progress for restoring the health of Puget Sound" (Puget Sound Partnership's Indicator Action Team 2010). The authors go on to say that an effective collection of indicators should: (1) "provide an ongoing snapshot of the overall health of the Sound", (2) "show the collective impacts of new and ongoing management strategies", (3) "reveal the results for key ecosystem, human and program dimension measurements in advance of State of the Sound reports", and (4) "be ecologically important and socially resonant" (Puget Sound Partnership's Indicator Action Team 2010).

Historic Context of the Bird Indicator

The collaborative work to identify indicators of the health of Puget Sound started some years ago and resulted in extensive, if not comprehensive lists of potential ecosystem measures. The effort by O'Neill (2008) resulted in nearly 700 indicators, 27 of which related to birds. In a later effort to evaluate indicators for Puget Sound, various pre-existing lists of indicators were compiled and evaluated against screening criteria (Levin et al. 2011, Puget Sound Partnership's Indicator Action Team 2010). Top-ranking indicators were assembled in three portfolios of "Vital Sign" indicators. All portfolios included a bird-based indicator, and the specific measures ranged from abundance of key terrestrial bird species and marbled murrelets to numbers of dead seabirds and shorebirds from beach surveys.

The portfolio that was recommended by the team of experts commissioned by the Partnership included birds, and the measure was "Numbers Key Terrestrial Bird Species" (Puget Sound Partnership's Indicator Action Team 2010). Ultimately, the bird indicator that was adopted by the Partnership was defined as "Bird species - Marbled murrelets and other bird abundance; breeding bird counts for composite (index) for a variety of species or selected other terrestrial species" (Document 08a – Draft Dashboard of Ecosystem Indicators 072010 available at http://www.psp.wa.gov/downloads/LC2010/072010/agenda.php). There was no mention of specific species other than the marbled murrelet and data sources were not identified. Thus, this indicator was in need of refinement.

Given this historical context, we were tasked by the Partnership with developing terrestrial and marine bird indicators. The bird Vital Sign was determined *a priori* to be associated with the Partnership's legislatively mandated goal of maintaining "healthy and sustaining populations of native species, including a robust food web", along with orca, herring and salmon. In order to be consistent with other Vital Signs, we set out to develop coarse-grained indicators , i.e., aimed at the general public and policy makers and easily understood (Kerschner et al. 2011), while also being ecologically meaningful and responsive to ecosystem changes. We did not intend to develop indicators to diagnose specific problems, monitor responses of the ecosystem to management actions or assess the causes for the patterns in the data. For all of the latter, other data, tools and analyses are needed (Washington State Academy of Sciences 2012).

Ecological Context

Birds have been proposed as good candidates for ecological indicators of environmental health, biodiversity, condition of habitats, and climate change (See Birdlife International, Gregory and van Strien 2010, Butchart et al. 2010). They are often considered good indicators because they: (1) are abundant, (2) are relatively well studied and time-series data are often available, (3) are conspicuous and charismatic, (4) our understanding of their population biology is often extremely high, (5) some species are often tightly linked to their prey resources (review in Durant et al. 2009) and upper trophic predators, like seabirds, offer an integrative view of the dynamics at lower levels of the food web (Furness and Greenwood 1993, Gregory et al. 2005, Boyd et al. 2006), (6) across multiple species, birds use all habitats, from marine to terrestrial, from wild to exurban to urban, (7) populations of habitat specialists can reflect land use changes (Drever et al. 2008), (8) there are resident breeders and seasonal migrants, allowing potential comparisons of local vs. global effects, and (9) birds can have considerable resonance value with many audiences, from the public to decision-makers (Gregory et al. 2005)

The Washington State Academy of Sciences recently reviewed the Partnership's selection of ecosystem status indicators (Washington State Academy of Sciences 2012). In their review, the Academy recommended that the Partnership develop a conceptual model that summarizes the structural and functional components of the ecosystem, and that they use this model to identify indicators that accurately represent each attribute of the ecosystem. At the time of writing this report, the Partnership had not yet adopted a conceptual model of the entire system. Therefore we had to develop indicators independently of this effort. However, models exist that support the idea that birds can be good indicators of perturbations to the system relative to other ecosystem components.

There are many ecosystem models for the Salish Sea and for the Strait of Georgia in particular (e.g.,Walters et al. 1997, Beamish et al. 2001, Martell et al. 2002, Preikshot et al. 2013). However, none have published results assessing the suitability of marine birds as potential indicators. One useful model was recently developed for the central basin of Puget Sound (Harvey et al. 2010, Harvey et al. 2012b). Harvey et al. (2012b) developed an empirical mass balance model to identify trophic interactions that are most important to the overall structure of the central Puget Sound food web. The model includes 66 functional groups ranging from phytoplankton and crabs to marine birds and orcas. It includes six bird groups based on diet and residency. Direct connections among groups in the model are mainly predator-prey interactions. The model is intended for asking coarse-scale, strategic questions and can be used to evaluate the response of ecosystem components to perturbations such as changes in fisheries, habitat change, changes in bottom-up (phytoplankton production) and top-down (predator removal) effects, and cumulative effects.

To help us put a potential marine bird indicator into an ecosystem perspective as recommended by the Academy, Chris Harvey used his ecosystem model to evaluate marine birds as ecosystem indicators of central Puget Sound. His simulations suggest that bird biomass on the water (derived from abundance estimates) is a good lagging (predictor of past conditions) proxy for the biomass of many other groups included in the food web for central Puget Sound. However, the strength of the correlations was variable (0-75% depending on the bird group and the perturbation). Thus, some bird groups are more effective ecosystem indicators than others. Also, because marine birds only correlate with only a portion of the food web, the selected bird indicators should be included with a broader suite of indicators. Gulls, resident diving (cormorants and alcids), migratory diving (grebes, loons and mergansers), and nearshore diving birds (scaups, scoters, and goldeneyes), in particular, are all good lagging indicators of changes in habitat conditions, top-down effects, and potentially fishing perturbations. Other bird groups appear to correlate poorly with other food web groups and include resident and migratory bald eagles and herbivorous birds (e.g., dabbling ducks), suggesting that they would be poor ecosystem indicators. However, even for species that appear to be good lagging indicators, it is important to include birds within a broader suite of indicators to capture perturbations to the ecosystem because the bird correlations were moderate. At the same time, marine birds are good leading (predictors of future states) indicators of ecosystem attributes like biodiversity. In other words, declining bird populations may indicate that biodiversity will also decline. Other researchers have also found seabirds to be good leading indicators of marine ecosystem change (e.g., Cairns 1987, Piatt et al. 2007, Mallory et al. 2010).

As in the marine realm, no conceptual ecosystem model exists for the entire terrestrial ecosystem within the watersheds of Puget Sound. Heppinstall et al. (2008) used an integrated modeling approach to simulate future land cover and predict the effects of future urban development and land cover on avian diversity in the central Puget Sound region of Washington State. They simulated land cover changes 28 years into the future. Their results suggest that native forest and synanthropic species (i.e., species that live near, and benefit from, an association with humans) of birds are sensitive to landscape composition (e.g., percent forest) and configuration (e.g., residential land use). Their simulations also indicate that the cover of mature forest will continue to decline in central Puget Sound through 2027 and that interior conifer forest and synanthropic birds are likely to be good indicators of this change. In addition to being good indicators of the predominant terrestrial ecosystem conversion that is likely to occur in the next 20–30 years, they are also an indicator of one of the primary threats to the marine environment - the conversion of predominantly forest communities to urban and suburban environments. This conversion has historically resulted in some of the most significant negative factors influencing the health of Puget Sound (e.g., changes in timing and flow of freshwater inputs, increased inputs of nutrients and toxic chemicals) (Pearson et al. 2010a).

Although using very different modeling approaches, both the terrestrial and marine ecosystem models indicate that bird abundance should be good indicators of the health of the Puget Sound and its watersheds. To the extent that certain bird parameters can serve as indicators of habitat conditions, bird indicators could also be potentially linked to the mandated goal of protecting, restoring and sustaining habitats.

Why use birds as indicators rather than simply monitor the habitats and assume that if the habitats are healthy, bird populations are also likely healthy? First, bird population trends appear to be effective indicators of human induced changes to the environment in both terrestrial (Leu and Knick 2008) and marine ecosystems (Halpern et al. 2008) and are relatively easily surveyed using volunteers. Second, the effects of environmental changes (e.g., habitat restoration, habitat loss, and habitat alteration) are often expressed in different ways at different levels of biological organization. The effects at one level, say the ecosystem level, can be expected "to reverberate through other levels, often in unpredictable ways" (Noss 1990). As a result, selecting indicators at multiple levels of biological organization such as habitats or ecosystems and species and communities is more likely to provide a better picture of ecological condition and response to change than an indicator focused on only one level of organization. Also, because birds respond to many factors such as food resources, they are not simply indicators of habitats.

The goal of this report is to evaluate the suitability of marine and terrestrial bird species indicators for indicating the ecological health of marine and terrestrial species, and ultimately the health of Puget Sound. Our approach begins with a compilation of existing indicators and an evaluation using published screening criteria. Based on these results, we rank and refine the indicators to finally provide recommendations for specific indicators and their reporting strategy. We define the geographic scope for our work as the U.S. portion of the Salish Sea (Puget Sound, including the Strait of Juan de Fuca) and associated watersheds (this includes the upland habitats in these watersheds).

METHODS AND RESULTS

Evaluation of Potential Indicators

Compiling marine and terrestrial indicators

We compiled species and food web indicators from the source lists in Kershner et al. (2011) for marine birds (itself primarily drawn from O'Neill et al. 2008), and Levin et al. (2011) for the terrestrial birds (see Supplementary Material Tables 1 & 2). For this purpose, indicators are defined as "quantitative biological, chemical, or physical measurements that reflect structure, composition, or functioning of an ecological system". However, it is important to note that the indicator language in these compilations sometimes refers to the type of monitoring effort and not to the indicator. For example, "marine bird aerial estimates (non-breeding populations)" refers to an indicator that combines both a measure (non-breeding at-sea marine bird abundance index) and monitoring effort (aerial surveys conducted by WDFW using established protocol).

Based on our knowledge of indicators and monitoring programs in the region, these compilations were incomplete. As a result, we added and scored the following monitoring indicators: (1) "Marine birds - shored-based estimates of non-breeding populations", (2)Rhinoceros auklet nesting population", and (3) Rhinoceros auklet reproduction". The shore-based estimates of non-breeding bird effort are conducted by the Seattle Audubon Puget Sound Seabird Survey. They recently completed their first summary report (draft manuscript), which was not available for consideration at the time our evaluation. Both rhinoceros auklet monitoring efforts (2 and 3) are conducted by WDFW, along with University of Puget Sound and NOAA. These were recently summarized in reports and manuscripts (Pearson et al. 2009, 2010, 2012), but also include historic data from the 1970s and 1980s (Wilson 1977, Wilson and Manuwal 1986). We do not know why these indicators were not included in the original compilations.

One other monitoring effort that we considered adding to the compilations but did not, was the Whidbey Island and Protection Island pigeon guillemot surveys. The guillemot surveys are relevant to the indicator "Pigeon guillemot nesting colony trends" (Tables 1 & 3 in the Supplementary Material) and are conducted by Pigeon Guillemot Conservancy on Whidbey Island and on Protection Island by Lee Robinson and the USFWS Washington Islands National Wildlife Refuge. Neither effort has published methods or results. Therefore, we did not include these in our compilation. However, we recommend future consideration of these data as discussed below.

Ranking of potential marine and terrestrial bird indicators

We used the indicator evaluation process and results in Kershner et al. (2011) and Levin et al. (2011) to identify potential marine and terrestrial bird indicators that serve the Partnership needs. As part of their evaluation, the authors used screening criteria to score and rank indicators. Screening criteria included: theoretically sound (indicators act as reliable surrogates for ecosystem characteristics like structure, composition and function), relevant to management concerns, concrete (measureable), historic data available, high signal-to-noise ratio, and so on (see Appendix I below for a full list and associated definitions). The advantage of using the ranking criteria of Kershner et al. (2011) is that it is methodological, transparent, and largely consistent with other suggested criteria for selecting bird indicators (e.g., Durant et al. 2009, Gregory and Strien 2010, etc.). Another advantage Kershner's method is that it very flexible (e.g. we can consider additional criteria) and has been peer reviewed.

Specifically, we used the 19 screening criteria from Kershner et al. (2011) (Appendix I). For marine birds, we used their quantitative scores for each of the criteria. For the terrestrial birds, we translated the implied qualitative scores (color shading scheme) in Levin et al. (2011) into quantitative scores following the example of Kershner et al. (2011) (see Supplementary Material Tables 1-4). Scores in both papers were derived by a team of experts who evaluated indicator performance against each criterion by examining the peer-reviewed literature. The experts documented any literature used to inform the evaluation process (see Supplementary Material Tables Tables 2 & 3). The scientific support for an indicator was scored as follows: indicators with peer-reviewed documents or expert opinion providing consistent and strong findings for its support received 1 (dark gray); indicators with peer-reviewed documents or expert opinion providing limited support received a 0.5 (gray); and indicators with no peer-reviewed evidence, evidence against, or conflicting support received a 0 (light gray). If no references were available for a particular criterion, no score was assigned (Kershner et al. 2011).

Kershner et al. (2011) added a weight to each of the 19 screening criteria that would result in coarse-grained indicators ("Vital Signs") and fine-grained indicators (i.e., technically robust and rigorous proxy for ecosystem structure and function; "ecosystem assessment"). Consistent with our goal of developing high level Vital Sign indicators, we used the coarse grained weighing factors. These give greater weight to factors such as relevance to management, availability of historic data, understandable to policy makers and the general public, numerical, continuous time series, cost-effectiveness, and our ability to link the indicator to progress on established targets (weighing factors: essential = 1.0; important = 0.75; moderate = 0.5; slightly important = 0.25; negligible = 0; Supplementary Material Tables 1 & 2). Each criterion was multiplied by its respective weighing factor and then summed across all criteria to derive a single score for each indicator.

Fatal flaw criteria

Because efforts are already underway to restore the health of Puget Sound, and there is a desire to measure interim progress up until 2020, we need indicators for which data exist to measure and report on current status and changes relative to some baseline. To this end, we added one additional “fatal flaw” criterion: presence of an established and ongoing monitoring program. If the indicator did not meet this criterion, the indicator was excluded from our final list, even if it was a valuable indicator otherwise. Conversely, it is conceivable that an indicator with a low score for some of the non-fatal flaw criteria made it to our final list of recommendations because overall it scored high.

