CHANGES IN WATER-ASSOCIATED BIRD ABUNDANCE

ON BUDD INLET AND CAPITOL LAKE, WA

FROM 1987 TO 2017

by

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ABSTRACT

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Tara Newman

The abundance of water-associated birds has been changing around the world in recent decades. Population trends vary by species and by location, and likely contributing factors are changes in food source availability and environmental contamination. While some studies have been done in the Puget Sound region, research has not yet investigated population trends locally on Budd Inlet and Capitol Lake in Olympia, Washington. Capitol Lake is an artificial reservoir that was created by constructing a dam preventing flow of the Deschutes River into Budd Inlet, and because of the unique characteristics and history of these sites, there may be factors that influence bird populations locally in ways that are not observed at the regional scale. This analysis seeks to fill the knowledge gap about this local ecosystem by using generalized linear models to determine the direction and significance of changes in water-associated bird abundance on Budd Inlet and Capitol Lake from 1987 to 2017, focusing on surface-feeding ducks, freshwater diving ducks, sea ducks, loons, and grebes. Many species that utilize Budd Inlet have experienced population declines over this period, while many species that utilize Capitol Lake have seen their populations increase. These trends are strongest for species that have a high degree of specificity for one habitat type or the other. On Capitol Lake, surface-feeding ducks and diving ducks that feed on aquatic vegetation have generally increased, and some benthic feeding species have declined. On Budd Inlet, many sea duck and loon species have declined, especially those that strongly prefer the saltwater habitat in Budd Inlet and consume primarily benthic organisms. Further research is needed to examine the reasons for these population changes, determine whether similar population changes have occurred elsewhere, and continue monitoring population trends in the future.

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INTRODUCTION

Populations of water-associated birds, both worldwide and at more local scales, have changed dramatically over the course of the last few decades. Some species and types of birds have undergone substantial declines, while others have seen increases and recoveries. Many of these changes are related to human activities and policies, either directly through hunting and fishing practices, or indirectly through water pollution, climate change, or habitat destruction.

Major declines have been observed throughout the world in populations of seabirds that were once abundant, due in large part to anthropogenic activities (Boersma et al. 2001; Bower 2009; Paleczny et al. 2015; Dickson & Gilchrist 2002; Tasker et al. 2000; Bower 2009). Worldwide assessment of seabird population status has found that a third of seabird species are threatened with extinction, half are declining, and at least four species are already extinct (Croxall et al. 2012). The reasons for these declines are not well-understood, but may be related to changes in food source availability, pollutants, climate change, fishing bycatch, habitat destruction, shoreline development, and/or increased abundance of predators (Boersma et al. 2001; Tasker et al. 2000; Bertram et al. 2005; Lee et al. 2007). Further research into documenting and understanding declines in important foraging and migration areas is needed to improve current knowledge of seabird populations and develop effective conservation measures (Boersma & Parrish 1999; Hyrenbach et al. 2000).

Over the same period of time that many seabird populations have been in decline, other water-associated birds, especially freshwater ducks, have seen their populations grow and recover (USFWS 2017). Because many waterfowl species are heavily hunted by humans, their abundances can be strongly influenced by hunting practices and policies. The rebounds in these populations have been at least partially related to the implementation of a ban on lead shot and efforts to restore important wetland habitats (Williams et al. 1999).