Reducing the list of marine and terrestrial candidate indicators

We eliminated any indicator – marine and terrestrial - with a final Vital Sign score below 6.4 (the maximum score was 10), which was the mean score of all of the Puget Sound indicators evaluated by Kershner et al. (2011). We considered indicators with a Vital Sign score of 6.4 or greater to be equally suited as potential indicators given the subjective nature of this scoring system. We did not want to overemphasize quantitative scores for a truly qualitative approach. The cutoff of 6.4 was arbitrary although there was a considerable gap between indicators below the mean and those above – we simply assumed that any indicator above the mean was worth considering.

There were 6 marine and 2 terrestrial indicators that scored higher than 6.4 and met the fatal flaw criteria of being supported by an ongoing monitoring program (Table 1; see Supplementary Materials Tables 1 and 2 for details).

The high scoring marine bird indicators are measures of at-sea bird abundance/density during the breeding and non-breeding season, breeding colony size, reproductive success and marine bird mortality (Table 1). For the terrestrial birds, the two indicators are measures of abundance trends for many breeding and over-winter birds, resulting from two survey efforts (Table 1).

The marine bird indicators that were eliminated because they did not meet the fatal flaw criteria, even if they may have scored higher than 6.4, were:

- Western sandpiper status & trends
- Cormorant abundance at nesting colonies
- Black oystercatcher abundance
- Scoter, Harlequin duck, goldeneye - non-breeding populations
- Glaucous-winged gull abundance at nesting colonies
- Marine bird fishing mortality
- Pigeon guillemot nesting colony trends
- Marine waterfowl harvest
- Marine bird breeding abundance
- Rhinoceros Auklet Chick diet composition

The terrestrial bird indicators that did not meet our fatal flaw criteria were:

- Peregrine falcon population size from nesting surveys
- Bald eagle status & trends
- Population size of band-tailed pigeon from mineral site counts
- Marbled murrelet presence at occupied sites
- Cavity nesting birds status & trends

Table 1. Top ranked marine and terrestrial birds indicators (i.e. had a mean score greater than 6.4) that were supported by ongoing monitoring programs.

Marine birds					
Key Attributes	**Indicator**	**Monitoring program/ Organization**	**Geographic Scale**	**Season**	**# Years**
At-sea abundance	Marine bird aerial estimates – non-breeding populations	PSAMP/Washington Dept. of Fish and Wildlife – aerial surveys	Puget Sound and Strait	Winter	20
At-sea abundance	Marine birds - shored-based estimates – non-breeding populations	Puget Sound Seabird Survey/Seattle Audubon – shore surveys	Southern and Central Puget Sound	Winter	4
At-sea density	Marine birds status & trends – breeding season	Marbled Murrelet at-sea surveys/ U.S. Forest Service, U.S. Fish and Wildlife Service, and Washington Dept. of Fish and Wildlife, NOAA Fisheries – boat surveys	Puget Sound and Strait	Spring/Summer	11
Colony population size	Rhinoceros auklet nesting colony size - breeding	Rhinoceros auklet population estimation/ Washington Dept. of Fish and Wildlife, Univ. of Puget Sound, Univ. of Washington	N. Puget Sound and E. Strait	June	3
Reproductive success	Rhinoceros auklet reproductive success - breeding	Rhinoceros auklet population estimation/ Washington Dept. of Fish and Wildlife, Univ. of Puget Sound, Univ. of Washington	N. Puget Sound and E. Strait	June	2-9
Mortality rates	Marine bird mortality - breeding and non-breeding	Coastal Observation and Seabird Survey Team (COASST), British Columbia Beached Bird Survey (BRITISH COLUMBIA BEACHED BIRD SURVEY)/ University of Washington, Bird Studies Canada	Salish Sea (Puget Sound, Straits of Georgia and Juan de Fuca)	Year-round	11 & 20
Terrestrial birds					
Abundance	Terrestrial breeding bird counts	Breeding Bird Survey/ U.S. Geological Survey's Patuxent Wildlife Research Center and Environment Canada's Canadian Wildlife Service	Salish Sea Watershed (41 routes)	Summer	45
Abundance	Winter bird populations	Christmas Bird Count/ National Audubon Society	Puget Sound and Strait - 17 count circles	December	> 50

Marine Bird Indicators

A brief overview of the breeding and over-wintering marine bird community in Puget Sound

The marine bird community of Puget Sound changes seasonally and spatially. There are more individual marine birds present in the Sound during the winter, and the over-wintering bird community is much more diverse than the summer community. When looking at the average dominance of over-wintering birds using the PSAMP aerial survey results (1994-2010), over 80% of the community is dominated (in order of dominance) by gulls (Larus spp.), bufflehead (*Bucephala albeola*), scoters (Melanitta sp.), goldeneyes (Bucephala sp.), common murre (Uria aalge), mergansers (Mergus spp.), western grebe (Aechmophorus occidentalis), American wigeon (Anas americana), mallard (*Anas platyrhynchos*), and double-crested cormorant (*Phalacrocorax auritus*) (N. Vilchis, pers. com.). During this time of year, birds are more concentrated in the nearshore and the distribution of birds throughout Puget Sound is uneven, with high concentrations in places like Skagit Bay, Padilla Bay, Bellingham Bay, and the waters near Dungeness Spit, Bremerton, and Poulsbo.

During the summer months, there are far fewer birds in South Puget Sound and Hood Canal and birds are more concentrated in places like Discovery Bay, Sequim Bay, Admiralty Inlet, the southern San Juan Archipelago, Port Susan, Skagit Bay, Drayton Harbor, Birch Bay, Lummi Bay and Bellingham Bay. The summer bird community is dominated by locally breeding birds including gulls [primarily glaucous-winged (*Larus glaucescens*)], terns [primarily Caspian (*Sterna caspia*)], alcids (primarily rhinoceros auklet, common murre, and pigeon guillemot), cormorants [primarily double-crested and pelagic], but with some ducks and geese [primarily scoters, Canada geese (*Branta Canadensis*), and dabbling species]. Presumably the scoters observed in the summer months are juvenile birds or birds in poor physical condition and therefore not flying to the far northern nesting localities to breed. Locally nesting birds are dominated by glaucous-winged gull, rhinoceros auklet, pigeon guillemot, double-crested and pelagic cormorants. Most of the nesting occurs on Protection and Smith islands with dispersed nesting also found throughout the Sound for the pigeon guillemot and cormorants (Speich and Wahl 1989; updated WDFW seabird colony database).

Proposal for marine bird indicators

Of the six remaining marine bird indicators/monitoring efforts, we recommend selecting a breeding and non-breeding at-sea marine bird abundance indicator (see below). Data sources include the marbled murrelet at-sea surveys and PSAMP aerial surveys for the breeding and non-breeding bird community, respectively (see Appendix 2 for a description of monitoring programs). We propose these indicators and associated monitoring efforts because they: (1)

are among the highest ranking indicators evaluated using the Vital Sign scores, (2) have ongoing programs (3) are supported by long-term data sets (> 10 years) and therefore have the preliminary data needed to asses changes in trends, (4) include multiple species and therefore allow us to select species that are highly dependent upon the marine ecosystem (see definition below) and that have different diets and foraging strategies and use different habitats, (5) include the entire Sound and Strait in their sampling approach, and (6) as we discussed in the Introduction, our ecosystem model suggests that the abundance of some groups of marine birds are good leading and lagging indicators of the ecosystem [gulls, resident diving (cormorants and alcids), migratory diving (grebes, loons and mergansers), and nearshore diving birds (scaups, scoters, and goldeneyes)].

At this time, we do not recommend including the non-breeding abundance trends derived from the Puget Sound Seabird Survey as part of the marine bird indicator. Although an excellent example of a monitoring program using volunteers, it currently does not include the spatial scope or number of years of data that the PSAMP effort does (but does have better temporal coverage within year) – hence the lower overall Vital Sign score. This program is currently confined to the nearshore environment and to a relatively small portion of the Sound and Strait but the scope is rapidly expanding. In addition, results are not as well supported by the peer-reviewed literature (see Table 3 in the Supplementary Material). However, the lack of publications is an artifact of a relatively new program that has not yet had the time or does not yet have adequate data to publish in the peer-reviewed literature and is not a reflection of the quality of the program. As a result, we recommend reconsidering this program as a potential future contributor to the marine bird indicator.

We also do not recommend including the rhinoceros auklet colony size and reproduction indicators in the overall marine bird indicator. These are single species efforts that may not reflect the overall condition of the marine bird community, which is the focus of our bird indicator. We do however view these efforts as providing critical supporting information to our abundance indicator. For example, we may find that successful local reproduction is driving the trends observed on the water. We also recommend expanding the efforts to monitor pigeon guillemot diet and reproduction to provide context to observed abundance trends for this species.

The COASST program is the only monitoring program representative of marine bird population condition (bird mortality). Because of the extensive spatial and temporal scale of this program, data provide baseline beached bird encounter rates. This indicator is particularly useful for identifying acute events such as large toxic algal blooms, large fisheries bycatch events, or an oil spill (Parrish et al. 2007, Hamel et al. 2009, Moore et al. 2009). Furthermore, results in the

Sound can be compared to results along the coast to provide perspective on local conditions – in other words, are the patterns unique to the Sound and Strait or part of a larger scale pattern.

However, using beached bird encounter rates as an indicator of marine bird condition is problematic because encounter rates can increase with an increasing population (more birds thus more dead birds), with good local reproduction, or they can be associated with negative local environmental conditions. Therefore, results are difficult to interpret on their own. Consequently, we recommend using the marine bird mortality indicator to help us understand potential mechanisms responsible for observed changes in abundance and not using it as a primary indicator for the Sound. For example, the occurrence of a toxic algal bloom is often first identified because large numbers of seabirds are observed dead on the beach by COASST volunteers. These events then trigger follow-up research to help identify the responsible mechanism (e.g., Jessup et al. 2009, Phillips et al. 2011, Parrish et al. in prep.). Once an acute event is identified, one can look for population level responses in the bird abundance trends. In other words, this is an opportunity to link research (identifies the mechanism), to the event (identified by volunteers), and ultimately a population level response (identified by abundance monitoring).

Identifying breeding and non-breeding marine birds that are highly dependent upon the marine environment in Puget Sound and the Strait of Juan de Fuca

The two recommended marine bird indicators (spring/summer densities of breeders and winter at-sea bird abundance of overwintering birds) are assessed by two recommended monitoring programs that detect hundreds of species of birds. Some species are rarely detected, some are widespread and abundant, and all differ in their dependence upon the Puget Sound. Given this variability, we further evaluated the indicators and survey efforts to identify and narrow the species used as indicators to those that are more likely influenced by Puget Sound conditions, and for which there are significant and appropriate for detecting trends should they occur.

Species that are highly dependent upon that environment to meet their life history needs are more likely to be good indicators of that environment. However, birds that use the marine environment of Puget Sound vary considerably in their dependency (Gaydos and Pearson 2011). We considered marine bird species that, when present in Puget Sound, (1) almost exclusively consume marine derived resources, and (2) spend nearly all of their time in marine waters when they are present in the Puget Sound region. This removes species that move readily between freshwater and marine environments to forage, such as double-crested cormorants and great blue herons.

To identify “highly dependent” species, we started with a list of birds that use the Salish Sea from Gaydos and Pearson (2011). The authors ranked each species by their abundance and dependence on Salish Sea’s marine environment [172 species; Table 1 in Gaydos and Pearson (2011)]. We selected species that were ranked as having both high dependence on marine and intertidal habitats and high dependence on marine derived foods. Applying this criterion, the list was reduced to the 53 species included in Table 5 of the Supplementary Material.

A useful indicator species needs to be reasonably abundant (so that we can detect trends) and well distributed throughout the Sound and Strait (not dependent upon a very small portion of the area). To this end, we removed species that are restricted to the western end of the Strait of Juan de Fuca and therefore not really associated with Puget Sound [all members of the families Procellariidae, and Diomedeidae and some members of the family Laridae – e.g., black-legged kittiwake (*Rissa tridactyla*)]. We also removed uncommon species and species that just migrate through the region with no winter/summer period of residency by converting all category abundance scores in Table 1 of Pearson and Gaydos (2011) to numeric values (High = 4; Medium = 3; Low = 2; Rare = 1; No Report = 0; Supplementary Material Table 5) and then deleting all species with an average abundance score across all seasons of < 3.0. Although this cut-off was somewhat arbitrary, this step successfully eliminated rare and migratory species and retained local breeders and over-wintering species that are widely distributed in Puget Sound and Strait of Juan de Fuca.

We also removed all shorebirds from the list because there is no existing sound-wide shorebird monitoring program for this region and therefore no shore-bird specific available monitoring data (black turnstone, black-bellied plover, and western sandpiper were removed).

Because we investigated both a breeding-season and over-wintering season indicator, we grouped the list accordingly. Because Tatoosh Island is located on the boundary line of the Salish Sea, we considered species whose only breeding colony in the Salish Sea was on Tatoosh Island as non-local breeders (e.g., Cassin's auklet and common murre) because species on this island can forage in both the California current and the Salish Sea when breeding.

Identifying marine birds for which we are likely to be able to detect abundance/density trend

The recommended monitoring efforts for the breeding and wintering marine bird indicators likely differ in their abilities to detect trends in this resulting list of highly dependent marine birds. As a result, we assessed our ability to detect trends or statistical power for each of the remaining species using trend results from both the PSAMP and marbled murrelet survey efforts. This analysis was conducted to determine if we are likely to detect trends should they occur or if there is too much variability in the data to allow us to assess trends. In the later case, trends could exist but we could not detect them. Although this was a retrospective power analysis, we emphasize that the goal of this power analysis was not to aid in the interpretation of past abundance trends (*sensu* Hoenig and Heisey 2001) but instead was used to inform our ability to detect trends moving forward. Power was calculated in Program R (R Development Core Team 2012) using a non-central t-distribution with T-2 degrees of freedom and non-centrality parameter, $\delta = |b_1| / MSE$, (Neter et al. 1996, pp. 55-56) where MSE (mean standard error) was obtained from the log-linear regression of abundance or density vs. year for each given species.