Water-associated birds play an important role in marine and coastal ecosystems, providing food for avian predators such as Bald Eagles and Peregrine Falcons, and consuming aquatic plants and animals, including forage fish, crustaceans, mollusks, insects, and polychaete worms. As such, changing populations have the potential to significantly alter these ecosystems (Baum & Worm 2009; Estes et al. 2011; Poloczanska et al. 2013). Additionally, most population changes are symptomatic of larger problems within the ecosystem, such as poor water quality or lack of adequate prey resources, and birds have commonly been used as indicator species for monitoring the overall health of ecosystems (Furness & Camphuysen 1997; Montevecchi & Myers 1995; Cairns 1987; Parsons et al. 2008; Trathan et al. 2007). Because marine birds are easily observable and closely tied to their prey, their presence can be indicative of the abundance of prey, prey composition in an area, and environmental conditions that support high concentrations of prey species (Cairns 1987; Furness & Camphuysen 1997; Parsons et al. 2008). Seabird research has often been the starting point for developing an understanding of trophic connections (Trathan et al. 2007; Frederiksen et al. 2006), and analysis of long-term datasets is needed for effective biomonitoring (Furness & Camphuysen 1997). In this way, research on waterbird population trends can also expand knowledge of populations of prey species—especially for important species such as forage fish, for which abundance data are often lacking—and as such can improve understanding and conservation of the ecosystem as a whole.

Many water-associated bird species are also important to the birdwatching community, attracting people from all over who wish to observe wildlife. Wildlife observation has become one of the most important economic activities in Washington and in other regions, bringing more than $3 billion into Washington each year and involving more than two million participants (U.S. Dept. of Interior et al. 2011). Approximately three quarters of those participants are specifically interested in birdwatching (U.S. Dept. of Interior et al. 2011). As such, preserving seabirds and other water-associated birds in Puget Sound has intrinsic value not only to the ecosystem, but to the economic well-being of local communities.

Because it is difficult and expensive to document long-term population changes, there is often a lack of long-term data and temporal trends can be hard to identify. The value of long time series, however, becomes obvious after major regime shifts and population changes occur as a necessary tool for understanding present conditions and forecasting future trends (Hyrenbach & Irons 2003). Future ecological research on water-associated birds and their distributions will be increasingly connected to the study of anthropogenic impacts and climate change, requiring a more integrated, interdisciplinary approach (Dickson & Gilchrist 2001; Hyrenbach & Irons 2003; Hyrenbach et al. 2000).

While some research and monitoring efforts have been completed in the greater Puget Sound area and in other regions, research has not yet investigated population changes specifically in Budd Inlet and Capitol Lake. Seabird populations in Budd Inlet have undergone a period of decline and it is important to determine whether regional trends hold for this area, or if there may be unique population changes due to localized conditions and food resources. Over the same period of time that seabirds have been declining in Budd Inlet, waterfowl populations have increased on Capitol Lake, and it seems likely that this change is related to water quality and increased vegetation growth in the lake. Because Budd Inlet and Capitol Lake are so closely connected and interdependent, it is important to document and understand changes in the water-associated bird populations and overall ecosystem in both places. Additionally, a proposal is currently underway to remove the dam separating Capitol Lake and Budd Inlet, effectively removing the lake and restoring the Deschutes estuary and mudflats. Impacts on waterfowl populations need to be understood and a baseline needs to be established before such efforts occur, so that future changes can be assessed.

The broad scale of existing population analyses does not adequately capture the changes that have occurred in the Capitol Lake and Budd Inlet ecosystems because of the unique characteristics and histories of the local sites, and because of the frequent small-scale movements of water-associated bird populations within Puget Sound in response to changing conditions. These local scale changes can easily be lost in bigger, broader datasets that attempt to characterize population changes within a larger region.

My research aims to fill these knowledge gaps by analyzing and documenting changes in water-associated bird abundance on Budd Inlet and Capitol Lake over the last 30 years and investigating some of their potential causes. This analysis will build from and expand existing studies of seabird population changes in the Puget Sound region and elsewhere, and will also provide the opportunity for important future comparisons, regardless of whether the restoration plan is completed.

LITERATURE REVIEW

The population dynamics of water-associated birds in the Budd Inlet and Capitol Lake area have not been well-studied, but there is a substantial body of research literature related to population changes in the greater Puget Sound region and throughout the rest of the world. Some studies have simply documented trends that have been observed, while others have sought to explain the reasons for those trends. In combination with a foundational understanding of the habitat conditions, characteristics, and historical factors that make the Budd Inlet and Capitol Lake ecosystems unique, these types of studies can be used to gain a better understanding of the population trends that may be occurring locally.

In this literature review, I will begin by providing an overview of the history, habitat, and ecosystems found in Budd Inlet and Capitol Lake, Washington. This will provide context for the unique characteristics of the study area that have influenced or may influence water-associated bird abundance and distribution in the past, present, and future. I will then describe the water-associated bird species of interest that will be at the foundation of my analysis, giving special attention to foraging behaviors and food sources that might be important determinants of population size and distribution. I will describe the mechanisms behind these and other potential drivers of change in waterbird abundance patterns in the following section. I will conclude by describing previous research and monitoring efforts that have been completed in the Puget Sound region in order to situate my research questions and study design within the relevant literature.

Overview and History of Budd Inlet and Capitol Lake

Budd Inlet is a shallow inlet of south Puget Sound north of Olympia, Washington that was formed by glacial erosion and deposition events that took place more than 13,000 years ago (Figure 1; Thurston County Historic Commission 1992). The current extent of the inlet is about 7 miles, with an average width of about 1.5 miles and an average low tide depth of about 9 meters (Thurston County Historic Commission 1992). Its current geography and physical features reflect a history of human intervention and local development (Hayes et al. 2008; Thurston County Historic Commission 1992). Before the arrival of Euro-American immigrants in the region, the southern section of Budd Inlet was a tidal estuary that extended almost to the base of Lower Tumwater Falls on the Deschutes River (Haring & Konovsky 1999). There are descriptions of extensive mud flats that were once found throughout much of southern Budd Inlet that were recorded by various observers and explorers at that time (Hayes et al. 2008). The 4th avenue bridge that connects downtown Olympia to the westside area was built in 1869 and was the first development that restricted tidal exchange into the estuary (Hayes et al. 2008). Development continued to restrict flow throughout the following century as shipping and transportation became more important in Olympia, and multiple attempts were made to make Budd Inlet deeper by dredging (Hayes et al. 2008). The placement of fill from these dredging efforts further limited tidal exchange into south Budd Inlet and created new land on which the lower part of downtown Olympia was built (Hayes et al. 2008). The southern part of Budd Inlet now ends at the 5th Avenue dam, which was put in place in 1951 to dam the Deschutes River and create the mostly freshwater reservoir currently known as Capitol Lake (Thurston County Historic Commission 1992).

Capitol Lake is an artificial lake that was designed primarily as a pool that would reflect the State Capitol buildings and enhance their visual appeal (Figure 2). Secondary objectives were to eliminate odors caused by the discharge of raw sewage into south Budd Inlet, remove the unsightly mud flats in the estuary, and develop a lake that could be used for recreation (Hayes et al. 2008). A railway built across the Deschutes River in 1929 now separates the Middle and North Basins of Capitol Lake. The 5th avenue dam outlet in the North Basin of Capitol Lake that releases water into Budd Inlet has two radial gates, a gate for fish passage, and a siphon that is used to stabilize the water level in the lake, control flooding, and maintain freshwater conditions (Roberts et al. 2012). There are no long-term historical records of water level in Capitol Lake (Roberts et al. 2004).

Figure 1. Map of southern Budd Inlet in Olympia, WA using aerial imagery.

Figure 2. Map of Capitol Lake in Olympia, WA using aerial imagery.

Budd Inlet Ecosystems and Biodiversity

Budd Inlet is the southernmost arm of Puget Sound. Because of its semi-enclosed structure and substantial urban development in its watershed, it has poor flushing of water into the rest of Puget Sound (Ahmed et al. 2017). Poor mixing combined with high nutrient inputs and previous industrial use has led to a history of water quality problems.