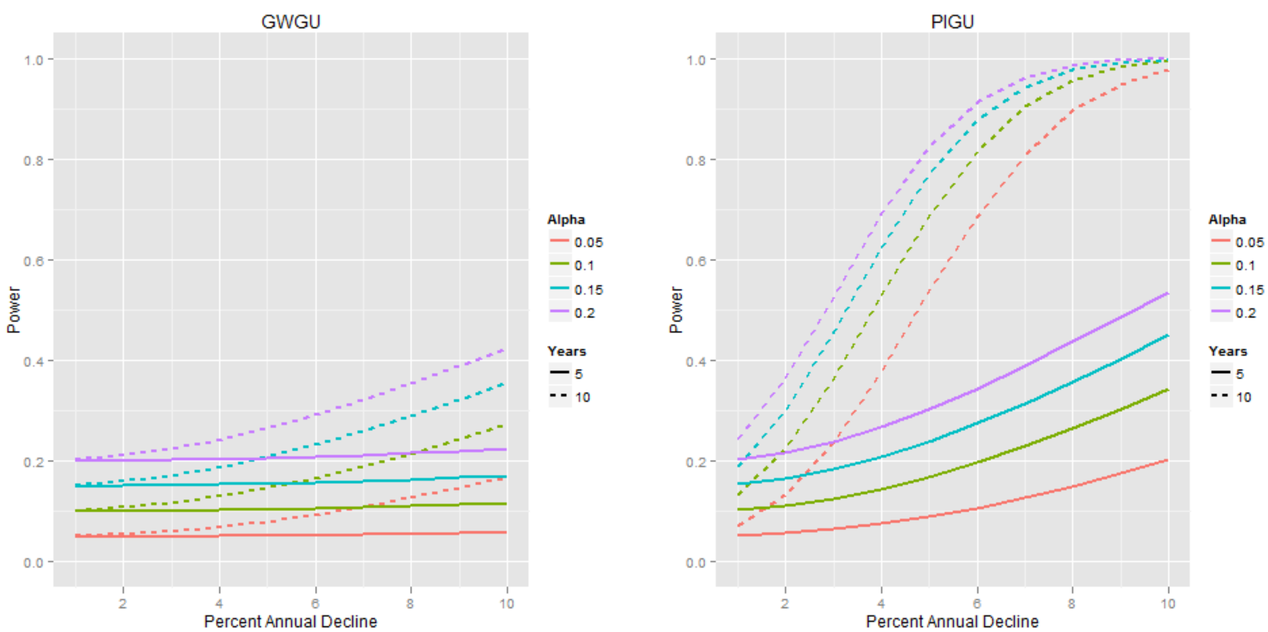


Figure 1. Two examples [glaucous-winged gull (GWGU) and pigeon guillemot (PIGU)] of our power analysis assessing our ability to detect percent annual declines over 5 and 10 year periods and using different alpha levels. For this example, we used yearly PSAMP abundance estimates from 1999-2010 excluding 2007. Note the relatively high power to detect 6% annual declines over a 10 year period (alpha = 0.10) for the guillemot and extremely low power to detect trends for the gull for either time period or any alpha level.

For the PSAMP analysis, we used the 1999-2010 time period with one abundance estimate per year, with the exception of no estimate for 2007. For the marbled murrelet survey dataset, we used the 2001-2010 time period with one density estimate/year. Species where the monitoring effort could detect a 10% decline or greater over a 10 year period with a power = 0.75 and α = 0.10 were retained and those with less power were eliminated (e.g., Figure 1). Unfortunately, the trend analysis of the PSAMP data that were available to us did not include information for species that made our list including the over-wintering common murre, rhinoceros auklet, and all three locally breeding cormorant species. We recommend that WDFW conduct a trend analysis for these species so that we can determine if they have adequate power to be included as potential indicator species.

Based on this process, we identified 12 species where we have both high power to detect trends and that are highly dependent upon the marine environment of Puget Sound when they are present in the region (Table 3). The life histories of these 12 species vary considerably and are therefore vulnerable to different stresses.

To illustrate diet and migratory differences and similarities, we grouped these species according to their feeding habits in Table 3: 1) local breeding piscivores that feed in the pelagic and epibenthic, 2) local breeders that feed in the epibenthic on gastropods, bivalves, crustaceans, etc., 3) overwintering piscivorous birds that feed in the pelagic and epibenthic, and 4) over-wintering birds that feed in the epibenthic on gastropods, bivalves, and crustaceans.

Table 2. Candidate species for the at-sea marine bird abundance/density indicator. Note: we may recommend modifying the species list once additional analyses of PSAMP data have been conducted.

Species (common name)	Species (scientific name)	Foraging location[1]	Diet[1]	Residency
Marbled murrelet	*Brachyramphus marmoratus*	Pelagic	Schooling pelagic fish	Local breeder
Rhinoceros auklet	*Cerorhinca monocerata*	Pelagic	Schooling pelagic fish	Local breeder
Pigeon guillemot	*Cepphus columba*	Pelagic, epibenthic	Schooling pelagic fish, demersal fish	Local breeder
Loons[2]	*Gavia sp.*	Pelagic, epibenthic	Schooling pelagic fish, demersal fish	Over-winter
Red-necked grebe	*Podiceps grisegena*	Pelagic, epibenthic	Schooling pelagic fish, demersal fish	Over-winter
Western grebe	*Aechmophorus occidentalis*	Pelagic, epibenthic	Schooling pelagic fish, demersal fish	Over-winter
Scoters[2]	*Melanitta sp.*	Epibenthic	Gastropods, bivalves, crustaceans, fish eggs, insects, plants	Over-winter
Harlequin duck	Histrionicus histrionicus	Epibenthic, surface	Gastropods, bivalves, crustaceans, fish eggs, insects, plants	Local breeder
Bufflehead	*Bucephala albeola*	Epibenthic	Gastropods, bivalves, crustaceans, fish eggs, insects, plants	Over-winter
Long-tailed duck	*Clangula hyemalis*	Epibenthic	Gastropods, bivalves, crustaceans, fish eggs, insects, plants	Over-winter
Scaup[2]	*Aythya marila*	Epibenthic	Gastropods, bivalves, crustaceans, fish eggs, insects, plants	Over-winter
Goldeneye[2]	*Bucephala sp.*	Epibenthic	Gastropods, bivalves, crustaceans, fish eggs, insects, plants	Over-winter

[1] Primary foraging location and diet – does not include minor portions of the diet or foraging locations.

[2]Species in these genera were grouped because of difficulty distinguishing species from airplane surveys - juveniles, females, and/or molting individuals were particularly difficult to distinguish beyond genera.

Selecting marine species breeding in Puget Sound

For the four species that breed locally in Table 2, we recommend using spring/summer at-sea density trends of the rhinoceros auklet, pigeon guillemot, and marbled murrelet as the breeding marine bird at-sea abundance indicators. All three species belong to a foraging group that was a good lagging indicator of other species groups and a good leading indicator of biodiversity in Chris Harvey's ECOSIM analysis. We do not recommend including the harlequin duck because its dependency on the marine environment varies seasonally. It is highly dependent upon the marine environment of Puget Sound and the Strait much of the year but during the breeding season most harlequin ducks leave the marine environment entirely. They spend this season along rivers (many in the watersheds of Puget Sound and the Strait) where they nest in tree cavities and eat freshwater food resources (it use of the Sound is more similar to an over-wintering species than a local breeder).

Rhinoceros auklet, pigeon guillemot, and marbled murrelet each have unique characteristics. All three of these species nest in terrestrial environments and consequently, successful reproduction is in part dependent upon terrestrial factors (all seabirds except emperor penguins nest on land). Pigeon guillemots and rhinoceros auklets nest in burrows on land immediately adjacent to the marine water. The rhinoceros auklet is arguably the least sensitive to terrestrial conditions because it digs its nesting burrow into the slopes of islands that have few mammalian predators (except for occasional visits from river otters) and the deep burrows protect eggs and chicks from most potential predators. In addition, adult rhinoceros auklets only visit colonies at night when there are few potential avian predators that might kill adults arriving or departing from the colony or kill departing fledglings (except owls and some night foraging eagles - see Hayward et al. 1993, Gaston and Dechesne 1996). We emphasize their nocturnal visits because diurnal avian predators, like bald eagles (*Haliaeetus leucocephalus*), can have significant impacts on seabird populations (Harvey et al. 2012) and seabird colonies, especially for surface nesting species (Hayward et al. 2010, Hipfner et al. 2012).

Pigeon guillemots nest in burrows on islands and along the cliffs and other locations on the mainland and, unlike the rhinoceros auklet, they visit their burrows during the day, which may make them more vulnerable to diurnal predators and to some mainland mammalian predators and diurnal avian predators (Ewins 1993).

Of the three recommended local breeders, the marbled murrelet is arguably the most influenced by terrestrial factors. As discussed in Miller et al. (2012) local declines in marbled murrelets could be attributed to marine, terrestrial or a combination of marine and terrestrial factors. The relative importance of marine and terrestrial factors on murrelet declines is currently being explored by an ongoing research effort led by Martin G. Raphael. The murrelet is subjected to marine and terrestrial conditions because it nests primarily on tree platforms located on older trees in conifer forests (USFWS 2009) yet forages entirely and spends the majority of its life on marine waters.

Terrestrial factors apparently correlate with successful murrelet reproduction. For example, murrelet nesting habitat use is positively associated with the presence and abundance of mature and old-growth forests, large core areas of old-growth, low amounts of edge habitat, reduced habitat fragmentation, and proximity to the marine environment (USFWS 2009). Nesting locations, in British Columbia range from 12-102 km inland from marine locations (39.2 ± 23.2 km; Hull et al. 2001), indicating that they are subject to a wide area of terrestrial influences. However, other than during the nestling stage and nest attendance, murrelets spend the remainder of their time on marine waters and are dependent upon marine derived resources year-round and for all life stages. One could argue that abundance trends for the marbled murrelet are a good indicator for the Puget Sound ecosystem because they integrate both terrestrial (upland) and marine factors. However, the caveat associated with keeping the murrelet is that it is currently difficult to disassociate the effect of one environment from the other.

The distribution of these species within the geographic area of interest can influence what they indicate. Although the pigeon guillemot is more widely distributed throughout the Sound than the other two locally nesting species in Table 2 during the breeding season, all three species are more abundant in central to northern Puget Sound and the eastern end of the Strait of Juan de Fuca (Nysewander et al. 2005). Distributions are similar during the winter for the guillemot and murrelet. During winter rhinoceros auklet abundance drops, and it becomes more widely distributed throughout the Sound (Nysewander et al. 2005).

For both guillemots and rhinoceros auklets, abundance trends can be linked to local breeding success trends, which provides information on potential mechanisms driving observed trends. As discussed above, there is ongoing research and monitoring that assess rhinoceros auklet colony population size and trends, reproductive success, and chick diet quality (calories and composition) at both Smith and Protection islands (Wilson 1977, Thompson et al. 1985, Wilson and Manuwal 1986, Pearson et al. 2009, 2010, 2012). Similarly, there is ongoing work to assess reproductive success for the pigeon guillemot on both Whidbey and Protection islands (Whidbey Island Guillemot Survey: http://www.whidbeyaudubon.org/pg/guillemot_survey.htm). Although the guillemot data have not been published, we have reviewed both the Whidbey Island Guillemot Survey methods and the monitoring conducted by volunteers and staff with U.S. Fish and Wildlife Service, and concluded that the data are of high quality and can be used to provide local vital rate information for this species.

The diets of the three recommended species differ slightly (e.g., see Lance and Thompson 2005, Lance and Pearson 2012), subject to different bottom-up influences. For example, the rhinoceros auklet and pigeon guillemots are both piscivorous. However guillemot diets are dominated by fish species that are more abundant in the nearshore and on the bottom, whereas rhinoceros auklets provision their chicks with schooling pelagic fish such as herring and sandlance (Lance and Thompson 2005, Lance and Pearson 2012).

Winter abundance trends in local nesting birds can provide valuable additional information. For example, if breeding trends are stable or increasing but wintering trends for these same species are declining, it would suggest that these birds are shifting their over-wintering distribution away from the Sound. If we find a similar trend for over-wintering species that do not breed locally, it would suggest that the Sound is not providing high quality wintering habitat. We could then look at common life history traits that might be driving the observed trends (e.g., N. Vilchis, pers. com.).

Selecting species for the non-breeding marine bird indicator

By themselves, trends in over-wintering birds may or may not be related to Puget Sound because these birds spend considerable portions of their lives on northern breeding grounds and in migration, and are therefore subject to environmental conditions outside Puget Sound that ultimately could be driving trends. As a result, if we want to use over-wintering birds as indicators of species associated with the Sound, we would ideally link their survival or health (e.g., weight gain, contaminant loads, etc.) to local conditions.

Given this significant caveat, we recommend including only scoters as indicators of the over-wintering bird community because they are arguably more dependent upon Puget Sound than all other over-wintering species, they return to the same molting sites year after year, and they depend on herring spawn and eelgrass beds. The surf and white-winged scoters are considerably more abundant than black scoters but because of difficulty distinguishing juvenile and female birds within and among scoter species during PSAMP aerial surveys, they are lumped together as “scoters”. Despite the fact that most of the population flies north to arctic and subarctic breeding grounds to nest and forage in freshwater lakes and ponds during the summer months, a considerable population of scoters present in the Puget Sound region year-round (unlike other over-wintering species). This is the case because a portion of the juvenile non-breeding population and birds not fit for reproduction remain in the area.

In addition, scoters are members of the nearshore diving birds in Chris Harvey’s ECOSIM simulation suggesting that they should be a good lagging indicator of biomass of other species groups in the ecosystem and a good leading indicator of biodiversity in Puget Sound.

We also include only scoters because, other than gulls (all Laridae pooled) and bufflehead, they are the most abundant group (when pooled) of marine birds during the fall, winter, and early spring months (N. Vilchis, pers. com.). They represent an important foraging guild not represented by local breeding birds and can be potentially linked to another species indicator, Pacific herring. Scoters consume herring spawn, and scoter abundance increases with increasing biomass of spawning herring (Anderson et al. 2009). At the same time they depend on a variety of food resources and habitats including mussel-dominated sites, eelgrass sites that provide either herring spawn and epifaunal invertebrates, and benthic habitats where they feed on soft-bodied prey such as crustaceans and polychaetes (Lacroix et al. 2005, Anderson et al. 2008, Anderson and Lovvorn 2011). Finally, unlike scoters wintering at other locations along the Pacific coast of North America, most scoters in the Puget Sound region molt in Puget Sound and are therefore dependent upon this region for successful molt. Body condition can affect the production of high quality feathers and the extent of feather replacement (Langston and Rohwer 1996). If birds are unsuccessful in replacing primary feathers, it can result in molt-breeding tradeoffs. Molt-breeding tradeoffs may have long-term consequences on future reproduction, since a year of breeding may need to be skipped to replace the accumulation of worn-out primaries (Langston and Rohwer 1996).

Summary of the selected marine bird indicators

Indicator #1: Spring/summer at sea density trends of pigeon guillemot, rhinocerous auklet and marbled murrelet. These species breed in Puget Sound and Strait of Juan de Fuca and that are highly dependent on the marine environment of this region.

Data source: At sea surveys conducted by the U.S. Forest Service. Note: All species detected are counted (including marine mammals), not just marbled murrelets.