Southern Budd Inlet, in particular, has poor water quality mainly due to anthropogenic nutrient inputs, which cause high levels of nitrogen, low dissolved oxygen concentrations, and high levels of fecal coliform. The Deschutes River watershed which drains into Budd Inlet is the 13th highest contributor to dissolved inorganic nitrogen loading in all of Puget Sound, and is second only to the Nisqually River watershed in South Puget Sound (Mohamedali 2011). Analysis of data collected from 1988 to 2007 shows that concentrations of total nitrogen and dissolved inorganic nitrogen have increased significantly (Roberts et al. 2012). Sources of nutrient loading in the Deschutes watershed include dairy farms and domestic animals, hatchery net pens that operated in Capitol Lake until 2007, removal of riparian vegetation, deteriorating sewer infrastructure, septic systems, fertilizer use, road construction, and natural processes (Roberts et al. 2012). Because the Deschutes River drains into Capitol Lake before entering Budd Inlet, however, some of the nutrients remain in the Capitol Lake system instead of passing into Budd Inlet (Mohamedali 2001). The LOTT wastewater treatment plant is the largest marine point source of nitrogen in Budd Inlet, but it reduced its discharge by half by 2007 as compared with 1990’s levels (Ahmed et al. 2014).

Nitrogen inputs increase algae growth because nitrogen tends to be the limiting nutrient, causing eutrophication. Decay of algae and other phytoplankton blooms subsequently contributes to persistently low dissolved oxygen concentrations in the deeper parts of the water column, because bacteria consume large amounts of oxygen in the decomposition process (Mohamedali 2011). Dissolved oxygen in Budd Inlet can reach levels that are detrimental to fish and benthic organisms during some parts of the year, and much of Budd Inlet is on the list of impaired water bodies under the Clean Water Act (for, among other contaminants, PCB's, copper, cadmium, chromium, and lead; Roberts et al. 2012). Additionally, the shores of Budd Inlet have a history of industrial use, including treatment of wood with creosote and PCP, which has led to increased inputs of toxic and carcinogenic substances such as dioxins and furans (NewFields 2015). Contaminants often end up in the bottom sediments and some contaminants, including PCBs and mercury, can bioaccumulate and biomagnify, concentrating in organisms higher on the food web, such as fish and seabirds (Selecky et al. 2006). Budd Inlet's industrial history has made its bottom sediments especially toxic (NewFields 2015). PCBs and mercury in Puget Sound have been found in the highest concentrations near urban centers such as Olympia, and high levels of contaminants have been measured in several fish species (Selecky et al. 2006).

Under the current managed lake system, mixing between freshwater and saltwater in Budd Inlet is also limited, as it is only able to occur during times when freshwater is discharged from Capitol Lake. This reduction in turbulent exchange has several implications for aquatic wildlife. One implication is increased vulnerability to predators because of a reduction in refuge cover (Hayes et al. 2008). This also limits the ability of prey species to forage for food because they may need to stay in dispersed refuges during times when turbulent exchange is not allowed. Another implication is the reduction or prevention of nutrient and oxygen mixing, which can lower marine primary productivity in the West Bay area of southern Budd Inlet (Hayes et al. 2008). There may also be more limited suspension of benthic food organisms in the water column, negatively affecting consumers of those resources, and more limited oxygen exchange to benthic areas (Hayes et al. 2008).

Despite its water quality problems, Budd Inlet supports a variety of marine life, including seabirds, marine mammals, fishes, and shellfish. Many bird species are associated with bays, estuaries, and inland marine waters in Washington and Oregon (Buchanan et al. 2001). Seabirds that can be found on Budd Inlet include gulls, terns, alcids, scoters, ducks, geese, kingfishers, loons, grebes, herons, cormorants, and shorebirds. Predatory birds include hawks, eagles, merlins, and falcons. Many of the seabird species are most common in the Puget Sound during the winter and undertake annual migrations of more than 1000 kilometers (Buchanan et al. 2001).

The two species of marine mammal that frequent Budd Inlet are the harbor seal (*Phoca vitulina*) and the California sea lion (*Zalophus californianus*). Harbor seals are common in South Puget Sound and are often observed near the fish ladder on the 5th avenue dam during salmon runs (Hayes et al. 2008). California sea lions migrate seasonally into Puget Sound, with peak numbers in the winter (Steiger & Calambokidis 1986; Everitt et al. 1980), but do not visit Budd Inlet every year (Hayes et al. 2008).