Justification:

- Long-term dataset and high power to detect trends.
- Ongoing monitoring program that is likely to produce trends.
- Sound-wide surveys that also include the Strait of Juan de Fuca – stratified random sample.
- Established and published methods including issues associated with detectability.
- Data can be used to detect trends for multiple species with different diets and habitat requirements.
- Data can be used to detect trends for seabirds that nest in Puget Sound and are observed in Puget Sound year-round, such that their populations (survival and

reproduction) are more likely to be influenced by local conditions (Nysewander et al. 2005, Gaydos and Pearson 2011).

- Many of the locally breeding seabirds are dependent upon forage fish for survival and represent both nearshore (e.g., pigeon guillemot) and more pelagic (e.g., rhinoceros auklet) foragers (e.g., Lance and Thompson 2005, Wilson and Manuwal 1986).
- Potential link to one of the other marine food web indicators because of their collective dependence on forage fish and on Pacific herring in particular.
- Abundance trends can be linked to unusual mortality events monitored by COASST.
- If the rhinoceros auklet and pigeon guillemot colony surveys, reproductive variables, and chick diet quality and quantity and mortality monitoring described above continue (which we strongly recommend), we recommend that those results be used to provide potential insights into observed density trends from this seabird monitoring program. Without information on why densities are changing (e.g., is it local reproductive success, changes in diet quality, or survival?), we end up with uninformed indicators – trends without understanding the mechanisms driving trends.
- Results for Puget Sound can be put into context of breeding birds regionally (i.e., are trends unique to the Sound?) because this survey effort also includes results from the Washington outer coast.

<u>Concerns</u>:

- The degree to which species that nest in Puget Sound depend remain in Puget Sound throughout the year is not well known and may vary. All species are seen year-round in Puget Sound. However, the abundance of some species is relatively stable all year (although their distribution may change), whereas the abundance of others declines during the non-breeding season (e.g., rhinoceros auklets).
- The distribution of locally nesting seabirds within Puget Sound varies seasonally but all species have higher year-round densities in central- to northern-Puget Sound and Strait of Juan de Fuca, and relatively low densities to the south.
- Need for an implicit link between density trends, ongoing efforts to monitor vital rates (e.g., colony based reproduction monitoring), and ecological conditions in the Puget Sound (see discussion below).
- Trends could be driven by conditions at the nest sites, which is a terrestrial factor (see discussion above). For example, the pigeon guillemot and rhinoceros auklets breed in burrows and are vulnerable to introduced mammalian predators or human disturbance (Ewins 1993).

Indicator #2: At sea abundance trends of scoter species (white-winged, surf, and black). These species over-winter in Puget Sound and Strait of Juan de Fuca, and are highly dependent on Puget Sound's marine environment.

Data source: PSAMP aerial surveys conducted by Washington Dept. of Fish and Wildlife.

Justification:

- Long-term data and high power to detect trends.
- Ongoing monitoring program that is likely to detect trends.
- Sound-wide assessment (Strait of Juan de Fuca and Puget Sound) – continuous transects.
- Winter trends for locally breeding species and therefore a complement to spring/summer trends.
- By including scoters, we compliment the foraging guilds represented by the marine bird indicator and pick up an important foraging guild only represented by over-wintering birds (birds that forage on soft-bodied inverts, crustaceans, bivalves, plants, plankton, etc.).
- Potential link to one of the other marine food web indicators because of their use of herring spawn.
- Can be used to assess changes in species abundances that depend upon the resources of the Sound to meet critical resource demands. For example, over-wintering birds depend upon the Sound to meet the resource demands of molting and migration.
- Trends can be linked to unusual mortality events monitored by COASST.
- Abundance trends have been linked to shoreline development (Rice 2007)

Concerns:

- Wintering species do not breed in Puget Sound and do not spend all year in Puget Sound. Changes in winter abundances could be the result of factors influencing reproduction and survival during the breeding season and migration (both events occur north of the Puget Sound region for all of the migratory birds that over-winter here in Table 2 below), or they may be the result of large-scale changes in wintering distributions along the North American coast. This is a significant caveat. However, scoters are more dependent upon the Sound that most other over-wintering species.
- Varying distribution throughout Puget Sound.

- Abundance trends should be linked to more detailed monitoring and research aimed at identifying causes for observed trends (changes in forage fish abundance, disturbance at molting sites, events on the summer breeding grounds, etc.)
- Would like to see a link between winter abundance trends and physiological condition or vital rates.
- No ongoing or regular parallel effort outside the Puget Sound to provide context to trends observed within the Sound.
- Methods have not been published in the peer-reviewed literature.
- Reporting occurs infrequently.

Survey approach, data and analysis, and context

Summer/spring densities of locally nesting species survey methodology

For additional details, see the description of this program in Appendix 2. We will assess trends of the three locally nesting seabirds (rhinoceros auklet, pigeon guillemot, marbled murrelet) using average at-sea densities (average daily counts of birds per km^2), with an associated estimate of precision. This is accomplished using line transect or distance sampling (Buckland et al. 2001, Thomas et al. 2010) and bootstrapping using SAS. Details of the methods used to calculate densities and ultimately population estimates to the Puget Sound and Strait of Juan de Fuca (and associated confidence intervals) are provided in Raphael et al. (2007) and Miller et al. (2012). Because of departures from protocol in 2000, we will only use estimates from 2001–2020.

To produce annual density trends for each selected species, we will fit a linear regression to the natural logarithm of annual density estimates to test for declining trends and to characterize the change over time as a constant percent change per year. We will test the null hypothesis that the slope equals zero or greater (no change or increase in numbers) against the alternative hypothesis of the slope being less than zero (i.e. a one-tailed test for decreasing densities). We will test the significance of the slope at the level of alpha = 0.1.

Winter Bird (PSAMP) survey methodology

For additional details, see the description of this program above. We will use data from 1994 forward, because the survey methods and areas of coverage were more consistent and comparable during this time period (J.R. Evenson pers. comm.). An annual scoter abundance estimate and its associated variance for the U.S. portion of the Salish Sea will be derived from the aerial strip-transect data using the statistical methods described by J.R. Skalski in Appendix A of Nysewander et al. (2005).

To produce annual abundance trends for scoters, we will fit a linear regression to the natural logarithm of annual abundance estimates to test for declining trends and to characterize the change over time as a constant percent change per year. We will test the null hypothesis that the slope equals zero or greater (no change or increase in numbers) against the alternative hypothesis of the slope being less than zero (i.e. a one-tailed test for decreasing densities). We will test the significance of the slope at the level of alpha = 0.05.

Reporting and preliminary results

We will report trends for species grouped by migratory status and foraging strategy: (1) locally breeding piscivorous birds that feed in pelagic and epibenthic habitats (murrelet, auklet and guillemot), and (2) over-wintering scoters that feed in epibenthic on gastropods, bivalves, crustaceans, fish eggs, insects, and plants. In Table 4, we provide preliminary results and our recommended reporting format.

Table 3. Example estimates of average annual rate of density/abundance change for the recommended indicator species (2001 to 2009) from spring/summer boat-based monitoring effort (densities) and PSAMP winter (1999-2010) aerial surveys (index of abundance). Highlighted species exhibited significant declines.

	Annual Change (%)	95% Conf. Limits for percent annual change			
Species	Estimate	Lower	Upper	R^2	*P*-value
Local breeding picivores that feed in the pelagic and epibenthic (2001-2009)					
Marbled murrelet	-7.00	-11.69	-2.06	0.61	0.013
Pigeon guillemot	1.51	-4.20	7.57	0.05	0.559
Rhinoceros auklet	3.45	-6.30	14.21	0.09	0.446
Overwintering birds that feed in the epibenthic on gastropods, bivalves, crustaceans, etc. (1999-2010)					
Scoters	-5.32	-7.48	-3.10	0.76	0.0005

Terrestrial Bird Indicators

Monitoring efforts and associated indicators

The terrestrial bird indicator is intended to indicate whether or not the Partnership is achieving its goal of "healthy and sustaining populations of native species". This is the only terrestrial species indicator and we again emphasize that this indicator is intended to provide a coarse-grained indicator aimed at the general public and policy makers and is not intended to provide the detailed information necessary to diagnose specific problems, develop strategies to mitigate problems, or monitor responses of the ecosystem to management actions.

Two terrestrial bird abundance indicators scored above the cutoff score of 6.4. The indicators are from two different bird counts, one conducted during the breeding season and the other during the winter. The Breeding Bird Survey (BBS) is a cooperative effort between the U.S. Geological Survey's Patuxent Wildlife Research Center and Environment Canada's Canadian Wildlife Service to monitor the status and trends of North American bird populations. Following a rigorous protocol, BBS data are collected by thousands of volunteers who survey thousands of randomly established roadside routes throughout North America. The sample unit for the BBS is a roadside survey route, and each route is surveyed by a single volunteer observer one time each year during a morning in late-spring/early summer (May-June). Each route is composed of 50 stops, at which a 3 min point count is conducted and all birds heard or seen within ~400 m of the point are counted.

The Christmas Bird Count (CBC) is conducted in December by volunteers of the National Audubon Society and consists of 1000s of count circles (15-mile diameter) throughout North America. The circles tend to be centered in urban areas and areas with high concentrations of birds and birders. A variety of methods are used to collect data (people on bicycles, cars, and boats) and the methods used can change among years, no qualifications are required to participate, and the protocol, oversight, and data analysis is much less rigorous than the BBS. Most analyses of abundance trends from CBC data have involved adjusting the total counts by observer effort, usually party-hours. The potential biases associated with these effort adjustments or with other aspects of the analyses of CBC data have never been the subject of thorough statistical review (Droege undated), while the BBS analysis approach has been subject to such a review (e.g., Link and Sauer 2002, 2007, Sauer et al. 2008, Sauer et al. 2011). Both efforts are very long-term datasets (≥ 45 years locally) and well documented.

The predominant land cover in the Puget Sound watershed is overwhelmingly conifer forests (Alberti et al. 2007). The effect of urbanization on the Puget Sound region includes the conversion of native forests to urban landscapes with greater abundance of non-native vegetation, less native tree cover, an increase in roads and buildings, and so on (Alberti et al. 2004, Hepinstall et al. 2008, Pearson et al. 2010). This conversion results in an increase in impervious surfaces, increased water runoff, and increased contaminant levels in Puget Sound (see summary in Pearson et al. 2010).

Research in the Seattle metropolitan region indicates that species associated with native conifer forests are predictably replaced by synanthropic species as the landscape moves from one dominated by native forests to an urban landscape (Donnelly and Marzluff 2004, 2006, Blewett and Marzluff, 2005, Marzluff 2005, Marzluff et al. 2007). Native forest and synanthropic species are sensitive to landscape composition (e.g., percent forest) and configuration (e.g., residential land use) (Heppinstall 2008).

Simulations by Hepinstall et al. (2008) indicate that the cover of mature forest will continue to decline in central Puget Sound, through 2027 and that interior conifer forest and synanthropic birds are likely to be good indicators of this change. As a result, we use the rates of loss and increase of interior conifer forest and synanthropic species respectively as indicators of native forest loss and urban growth.

Given that terrestrial bird populations respond, at least in part, to changes in habitat conditions, there are potential linkages to the Partnership's land use/land cover targets. Specifically, birds may respond to the effects of: (1) reducing the rate of conversion of conifer forests to urban landscapes and (2) restoring and increasing riparian habitats, as the foundation for our recommended targets. However, through the process described below, we could not identify appropriate riparian bird indicators and, as a result, focus on the conversion of conifer forest habitats to urban landscapes.

Proposal for terrestrial bird indicators

Given this background, we recommended refining the abundance indicators identified in Table 1 as following:

Indicator #1: Breeding abundance trends of resident species associated with interior conifer forests.

Indicator #2: Breeding abundance trends of resident synanthropic species.

Data sources: The Breeding Bird Surveys led by USGS.

We considered including the group riparian birds as indicator of changes to species associated with riparian habitats but only identified candidate species that were migratory or that were also fairly widespread in upland habitats. Migratory species were not considered as potential indicators because they spend most of their time in habitats to the south and are therefore strongly influenced by events that occur during migration or during the over-winter period. For this reason, we limited our selection of year-round resident species for all terrestrial bird indicators.

The BBS results are well suited as an indicator for the Salish Sea region because locally breeding birds are likely to be tied to local conditions and because of the ability to link the abundance trends to specific habitat types. Of the locally nesting species, year-round residents are particularly well suited as indicators because they are not influenced by conditions occurring during migration or that occur in the southern wintering habitats.

Development of indicator groups

Indicator groups are selected groups of bird species that characterize specific ecological conditions and when measured collectively, they provide a measure of the status of those communities. For the indicator species groups that follow, we included all species that met the stated criteria for each group and that are broadly distributed across the watersheds of the Salish Sea and are reasonably abundant (see Table 6 of Supplementary Material). As a result, species that are very patchily distributed (e.g., Red-eyed Vireo) or that occur at very low densities (e.g., American dipper) are not included in the lists below even though they are clearly associated with riparian habitats.

Synanthropic species-- Synanthropic species are associated with high percent urban land cover, large urban patches, low settlement tree density, higher percent cover of non-native plant species, and older developments using the data and tables provided in Donnelly and Marzluff (2004 and 2006). In addition, these species often nest on human structures and frequently eat human food subsidies (Marzluff 2005). For a list of species membership and habitat associations see Table 6 in the Supplementary Material. From this list, we selected the five resident species from this group as our synanthropic species indicator group (see Table 5 below) because year-round residents are more likely to be influenced by local conditions than migrants.

Interior conifer forest species—Interior conifer forest species nest and forage in conifer forests (Rosenberg and Raphael 1986, McGarigal and McComb 1995, 1999), are associated with young, mature and old forests in both managed (Manuwal and Pearson 1997) and unmanaged landscapes (Carey et al. 1991, Gilbert and Allwine 1991, Manuwal 1991), and, when found in urbanizing landscapes, they are generally associated with high tree density and large forested reserves (Donnelly and Marzluff 2004, 2006) (see review in Table 6 of the Supplementary

Material). We intentionally excluded species that (1) were not resident or partial migrants (e.g., elevational migrants that stay in the region or (2) frequently eat human food subsidies (e.g., red-breasted nuthatch, hairy woodpecker). The latter case because population changes associated with changes may be offset by supplementary food (higher densities). The three species that met all of these criteria are listed in Table 4 below.

Riparian—Riparian species are associated with riparian habitats (McGarigal and McComb 1992, Hagar 1999, Pearson and Manuwal 2001, Shirley and Smith 2005) and are more abundant in riparian habitats than adjacent upland habitats (Pearson and Manuwal 2001) but tend to be largely absent from upland habitats that are not adjacent to riparian habitat (Person and Manuwal 2001). The only resident species that fits into this category is the Pacific wren. However, it is also quite common in upland habitats and was therefore deemed to be a poor indicator of this habitat type. As a result, this habitat type was dropped. For a list of species membership see Table 6 in the Supplementary Material.

Table 4. Selected interior conifer forest and synanthropic indicator groups

Interior Conifer Forest	
Species	**Migratory?**
Brown creeper	Resident
Golden-crowned kinglet	Resident
Varied thrush	Partial migrant
Synanthropic	
Species	**Migratory?**
American crow	Resident
House sparrow	Resident
House finch	Resident
Rock pigeon	Resident
European starling	Resident

Survey approach, data and analysis, and context

The North American Breeding Bird Survey (BBS) is a primary source of information regarding population change of North American bird populations, and provides useful information on breeding populations for ~420 species of birds. The sample unit for the BBS is a roadside survey route, and each route is surveyed by a single volunteer observer one time each year during a morning in late-spring/early summer (May-June). Each route is composed of 50 stops, at which a 3 min point count is conducted and all birds heard or seen within ~400 m of the point are counted.

There are 42 routes in the Salish Sea region with 22 in the United States and 20 in Canada (Figure 2). There are survey routes throughout Puget Sound watersheds, with more coverage on the east side (Figure 2). As of 2010, these routes have been surveyed a mean of 18.3 years, with a range of 1 to 43 years. As in all western states and provinces, the first year of data is 1968 and all analyses use 1968 as their base year. Only 6 routes in the Puget Sound region have data from 1968, and many routes have inconsistent coverage with more consistent coverage in recent years. This pattern of coverage is typical in most regions surveyed by the BBS, and temporal differences in precision of estimates reflect the lower amounts of data in earlier years (Sauer and Link 2011). We note that 5 routes used in the analysis were only partially contained in the region (Route #11013: 40.7% in the region, #11202: 17.1%, #89002: 42.0%, #89010: 62.8%, #89061: 32.4%). We chose to include these routes, as they provide some information for the region.

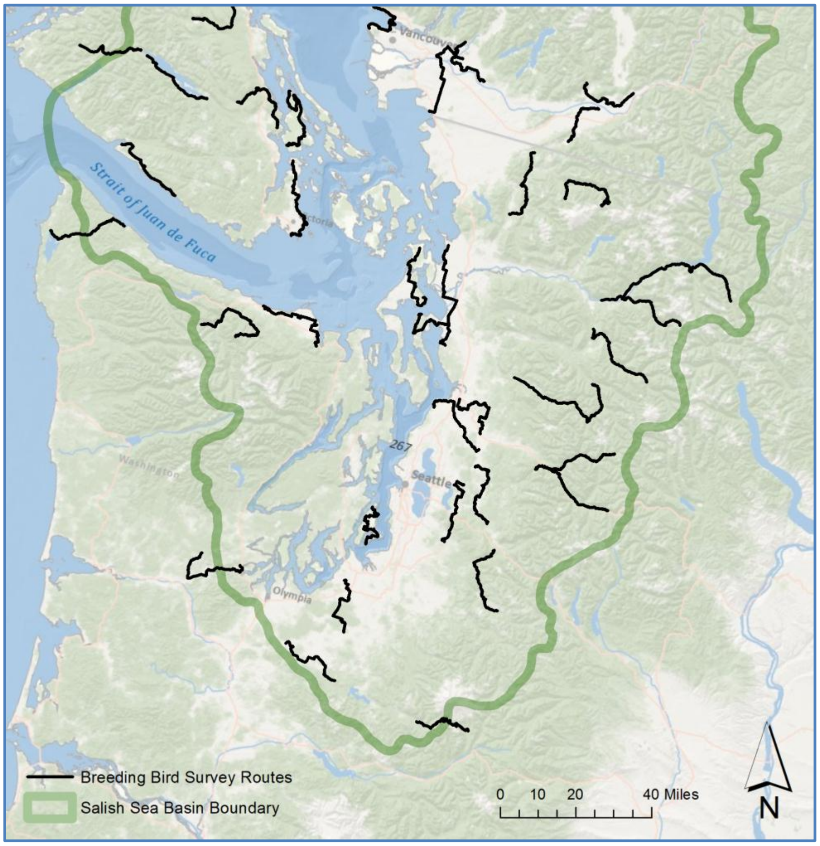


Figure 2. Map of the Salish Sea region and Breeding Bird Survey routes that occur within the area.

Analysis.-- Trends for indicator species groups will be analyzed with a hierarchical model that was developed to construct a composite population trajectory for the collections of species (Sauer and Link 2011). These composite population trajectories are scaled so that the first year (the base year) in the series is 0, and the value for every subsequent year is the composite change for the group, permitting easy evaluation of the change from the base year to all later years. The yearly change values are estimated as a geometric mean of the change from the base year to the year of interest for each species in the collection. The hierarchical model allows for accommodating differences in the quality of estimates of the component species (Sauer and Link 2011).

Assessing power to detect trends is not strait forward with a Bayesian analysis. Looking at the credible intervals, it appears that we should be able to detect a 5% change over a 10 year period for all species other than the Rock Pigeon. As a result, we recommend dropping this species from our analysis.

What habitats are being surveyed? -- The National Land Cover Database (NLCD) was developed for the continental United States from Landsat 5 data from the interval 1992-1995 by a consortium of Federal Agencies including the US Geological Survey (Vogelman et al. 2001, http://www.mrlc.gov/index.php). They defined 21 land use classes (Appendix 2), and interpreted the Landsat data in 30m pixels (http://www.mrlc.gov/nlcd1992.php). We overlaid the NLCD data on 19 BBS routes in Washington (BBS route 89012 was not included in the analysis as it was only surveyed from 1968-1971).

To define the area surveyed along a BBS routes, we digitized route paths of BBS routes (c.f., http://www.mbr-pwrc.usgs.gov/bbs/trend/rtehtm07a_nlcd.html) and buffered them by the counting radius (401m). Land cover attributes of the 30m pixels that were contained within these areas associated with each route were summed by land cover category for the route, then divided by the total number of pixels analyzed to get proportions of each land cover type. We summed categories associated with Woodland (Deciduous Forest, Coniferous Forest, Mixed Forest, Woody Wetlands), Urban (Residential - Low Intensity, Residential - High Intensity, Commercial), and Agricultural (Orchards/Vineyards, Pasture, Row Crops, Small Grains, Fallow). On average, BBS routes in the Salish Sea region in Washington were 62% forested, 5% Urban, and 20% agricultural, although the proportions of forested and agricultural habitats varied greatly among routes. For the residential category, routes ranged from 0 (N = 2) to 25% urban with an average of 5% urban per survey route. This analysis indicates that the habitats that we are concerned with (urban and interior conifer forest habitats) are sufficiently surveyed, although we would ideally like to have > 5% urban landscapes in our survey area. We are considering confining our analysis to routes that contain some urban land cover.

Reporting and preliminary results

We will report the following metrics for the U.S. portion of the Salish Sea annually (see Figure 3, 4 and 5 for examples). We will also report results for the Canadian portion to add perspective on the results observed in the U.S.

- Percent change in abundance of individual resident conifer species in recent years (2000-present) relative to historic trends (1970-2000). Reported as a percent change year^{-1} with associated credible intervals (roughly a Bayesian equivalent to confidence intervals)
- Percent change in abundance of resident synanthropic species in recent years (2000-present) relative to historic trends (1970-2000). Reported as a percent change year^{-1} with associated credible intervals (roughly a Bayesian equivalent to confidence intervals)

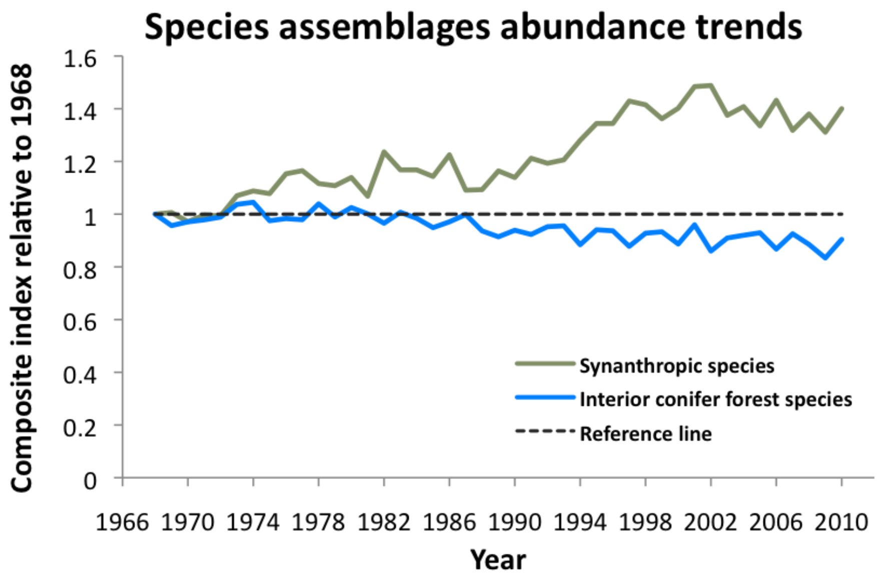


Figure 3. The abundance of interior forest species decreased over time, driven by a decline of golden-crowned kinglets, dampened by the effect of brown creepers increasing over time (see Figure 5 below). In contrast, synanthropic species increased over time, driven by house sparrows, and not affected by any other species (see Figure 6 below). Ultimately, we intend to compare recent trends (2000 – present) to older trends (1970-2000) and not the full time series pictured here.

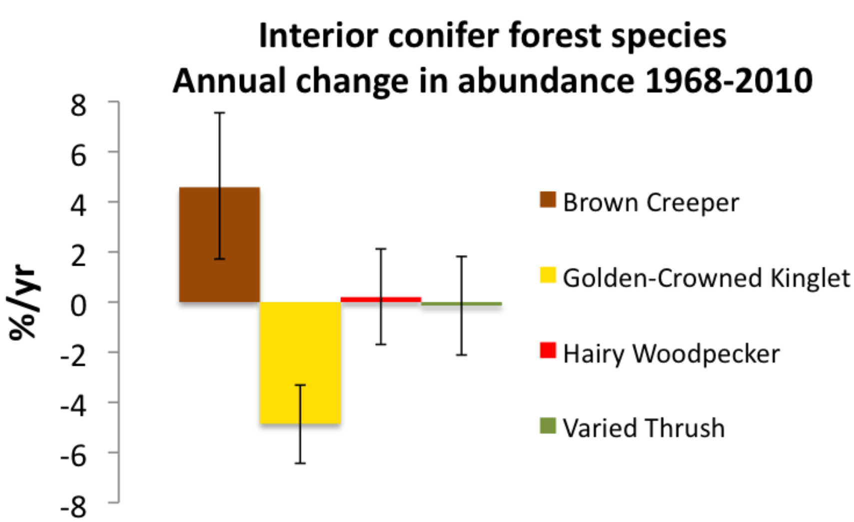


Figure 4. The annual index of abundance of brown creepers significantly increased over time. Golden-crowned kinglet abundance decreased significantly. The index values of the other two species did not change. We dropped hairy woodpeckers for our recommendation.

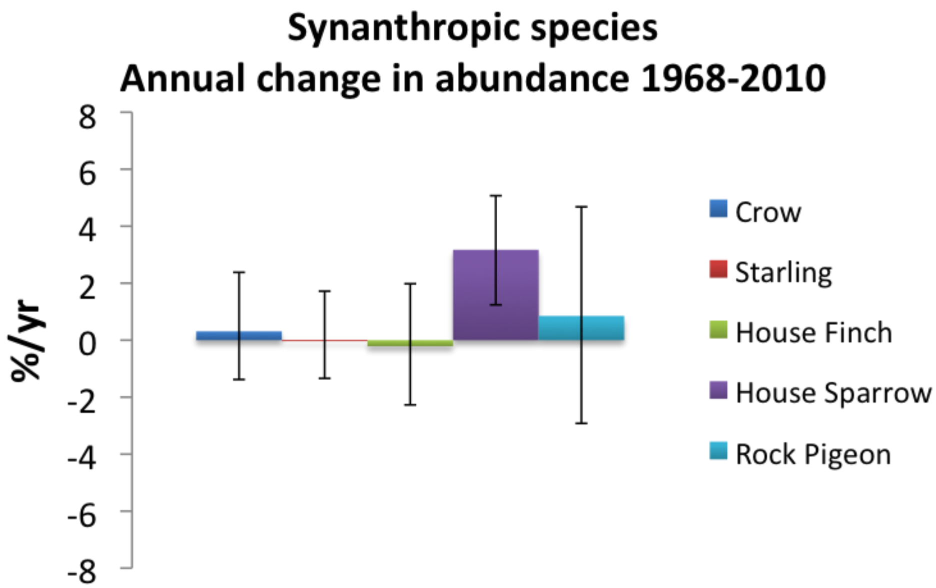


Figure 5. Only house sparrows had a significant trend, increasing over time. The annual index of abundance did not change for all other synanthropic species.

ACKNOWLEDGEMENTS

Chris Harvey conducted mass balance model simulations to help us assess the ecological context of the marine bird indicator. Shannon Knapp provided statistical advice for the power analyses that we conducted. John Sauer provided advice and conducted analyses using the Breeding Bird Survey Data for the terrestrial bird indicator and advice on the use of the BBS data and development of a terrestrial bird indicator. John Marzluff, Jack DeLap, and Ben Shryock provided advice on assigning terrestrial birds to appropriate indicator groups. Joe Evenson, Tom Good, and Julia Parrish provided comments on an earlier draft of this document. In addition, this manuscript benefitted from four anonymous reviews. Thank you all!!

LITERATURE CITED

Alberti, M., R. Weeks, and S. Coe. 2004. Urban land-cover change analysis in Central Puget Sound. Photogrammetric Engineering and Remote Sensing 70:1043-1052.

Alberti, M., D. Booth, K. Hill, B. Coburn, C. Avolio, S. Coed, D. Spirandelli. 2007. The impact of urban patterns on aquatic ecosystems: An empirical analysis in Puget lowland sub-basins. Landscape and Urban Planning 80: 345–361.

Anderson, E.M., J.R. Lovvorn, and M.T. Wilson. 2008. Reevaluating marine diets of Surf and White-winged Scoters: Interspecific differences and the importance of soft-bodied prey. Condor 110:285-295

Anderson, E.M., J.R. Lovvorn, D. Esler, W.S. Boyd, and K.C. Stick. 2009. Using predator distributions, diet, and condition to evaluate seasonal foraging sites: sea ducks and herring spawn. Marine Ecology Progress Series 386: 287–302

Anderson, E.M. and J.R. Lovvorn. 2011. Contrasts in Energy Status and Marine Foraging Strategies of White-Winged Scoters (*Melanitta fus*ca) and Surf Scoters (*M. Perspicillata*). The Auk 128:248-257

Badzinski, S.S., R.J. Cannings, T.E. Armenta, J. Komaromi and P.J.A. Davidson. 2006. The British Columbia Coastal Waterbird Survey: An evaluation of survey power and species trends after five years of monitoring. Technical Report Series No. 455. Canadian Wildlife Service Pacific & Yukon Region, British Columbia and Bird Studies Canada.

Badzinski, S.S., R.J. Cannings, T.E. Armenta, J. Komaromi, and P.J.A. Davidson. 2008. Monitoring coastal bird populations in BC: the first five years of the Coastal Waterbird Survey (1999-2004). British Columbia Birds 17:1-35.

Beamish, R.J., G.A. McFarlane, C.M. Neville and I. Pearsall. 2001. Changes in the Strait of Georgia ECOPATH model needed to balance the abrupt increases in productivity that occurred in 2000. PICES Sci. Rept. 17: 5-9Blewett, C.M. and Marzluff, J.M. 2005. Effects of urban sprawl on snags and the abundance and productivity of cavity-nesting birds. Condor 107: 677–692.

Boulinier, T, J. D. Nichols, J. E. Hines, J. R. Sauer, C. H. Flather, and K. H. Pollock. 1998a. Higher temporal variability of forest bird communities in fragmented landscapes. Proc. Nat. Acad. Sci. 95:7497-7501.

Boulinier, T, J. D. Nichols, J. R. Sauer, J. E. Hines, and K. H. Pollock. 1998b. Estimating species richness to make inference in community ecology: The importance of heterogeneity in species detectability as shown from capture-recapture analyses of North American Breeding Bird Survey Data. Ecology 79:1018-1028.

Buchanan, J.B. 1988. The abundance and migration of shorebirds at two Puget Sound estuaries. Western Birds 19:69-78.

Buchanan, J.B. 2006. Black-bellied Plovers at Totten Inlet, Washington: phenology of spring migration, and changes in winter, spring and autumn abundance. Washington Birds 9:24-34.

Buchanan, J.B. 2007. Changes in the seasonal abundance of Greater Yellowlegs at Totten Inlet, Washington. Bird Populations 8:21-25.

Buckland, S. T., D. R. Anderson, K. P. Burnham, J. L. Laake, D. L. Borchers, and L. Thomas. 2001. Introduction to distance sampling: estimating abundance of biological populations. Oxford University Press, New York.

Burnham, K. P. and W. S. Overton. 1979. Robust estimation of population size when capture probabilities vary among animals. Ecology 60:927-936

Butchart et al. 2010. Global biodiversity: Indicators of recent declines. Science 328: 1164-1168.

Cairns, D.K. 1987. Seabirds as indicators of marine food supplies. Biological Oceanography 5: 261-271.

Carey, A.B., M.M. Hardt, S.P. Horton, and B.L. Biswell. 1991. Spring bird communities in the Oregon Coast Range. Pages 123-142 in Leonard F. Ruggiero, K.B. Aubry, A.B. Carey, and M.H. Huff (eds.). Wildlife and vegetation of unmanaged Douglas-fir forests. General Technical Report PNW-GTR-285, Portland, Oregon.

Caro, T.M. and G. O'Doherty. 1999. On the use of surrogate species in conservation biology. Conservation Biology 13: 805–814.

Cochran, W. G. 1977. Sampling techniques. 3rd edition. John Wiley and Sons, New York.

Cowles, D.L., J.G. Galusha, J.L. Hayward. 2012. Negative interspecies interactions in a glaucous-winged gull colony on Protection Island, Washington. Northwestern Naturalist 93:89–100.

Crewe1, T., K. Barry, P. Davidson, and D. Lepage. 2012. Coastal waterbird population trends in the Strait of Georgia 1999–2011: Results from the first 12 years of the British Columbia Coastal Waterbird Survey British Columbia Birds 22:8-35.

Cury, P.M., I. L. Boyd, S. Bonhommeau, T. Anker-Nilssen, R.J.M. Crawford, R.W. Furness, J.A. Mills, E.J. Murphy, H. Österblom, M. Paleczny, J.F. Piatt, J. Roux, L. Shannon, and W.J. Sydeman. Global seabird response to forage fish depletion—One-third for the birds. Science 334:1703-1706.

Cushman, S.A., and K. McGarigal. 2003. Landscape-level patterns of avian diversity in the Oregon Coast Range. Ecological Monographs 73:259-281

Davoren, G.K., Montevecchi, W.A. 2003. Signals from seabirds indicate changing biology of capelin stocks. Marine Ecology Progress Series 258:253-261.

Donnelly, R. 2002. Design of habitat reserves and settlements for bird conservation in the Seattle metropolitan area. PhD dissertation, University of Washington, Seattle, Washington.

Donnelly, R. and J.M. Marzluff. 2004. Importance of reserve size and landscape context to urban bird conservation. Conservation Biology 18, 733–745.

Donnelly, R. and J.M. Marzluff. 2006. Relative importance of habitat quality, structure, and spatial pattern to birds in urbanizing environments. Urban Ecosystems 9:99-117

Drever, M.C., Aitken, K.E.H., Norris, A.R. and Martin, K. 2008. Woodpeckers as reliable indicators of bird richness, forest health and harvest. Biological Conservation 141: 624-634.

Droege, S. Undated. Christmas Bird Count Mangers Monitoring Manual. http://www.pwrc.usgs.gov/monmanual/techniques/christmasbirdcount.htm

Durant JM, Hjermann DØ, Frederiksen M, Charrassin JB and others. 2009. Pros and cons of using seabirds as ecological indicators. Clim Res 39:115-129

Evenson, J.R. and J.B. Buchanan. 1997. Seasonal abundance of shorebirds at Puget Sound estuaries. Washington Birds 6:34-62.

Ewins, P.J. 1993. Pigeon Guillemot (Cepphus Columba). *In* The Birds of North America, No. 49 (A. Poole and F. Gill, eds.). The Academy of Natural Sciences, Philadelphia, PA, and The American Onithologists' Union, Washington, D.C.

Ford, H.A., Barrett, G.W., Saunders, D.A., and Recher, H.F. 2001. Why have birds in the woodlands of Southern Australia declined? Biological Conservation 97: 71-88.

Furness, R.W. and J.J.D. Greenwood (eds.). 1993. Birds as Monitors of Environmental Change. Chapman & Hall, London.

Furness, R.W., and Tasker, M.L. 2000. Seabird-fishery interactions: quantifying the sensitivity of seabirds to reductions in sandeel abundance, and identification of key areas for sensitive seabirds in the North Sea. Marine Ecology Progress Series 202:253-264.

Garrott, R.A., P.J. White, C.A. Vanderbilt White. 1993. Overabundance: an issue for conservation biologists? Conservation Biology 7: 946-949.

Gaston, A.J., and S.B.C. Dechesne. 1996. Rhinoceros auklet (*Cerorhinca monocerata*). *In* The Birds of North America, No. 212 (A. Poole and F. Gill, eds.). The Academy of Natural Sciences, Philadelphia, PA, and The American Onithologists' Union, Washington, D.C.

Gaydos, J.K. and S.F. Pearson. 2011. Birds and mammals that depend on the Salish Sea: A compilation. Northwest Naturalist: 92:79–94.

Gilbert, F.F., and R. Allwine. 1991. Spring bird communities in the Oregon Cascade Range. Pages 145-158 in Leonard F. Ruggiero, K.B. Aubry, A.B. Carey, and M.H. Huff (eds.). Wildlife and vegetation of unmanaged Douglas-fir forests. General Technical Report PNW-GTR-285, Portland, Oregon.

Gregory, R.D., A. van Strien, P. Vorisek, A.W. Gmelig, D.G. Noble, R.P.B. Foppen, and D.W. Gibbons. 2005. Developing indicators for European birds. Philosophical Transactions of the Royal Society B360: 269–288

Hagar, J.C. 1999. Influence of riparian buffer width on bird assemblages in western Oregon. The Journal of Wildlife Management 63:484-496

Halpern, B. S., S. Walbridge, K. A. Selkoe, C. V. Kappel, F. Micheli, C. D'Agrosa, J. F. Bruno, K. S. Casey, C. Ebert, H. E. Fox, R. Fujita, D. Heinemann, H. S. Lenihan, E. M. P. Madin, M. T. Perry, E. R. Selig, M. Spalding, R. Steneck, and R. Watson. 2008. A global map of human impact on marine ecosystems. Science 319:948-952.

Hamel, N.J., A.E. Burger, K. Charleton, P. Davidson, S. Lee, D.F. Bertram, and J.K. Parrish. 2009. Bycatch and beached birds: assessing mortality impacts in coastal net fisheries using marine bird strandings. Marine Ornithology 37: 41-60.

Harvey, C.J., K.K. Bartz, J.R. Davies, T.B. Francis, T.P.Good, A.D. Guerry, M.B. Hanson, K.K. Holsman, J. Miller, M. Plummer, J.C.P. Reum, L.D. Rhodes, C.A. Rice, J.F. Samhouri, G.D.Williams,N.J. Yoder, P.S., Levin, and M.H. Ruckelshaus. 2010. A mass-balance model for evaluating food web structure and community-scale indicators in the central basin of Puget Sound. NOAA Tech. Memo. NMFS-NWFSC-106.

Harvey, C.J., T.P. Good, and S.F. Pearson. 2012a. Top–down influence of resident and overwintering Bald Eagles (*Haliaeetus leucocephalus*) in a model marine ecosystem. Canadian Journal of Zoology 90: 903–914.

Harvey, C. J., G. D. Williams, P. S. Levin. 2012b. Food web structure and trophic controls in central Puget Sound. Estuaries and Coasts 35:821-838.

Harwell MA, Myers V, Young T, Bartuska A, Gassman N, et al. .1999. A framework for an ecosystem integrity report card. Bioscience 49: 543–556.

Hayward, J.L., J.G. Galusha, and G. Frias. 1993. Analysis of great horned owl pellets with rhinoceros auklet remains. The Auk 110:133-135.

Hayward, J.L., J.G. Galusha, and S.M. Henson. 2010. Foraging-related activity of Bald Eagles at a Washington seabird colony and seal rookery. Journal of Raptor Research 44:19-29.

Hepinstall, J. A., M. Alberti, and J. M. Marzluff. 2008. Predicting land cover change and avian community responses in rapidly urbanizing environments. Landscape Ecology 23:1257-1276.

Hines, J.E., T. Boulinier, J.D. Nichols, J.R. Sauer, and K.H. Pollock. 1999. COMDYN: software to study the dynamics of animal communities using a capture-recapture approach. Bird Study 46 (suppl.):S209-217.

Hipfner, J.M., L.K. Blight, R.W. Lowe, S.I. Wilhelm, G.J. Robertson, R.T. Barrett, T. Anker-Nilssen, and T.P. Good. 2012. Unintended consequences: How recovery of sea eagle *Haliaeetus spp*. Populations in the Northern Hemisphere is affecting seabirds. Marine Ornithology 40: 39–52.

Hoenig, J.M., and D.M. Heisey. 2001. The abuse of power: The pervasive fallacy of power calculations for data analysis. American Statistician 55:19-24.

Hull, C.L., G.W. Kaiser, C. Lougheed, L. Lougheed, S. Boyd, and F. Cooke. 2001. Intraspecific Variation in Commuting Distance of Marbled Murrelets (*Brachyramphus marmoratus*): Ecological and Energetic Consequences of Nesting Further Inland. Auk 118:1036-1046.

Jessup DA, Miller MA, Ryan JP, Nevins HM, Kerkering HA, et al. 2009. Mass Stranding of Marine Birds Caused by a Surfactant-Producing Red Tide. PLoS ONE 4(2): e4550. doi:10.1371/journal.pone.0004550

Johnston, R. F. 2001. Synanthropic birds of North America. Pages 49–67 in J. M. Marzluff, R. Bowman, and R. Donnelly, editors. Avian ecology and conservation in an urbanizing world. Kluwer Academic, Boston, Massachusetts, USA.

Jokimaki, J., and Huhta, E. 2000. Artificial nest predation and abundance of birds along an urban gradient. Condor 102: 838-847.

Kato, A., Y. Watanuki, and Y. Naito. 2003. Foraging behaviour of chick-rearing rhinoceros auklets Cerorhinca monocerata at Teuri Island, Japan, determined by acceleration-depth recording Micro Data Loggers. Journal of Avian Biology 34: 282-287

Kershner J., J.F. Samhouri, C.A. James, P.S. Levin. 2011. Selecting Indicator Portfolios for Marine Species and Food Webs: A Puget Sound Case Study. PLoSONE 6(10): e25248. doi:10.1371/journal.pone.0025248Lacroix D.L., S. Boyd, D. Esler, M. Kirk, T. Lewis, and S. Lipovsky. 2005. Surf scoters *Melanitta perspicillata* aggregate in association with ephemerally abundant polychaetes. Marine Ornithology 33:61–63

Lance, M.M., and C.W. Thompson. 2005. Overlap in diets and foraging of common murres (Uria aalge) and rhinoceros auklets (cerorhinca monocerata) after the breeding season. Auk 122:887-901.

Lance, M.M., and S.F. Pearson. 2012. Assembling and Assessing Seabird Diet Information in the Salish Sea. Washington Department of Fish and Wildlife, Wildlife Research Division, Olympia, Washington

Lance, M.M., S.F. Pearson, M.G. Raphael, and T. D. Bloxton, Jr. 2012. Washington 2011 at-sea marbled murrelet population monitoring: Research Progress Report. Washington Department of Fish and Wildlife, Wildlife Science Division and USDA Forest Service Pacific Northwest Research Station, Olympia, WA.

Langston, N.E. and S. Rohwer. 1996. Molt-Breeding Tradeoffs in Albatrosses: Life History Implications for Big Birds. Oikos 76: 498-510.

Leadership Council. 2010. Puget Sound Leadership Council Meeting Summary. July 29 & 30 2010 Mount Vernon, WA.

Leckrone Lee, J., K.B. Pierce, and K. Stiles. 2011. Setting targets for ecosystem protection and recovery – land cover and land development. Puget Sound Partnership, Tacoma, WA

Legg, C.J., and L. Nagy. 2006. Why most conservation monitoring is, but need not be, a waste of time. Journal of Environmental Management 78:194-199.

Leu, M., S. E. Hanser, and S. T. Knick. 2008. The human footprint in the west: A large-scale analysis of anthropogenic impacts. Ecological Applications 18:1119-1139.

Levin, P.S., A. James, J. Kershner, S. O'Neill, T. Francis, J. Samhouri, C. Harvey, M.T. Brett, and D. Schindler. 2011. April 2011. Understanding Future and Desired System States in Puget Sound Science Update, April 2011 version. Accessed from http://www.psp.wa.gov/. Puget Sound Partnership. Tacoma, Washington.

Link, W. A. and J. R. Sauer. 2002. A hierarchical analysis of population change with application to cerulean warblers. Ecology 83:2832–2840

Link, W. A. and J. R. Sauer. 2007. Seasonal components of avian population change: Joint analysis of two large-scale monitoring programs. Ecology 88(1):49-55.

Mallory, M. L., S. A. Robinson, C. E. Hebert, and M. R. Forbes. 2010. Seabirds as indicators of aquatic ecosystem conditions: A case for gathering multiple proxies of seabird health. Marine Pollution Bulletin 60:7–12.

Manuwal, D.A. 1991. Spring bird communities in the southern Washington Cascade Range. Pages 161-174 in Leonard F. Ruggiero, K.B. Aubry, A.B. Carey, and M.H. Huff (eds.). Wildlife and vegetation of unmanaged Douglas-fir forests. General Technical Report PNW-GTR-285, Portland, Oregon.

Manuwal, D.A., and S.F. Pearson. 1997. Bird populations in managed forests in the western Cascade Mountains, Washington. Pp. 1-61 in Wildlife use of managed forests: A landscape perspective (K. B. Aubry, J. G. Hallett, S. D. West, M. A. O'Connell, & D. A. Manuwal, eds.). Timber Fish and Wildlife General Technical Report:WL4-98-002.

Martell, S.J.D., Beattie, A.I., Walters, C.J., Nayar, T., Briese, R., 2002. Simulating fisheries management strategies in the Strait of Georgia ecosystem using Ecopath and Ecosim. Pages 16–23 in Pitcher, T., Cochrane, K. (Eds.), The Use of Ecosystem Models to Investigate Multispecies Management Strategies for Capture Fisheries Fish Center Research Reports. 10(2).

Marzluff, J.M. 2005. Island biogeography for an urbanizing world: how extinction and colonization may determine biological diversity in human-dominated landscapes. Urban Ecosystems 8: 157–177

Marzluff, J.M., Withey, J.C., Whittaker, K.A., Oleyar, M.D., Unfried, T.M., Rullman, S., and DeLap, J. 2007. Consequences of habitat utilization by nest predators and breeding songbirds across multiple scales in an urbanizing landscape. Condor 109: 516-534.

McFarlane-Tranquillla, L., J.L. Ryder, W.S. Boyd, S.G. Shisko, K. Amey, D.F. Bertram, and J.M. Hipfner. 2004. Diurnal marine distributions of marked Cassin's and rhinoceros auklets breeding at Triangle Island, British Columbia. Canadian Wildlife Service Technical Report Series No. 423

McGarigal, K., and W.C. McComb. 1992. Streamside versus upslope breeding bird communities in the central Oregon Coast Range. The Journal of Wildlife Management 56:10-23.

McGarigal K, and WC McComb. 1995. Relationships between landscape structure and breeding birds in the Oregon Coast Range. Ecological Monographs 65(3):235-260.

McGarigal K, and WC McComb. 1999. Forest fragmentation effects on breeding birds in the Oregon Coast Range. Pages 223-246 in JA Rochelle, LA Lehman, and J Wisniewski (eds.), Forest fragmentation: wildlife and management implications. Koninklijke Brill NV, Leiden, The Netherlands.

McKinney, M.L. 2006. Urbanization as a major cause of biotic homogenization. Biological Conservation 127: 247-260.

Miller, S.L, C. J. Ralph, M. G. Raphael, C. Strong, C. W. Thompson, J. Baldwin, M. H. Huff, and G. A. Falxa. 2006. At-sea monitoring of Marbled Murrelet population status and trend in the Northwest Forest Plan area, p. 31-60. In M.H. Huff, M. G. Raphael, S. L. Miller, S. K. Nelson, and J. Baldwin [tech. cords.], Northwest Forest Plan—The first 10 years (1994-2003): status and trends of populations and nesting habitat for the Marbled Murrelet. USDA Forest Service General Technical Report PNW-GTR-650.

Miller, S.L., M.G. Raphael, G.A. Falxa, C. Strong, J. Baldwin, T. Bloxton, B.M. Galleher, M. Lance, D. Lynch, S.F. Pearson, C.J. Ralph, and R.D. Young. 2012. Recent population decline of the marbled murrelet in the Pacific Northwest. Condor 114:771-781.

Montevecchi, W.A., and R.A. Myers. 1995. Prey harvests of seabirds reflects pelagic fish and squid abundance on multiple spatial and temporal scales. Marine Ecology Progress Series 117:1-9.

Moore, E. S. Lyday, J. Roletto, K. Litle, J. K. Parrish, H. Nevins, J. Harvey, J. Mortenson, D. Greig, M. Piazza, A. Hermance, D. Lee, D. Adams, S. Allen, and S. Kell 2009. Entanglements of marine mammals and seabirds in central California and the north-west coast of the United States 2001–2005. Marine Pollution Bulletin 58:1045–1051

Nee, S., and May, R.M. 1992. Dynamics of metapopulations - habitat destruction and competitive coexistence. Journal of Animal Ecology 61:37-40.

Neter, John, Michael H. Kutner, Christopher J. Nachtsheim, and William Wasserman. 1996. Applied Linear Statistical Models. 4th ed. WCB McGraw-Hill. Boston, MA, USA.

Nichols, J. D., T. Boulinier, J. E. Hines, K. H. Pollock, and J. R. Sauer. 1998a. Estimating rates of local species extinction, colonization, and turnover in animal communities. Ecological Applications 8:1213-1225.

Nichols, J. D., T. Boulinier, J. E. Hines, K. H. Pollock, and J. R. Sauer. 1998b. Inference methods for spatial variation in species richness and community composition when not all species are detected. Conservation Biology 12:1390-1398.

Noss, R.F. 1990. Indicators for monitoring biodiversity: A hierarchical approach. Conservation Biology 4:355-364.

Nysewander, D.R., J.R. Evenson, B.L. Murphie, and T.A. Cyra. 2005. Report of marine bird and mammal component, Puget Sound Ambient Monitoring Program, for July 1992 to December 1999 period [Unpublished report]. Olympia, WA: Washington State Department of Fish and Wildlife, Wildlife Management Program. 181 pp.

O'Hara, P.D., P. Davidson, and A.E. Burger. 2009. Aerial surveillance and oil spill impacts based on beached bird survey data collected in southern British Columbia. Marine Ornithology 37: 61–65.

O'Neill S.M., C.F. Bravo, and T.K. Collier. 2008. Environmental Indicators for the Puget Sound Partnership: A Regional Effort to Select Provisional Indicators (Phase 1). Summary Report. Seattle, WA: National Oceanic and Atmospheric Administration.

Pardieck, K. L. and J. R. Sauer. 2007. The 1999-2003 Summary of the North American Breeding Bird Survey. Bird Populations 8:28-45.

Parrish, J.K., and Zador, S.G. 2003. Seabirds as indicators: an exploratory analysis of physical forcing in the Pacific Northwest Coastal Environment. Estuaries 2:1045-1058.

Parrish, J. K., N. Bond, H. Nevins, N. Mantua, R. E. Loeffel, W. T. Peterson and J. T. Harvey 2007. Beached birds and physical forcing in the California Current System. Marine Ecology-Progress Series 352: 275-288.

Pearson S.F, and D.A. Manuwal. 2000. Influence of niche overlap and interspecific territoriality on hybridization between hermit and Townsend's warblers. Auk: 117:175-183.

Pearson, S.F. and S. Rohwer. 2000. Asymmetries in male aggression across an avian hybrid zone. Behavioral Ecology 11:93-101.

Pearson, S.F., and D.A. Manuwal. 2001. Breeding bird response to riparian buffer width in managed Pacific Northwest Douglas-fir forests. Ecological Applications 11:840-853.

Pearson, S.F., P.J. Hodum, M. Schrimpf, J. Dolliver, T.P. Good, and J.K. Parrish. 2009. Rhinoceros Auklet (Cerorhinca monocerata) Burrow Counts, Burrow Density, Occupancy Rates, and Associated Habitat Variables on Protection Island, Washington: 2008 Research Progress Report. Washington Department of Fish and Wildlife, Wildlife Science Division, Olympia.

Pearson, S.F., N. Hamel, S. Walters, and J. Marzluff, *eds*. 2010a. Chapter 3: Impacts of Human Activities on the Ecosystem. In Puget Sound Science Update, Puget Sound Partnership, Tacoma, Washington.

Pearson, S.F., P.J. Hodum, T.P. Good, M. Schrimpf, J. Dolliver, and J.K. Parrish. 2010b. Rhinoceros Auklet (Cerorhinca monocerata) Burrow Counts, Burrow Density, Occupancy Rates, and Associated Habitat Variables on Protection and Destruction Islands, Washington: 2009 Field Season Research Progress Report. Washington Department of Fish and Wildlife, Wildlife Science Division, Olympia.

Pearson, S.F., P. Hodum, M. Schrimpf, J.K. Parrish, T.P. Good, J. Dolliver. 2012. Variation in rhinoceros auklet diet and reproduction across oceanographic regimes. In prep.

Pearson, S.F., P.J. Hodum, T.P. Good, M. Schrimpf, S. Knapp. 2013. A model approach for estimating colony size, trends and habitat associations of burrow-nesting seabirds. Condor 115(2):356–365.

Petrova1, M., A. Sedgley, G. Joyce, P.J. Hodum, S.F. Pearson, N.J. Hamel, T. Hass, I. Logan, H. Curl, K.N. Marshall, E.J. Ward. 2012. Examination of trends and effects of climate drivers on seabird densities in Puget Sound. Marine Ecology Progress Series in press.

Phillips, E.M., J.E. Zamonb, H.M. Nevins, C.M. Gibble, R.S. Duerr, and L.H. Kerr. 2011. Summary of Birds Killed by a Harmful Algal Bloom along the South Washington and North Oregon Coasts During October 2009. Northwestern Naturalist 92:120-126.

Piatt, J. F., W. J. Sydeman, and F. Wiese. 2007. Introduction: A modern role for seabirds as indicators. Marine Ecology Progress Series 352:199–204.

Pidgeon, A.M., V. C. Radeloff, C. H. Flather, C. A. Lepczyk, M. K. Clayton, T. J. Hawbaker, and R. B. Hammer. 2007. Associations of forest bird species richness with housing and landscape patterns across the USA. Ecological Applications 17:1989–2010.

Preikshot, D. R.J. Beamish, and C.M. Neville. 2013. A dynamic model describing ecosystem-level changes in the Strait of Georgia from 1960 to 2010. Progress in Oceanography 115:28–40.

Puget Sound Partnership. 2008. Puget Sound Action Agenda, Protecting and Restoring the Puget Sound Ecosystem by 2020. Olympia, WA. 207 p.

Puget Sound Partnership. 2010. Strategic Science Plan. Olympia, WA: Puget Sound Partnership. 58 p.

Puget Sound Partnership's Indicator Action Team. 2010. Development of the dashboard of ecosystem indicators for Puget Sound. Draft report. 47 pp.

R Development Core Team. 2012. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/.

Raphael, M. G., J. Baldwin, G. A. Falxa, M. H. Huff, M. Lance, S. L. Miller, S. F. Pearson, C. J. Ralph, C. Strong, and C. Thompson. 2007. Regional population monitoring of the Marbled Murrelet: field and analytical methods. USDA Forest Service General Technical Report PNW-GTR-716.

Rice, C.A. 2007. Evaluating the biological condition of Puget Sound. PhD dissertation, University of Washington, Seattle, WA. 270 pp.

Rohwer, S., and C. Wood. 1998. Three hybrid zones between hermit and Townsend's warblers in Washington and Oregon. Auk 115:284-310.

Rosenberg, K.V. and M.G. Raphael. 1986. Effects of forest fragmentation in Douglas-fir forests. In: . Verner, M. L. Morrison, and C. J. Ralph. Wildlife 2000: Modeling habitat relationships of terrestrial vertebrates. Madison, WI: University of Wisconsin Press: 470.

Ruckelshaus, M.H., and M.M. McClure. 2007. Sound Science: Synthesizing ecological and socioeconomic information about the Puget Sound ecosystem. Seattle, WA: National Oceanographic and Atmospheric Administration, Northwest Fisheries Science Center.

Sauer, J. R., W. A. Link, W. L. Kendall, J. R. Kelley, and D. K. Niven. 2008. A hierarchical model for estimating change in American Woodcock populations. Journal of Wildlife Management 72(1):204-214.

Sauer, J. R., J. E. Hines, J. E. Fallon, K. L. Pardieck, D. J. Ziolkowski, Jr., and W. A. Link. 2011. The North American Breeding Bird Survey, Results and Analysis 1966 - 2010. Version 12.07.2011 USGS Patuxent Wildlife Research Center, Laurel, MD

Sauer, J. R., and W. A. Link. 2011. Analysis of The North American Breeding Bird Survey Using Hierarchical Models. The Auk 128: 87-98. +Supplemental Online Material

Sauer, J. R., J. E. Hines, J. E. Fallon, K. L. Pardieck, D. J. Ziolkowski, Jr., and W. A. Link. 2011. The North American Breeding Bird Survey, Results and Analysis 1966 - 2009. Version 3.23.2011 USGS Patuxent Wildlife Research Center, Laurel, MD

Shirley, S.M., and J.N.M. Smith 2005. Bird community structure across riparian buffer strips of varying width in a coastal temperate forest. Biological Conservation 125:475-489

Shochat, E., Lerman, S.B., Anderies, J.M., Warren, P.S., Faeth, S.H., and Nilon, C.H. 2010. Invasion, Competition, and Biodiversity Loss in Urban Ecosystems. Bioscience 60: 199-208.

Sokal, R. R., and F. J. Rohlf. 1981. Biometry: the principles and practice of statistics in biological research. 2nd ed. W.H. Freeman and Company, San Francisco, CA.

Speich, S.M., and T.R. Wahl. 1989. Catalog of Washington seabird colonies. U.S. Fish and Wildlife Service Biological Report 88(6). 510 pp.

Thomas, L., S. T. Buckland, E. A. Rexstad, J. L. Laake, S. Strindberg, S. L. Hedley, J. R. B. Bishop, T. A. Marques, and K. P. Burnham. 2010. Distance software: design and analysis of distance sampling surveys for estimating population size. Journal of Applied Ecology 47: 5-14. DOI: 10.1111/j.1365-2664.2009.01737.x. Distance 6.0. < http://www.ruwpa.st-and.ac.uk/distance/> (2 June 2011).

Thompson, S.P., McDermond, D.K., Wilson, U.W., and Montgomery, K. 1985. Rhinoceros auklet burrow count on Protection Island, Washington. Murrelet 66:62-65.

U.S. Environmental Protection Agency. 2002. A Framework for Assessing and Reporting on Ecological Condition: A Science Advisory Board Report. Washington, D.C. 142 p.

U.S. Fish and Wildlife Service (USFWS). 2009. Marbled Murrelet (*Brachyramphus marmoratus*): 5 Year Review. Washington Fish and Wildlife Office, Lacey, WA. 108 p.

U.S. NABCI Committee. 2009. The State of the Birds, United States of America, 2009. [Online.] U.S. Department of the Interior, Washington, D.C. Available at www.stateofthebirds.org/2009/.

Vogelmann, J.E., S.M. Howard, L. Yang, C. R. Larson, B. K. Wylie, and J. N. Van Driel, 2001. Completion of the 1990's National Land Cover Data Set for the conterminous United States, Photogrammetric Engineering and Remote Sensing 67:650-662.

Wahl T.R., S.M. Speich. 1994. Distribution of Foraging Rhinoceros Auklets in the Strait of Juan de Fuca, Washington. Northwestern Naturalist 75:63-69

Walters, C.J., Christensen, V., Pauly, D. 1997. Structuring dynamic models of exploited ecosystems from trophic mass-balance assessments. Reviews in Fish Biology and Fisheries 7:139–172.

Washington State Academy of Sciences. 2012. Sound Indicators: A Review for the Puget Sound Partnership. Olympia, WA. 101 pp.

Wilson, U. W. 1977. A study of the biology of the rhinoceros auklet on Protection Island, Washington. M.Sc. thesis. University of Washington, Seattle, WA.

Wilson, U.W. 2005. The effect of the 1997-1998 El Nino on rhinoceros auklets on Protection Island, Washington. Condor 107:462-468.

Wilson U.W., Manuwal, D.A. 1986. Breeding biology of the rhinoceros auklet in Washington. Condor 88:143-155.

Appendices

Appendix I. Table 3 from Kershner et al. (2011): Criteria used to evaluate marine and terrestrial bird species indicators for Puget Sound.

Primary Considerations
1) **Theoretically-sound (TS)** - Scientific, peer-reviewed findings should demonstrate that indicators act as reliable surrogates for ecosystem key attribute(s).
2) **Relevant to management concerns (RM)** - Indicators should provide information related to specific management goals and strategies.
3) **Responds predictably and is sufficiently sensitive to changes in a specific ecosystem key attribute(s) (REA)** - Indicators should respond unambiguously to variation in the ecosystem key attribute(s) they are intended to measure, in a theoretically- or empirically-expected direction.
4) **Responds predictably and is sufficiently sensitive to changes in specific management action(s) or pressure(s) (RMAP)** - Management actions or other human-induced pressures should cause detectable changes in the indicators, in a theoretically- or empirically-expected direction, and it should be possible to distinguish the effects of other factors on the response.
5) **Linkable to scientifically-defined reference points and progress targets (LT)** – It should be possible to link indicator values to quantitative or qualitative reference points and target reference points, which imply positive progress toward ecosystem goals.
Data Considerations
6) **Concrete (C)** - Indicators should be directly measureable.
7) **Historical data or information available (HD)** - Indicators should be supported by existing data to facilitate current status evaluation (relative to historic levels) and interpretation of future trends.
8) **Operationally simple (OS)** - The methods for sampling, measuring, processing, and analyzing the indicator data should be technically feasible.
9) **Numerical (N)** - Quantitative measurements are preferred over qualitative, categorical measurements, which in turn are preferred over expert opinions and professional judgments.
10) **Broad spatial coverage (BSC)** - Ideally, data for each indicator should be available throughout its range in Puget Sound.
11) **Continuous time series (CTS)** - Indicators should have been sampled on multiple occasions, preferably without substantial time-gaps between sampling.
12) **Spatial and temporal variation understood (STV)** - Diel, seasonal, annual, and decadal variability in the indicators should ideally be understood, as should spatial heterogeneity or patchiness in indicator values.
13) **High signal-to-noise ratio (HSN)** - It should be possible to estimate measurement and process uncertainty associated with each indicator, and to ensure that variability in indicator values does not prevent detection of significant changes.
Other considerations
14) **Understood by the public and policy makers (UP)** - Indicators should be simple to interpret, easy to communicate, and public understanding should be consistent with technical definitions.
15) **History of public reporting (HR)** - Indicators already perceived by the public and policy makers as reliable and meaningful should be preferred over novel indicators.

16) **Cost-effective (CE)** - Sampling, measuring, processing, and analyzing the indicator data should make effective use of limited financial resources.
17) **Anticipatory or leading indicator (A)** - A subset of indicators should signal changes in ecosystem attributes before they occur, and ideally with sufficient leadtime to allow for a management response.
18) **Regionally/nationally/internationally compatible (CM)** - Indicators should be comparable to those used in other geographic locations, in order to contextualize ecosystem status and changes in status.
Post-hoc analysis
19) **Complements existing indicators** - This criterion is applicable in the selection of a suite of indicators, performed after the evaluation of individual indicators in a post-hoc analysis. Sets of indicators should be selected to avoid redundancy, increase the complementary of the information provided, and to ensure coverage of key attributes.
New Criteria
1) **Established program (EP)** -Is there an established and ongoing monitoring program?
2) **Statistical power (SP)** - Can the effort detect trends should they occur?

Primary considerations provide scientifically useful, management-relevant information about the status of an indicator; data considerations relate to the actual measurement of an indicator, and are listed separately to highlight indicators for which data are currently unavailable; other considerations may be important to some user groups but are not necessarily essential for indicator performance, and are meant to incorporate non-scientific information into the indicator evaluation process. “New criteria” are criteria that we added to those developed by Kershner et al. (2011).

Appendix 2. Marine Bird Monitoring Efforts and Associated Indicators

Abundance/density during the breeding season

Five indicators relate to abundance or density, but the associated survey efforts vary by time of year and species surveyed (Table 2). Two survey efforts focus on marine bird abundance or density during the breeding season (May-July). One of these programs, the "Marbled murrelet at-sea surveys" in Puget Sound and the Strait of Juan de Fuca, measures densities of all marine bird species observed on the water during boat based surveys. This relatively long-term monitoring program (12 years) was designed to evaluate the effectiveness of the Northwest Forest Plan (Madsen et al. 1999), which is a large-scale ecosystem management plan for federal lands in the Pacific Northwest. As a part of this effort, the U.S. Forest Service has conducted boat-based surveys for the marbled murrelet since 2000 in Puget Sound and Strait of Juan de Fuca (Miller et al. 2006, in press, Raphael et al. 2007, Lance et al. 2011). This boat-based monitoring effort uses line transect distance sampling methods that take into account detectability of different species. All detected seabirds and mammals are recorded.

These marbled murrelet at-sea surveys are a promising source of data because results can be used to assess the trends of local breeding species in Puget Sound, and whose abundances are more likely to be tied to local ecological conditions than non-breeding birds. These surveys occur when birds are closely tied to local nesting sites and before young of the year are on the water (juveniles are not necessarily tied to local nesting sites). Because there is an identical survey effort for the outer coast of Washington and Oregon, the results for Puget Sound can be put into a broader, regional context to determine if observed spring/summer bird abundance trends are unique to the Sound or part of larger trends not driven by local conditions. Furthermore, the methods have been well described and vetted, and findings have been published both in annual reports and the peer-reviewed literature (Raphael et al. 2007, Miller et al. 2012). This project has been consistently funded and conducted since 2000, and is anticipated to continue for the next several years.

The other survey effort that occurs during the breeding season focuses on the rhinoceros auklet colonies (Protection Island, one of North America's largest nesting colonies, and Smith Island; see Pearson et al. 2013). The work is colony-based, rather than at-sea, and tracks colony size along with nesting success. However, changes in colony population sizes may lag ecological changes due to the delayed appearance of juveniles recruiting into the population. Other programs in Puget Sound assess the size and trends of nesting colonies in Puget Sound (e.g., glaucous-winged gull, pigeon guillemot, cormorants, etc.), but only the rhinoceros auklet colony size estimation effort has a published monitoring scheme including a power analysis of the effort's ability to detect trends (Pearson et al. 2009, 2010, 2013). The rhinoceros auklet program has other advantages because it includes an ongoing effort to evaluate breeding success and diet quality and composition (see below). Furthermore, results can be put into a broader geographical context by comparing the Puget Sound colony to outer coast colonies, as well as a historical context by comparing current status to the 1970s (Wilson 1977, Wilson and Manuwal 1986). Periodic re-assessments of colony size and condition can complement and provide insight into the at-sea breeding abundance trends described above. Once monitoring schemes are published and statistical power has been evaluated, other efforts to monitor nesting colonies of other species could eventually be added to the list of selected monitoring programs assuming they can help provide insights into the health of Puget Sound.

Abundance during the non-breeding season

Two programs count marine birds on the water during the non-breeding season (indicator = marine bird abundance non-breeding), namely, the Puget Sound Asssessment and Monitoring Program (PSAMP) surveys and the Puget Sound Seabird Surveys. Of these, only the PSAMP winter aerial survey program is at the scale of the entire Puget Sound and Strait of Juan de Fuca. Since 1992, Washington Department of Fish and Wildlife has conducted aerial surveys of all marine birds in Puget Sound between December and February, a period with minimal migratory movement (Nysewander et al. 2005). In each winter, all shorelines and a sample of offshore waters (>20 m deep) were surveyed once. An observer records all birds within a transect 50 m wide on each side of the plane (i.e. total transect width was 100 m). This aerial survey effort is especially suited for seaducks, loons, and grebes (see details below). The program has used the same airplane make and model and the same observers for nearly its entire history and as a result, the trends observed are likely to reflect true changes in seabird abundances or distributions. Efforts are currently underway to address potential issues of detectability and to develop better data analysis and reporting tools. Data from this program have been used successfully to examine the effect of shoreline development on wintering bird abundance (Rice 2007).

Two other monitoring efforts count marine birds during the non-breeding season, the Puget Sound Seabird Survey and the British Columbia Coastal Waterbird Survey but the later is not included in our compilation because it is a Canadian effort and our goal is to develop a Puget Sound indicator. Both of these programs monitor birds from fixed, shore-based observation stations using volunteer observers. The programs have a more restricted geographical scale than the PSAMP winter surveys (i.e., observations do not go beyond 300 m from shore and cover fewer basins and less coastline). However, surveys occur monthly, over more months (October –April). The Puget Sound Seabird Survey started in 2007 in the Seattle area and has expanded to include observation stations in the central and southern Puget Sound (King and Pierce Counties primarily, and some in Thurston, Jefferson, Snohomish, and Island counties). Currently, nearly all observation stations are located on the eastern shore of the Sound. The program is in a period of expansion and just received a grant to expand to Whidbey Island and the Strait of Juan de Fuca. This program directly addresses issues of detectability in its design and includes high quality training, oversight and includes annual reporting. Similarly, the British Columbia Coastal Waterbird Survey is a 12-year effort that includes broad coverage of both shores of the Georgia Strait and the northern shore of the Strait of Juan de Fuca and also reports results annually. The results of these two efforts, because of their similarity in methodology (point counts from shore) and timing (October – April), could potentially be combined to provide a fairly broad transboundary indicator of fall through spring, nearshore bird abundances. However, an analytical approach for combining results from these efforts has not been developed. These efforts are particularly effective at tracking trends in western and horned grebes, common, red-throated, and Pacific loons, rhinoceros auklet, and several sea ducks (black and white-winged scoters, long-tailed duck, Barrow's goldeneye, harlequin duck) (Crewel et al. 2012).

Population condition

Two monitoring efforts provide indicators of marine bird condition (marine bird mortality), the Coastal Observation and Seabird Survey Team (COASST) and the British Columbia Beached Bird Survey. Again, the Canadian effort is not included in our compilation because the goal is to develop a Puget Sound indicator. In both of these programs, volunteers monitor the number of bird carcasses on beaches monthly throughout the year to assess patterns of seabird mortality. The COASST program monitors 213 beaches in Puget Sound and Strait of Juan de Fuca and the British Columbia Beached Bird Survey monitors 67 beaches along the Straits of Georgia and Juan de Fuca. Volunteer observers receive extensive training, are provided with high quality bird identification materials aimed at facilitating accurate species identification, and the program has well established methods to verify the accuracy of observations and reporting. Results from these efforts establish baseline beached bird encounter rates, and thus are particularly suited for detecting acute mortality events for both resident and migrant species that are detected fairly regularly on Puget Sound beaches - glaucous-winged gull, surf scoter, rhinoceros auklet, common murre, and western grebe. Results from these efforts have been used to detect changes in mortality rates following oil spills (e.g., Dalco Passage Spill), evaluate the effectiveness of aerial surveillance in preventing small oil discharges (O'Hara et al. 2009), assess the impact of entanglement in fishing gear (Hamel et al. 2009, Moore et al. 2009), and understand the effect of oceanographic conditions (Parrish et al. 2007).

Community composition

Only the rhinoceros auklet diet monitoring (indicator = seabird diet – rhinoceros auklet) assesses changes in community composition, an attribute of food web interactions. This indicator was not included in our final selection because there is currently no funding for an ongoing monitoring program. This effort focused on measuring changes in chick diet composition (prey species) and quality (size of prey and calories) on Protection Island. Chick diet is dominated by forage fish species. The birds act like "samplers" of local populations of forage fish as they locate suitable and available prey, generally within 40-87 km of their colony (Wahl & Speich 1994, Kato et al. 2003, McFarlane-Tranquilla et al. 2004). This radius includes portions of the Strait of Juan de Fuca, the San Juan Archipelago, and northern-central Puget Sound. Data from the 1970s and from recent years (Wilson 1977, Wilson and Manuwal 1986, Wilson 2005, Pearson et al. in prep.) can be compared. Again, because similar data were also gathered at a coastal colony (Destruction Island), trends observed in Puget Sound can be put into a larger context that provides the opportunity to distinguish trends unique to the Sound. Puget Sound rhinoceros auklet chick diet is very diverse but is dominated Pacific sand lance (*Ammodytes hexapterus*) and Pacific herring (*Clupea harengus pallasi*). Pacific herring is also on Partnership's "dashboard" of Vital Signs. It would be interesting to link these two indicators by examining the relationship between the relative abundance of herring in the auklet diet and herring stock size. This link, if it exists, would provide information on the strength of food web relationships among species. This monitoring effort could be expanded to Smith Island to increase its spatial scope.