Commercially and recreationally important shellfish species found in Budd Inlet include geoducks (*Panopea generosa*), manila clams (*Venerupis philippinarum*), native littleneck clams (*Leukoma staminea*), butter clams (*Saxidomus gigantean*), cockles, mussels, squid, red rock crabs (*Cancer productus*), and oysters. However, shellfish harvesting in much of Budd Inlet has been closed or is under advisory due to contamination and wastewater discharges (PSI 2014; Roberts et al. 2012).

Fish that can be found in Budd Inlet include three-spined stickleback (*Gasterosteus aculeatus*), salmon, English sole (*Parophrys vetulus*), Pacific herring (*Clupea pallasii*), smelt, and sand lance. Three-spined stickleback have been found to be the most abundant fish species in Budd Inlet (Steltzner 2003). Five species of salmonid utilize the Deschutes watershed for spawning and rearing, including steelhead, cutthroat, coho, chinook, and chum (Haring & Konovsky 1999). Other fish species likely can also be found in Budd Inlet at times, but surveys and documentation are lacking. Budd Inlet is more contaminated with aromatic and chlorinated hydrocarbons than most other Puget Sound estuaries, and this contamination can be seen both in its sediments and in its bottom-dwelling fishes (Hayes et al. 2008; NewFields 2015; Stehr et al. 1998).

Capitol Lake Ecosystems and Biodiversity

Capitol Lake supports a mainly freshwater ecosystem that has many of the same water quality problems previously discussed with regard to Budd Inlet, but it also has additional problems with sedimentation and aquatic plant growth. Capitol Lake's original surface area of 320 acres has been reduced by sedimentation to 267 acres (Roberts et al. 2004). This has also resulted in a decrease in depth of about 1.1 meters and a 60 percent decrease in water volume (George et al. 2006) Annual sediment accumulation ranges from approximately 30,000 to 50,000 cubic yards, mainly due to erosion on the Deschutes River caused by land disturbances and increased stormwater runoff (Raines 2007; Roberts et al. 2004; Roberts et al. 2012). Between 26 and 32 percent of sediment inputs to the Deschutes

River system come from anthropogenic sources (Raines 2007). Dredging and flushing of Capitol Lake to remove excess sediments and control macrophyte growth was stopped in 1986, but high levels of sedimentation remain problematic (Roberts et al. 2004). The reduction in water levels due to sediment accumulation causes stranding of large woody debris, increases fecal coliform and phosphate concentrations in the lake, and makes the lake more vulnerable to solar heating (Hayes et al. 2008). Microbiological activity is likely to release nitrogen and phosphorous from accumulated sediments (CH2MHill 2001; Roberts et al. 2012). Additional nutrients are added to Capitol Lake due to continuous inflow from the Deschutes River (Hayes et al. 2008).

Increased phosphate concentrations and temperatures promote the growth of aquatic vegetation and Capitol Lake's circulation promotes eutrophication (Hayes et al. 2008). Plant growth in Capitol Lake includes algae as well as macrophytes, which can be emergent, submerged, or floating and may or may not be rooted to the substrate (Roberts et al. 2012). The cycle of plant growth and respiration reduces dissolved oxygen and raises pH levels in the lake (Roberts et al. 2012). Phosphorous probably controls primary productivity in Capitol Lake during most of the year, but nitrogen might be the limiting factor during the summer (CH2MHill 2001; Roberts et al. 2012). A survey completed in 2001 found that *Elodea*, a type of pondweed, covered 75% to 90% of the middle basin (CH2MHill 2001). Eurasian watermilfoil (*Myriophyllum spicatum*), another type of pondweed, is an exotic invasive aquatic plant species which saw the most growth in recent years, but removal efforts and herbicide treatment in 2004 have controlled it to some extent (Hayes et al. 2008). However, floating beds of other aquatic plant species have generally increased each year (Hayes et al. 2008). High productivity in Capitol Lake is caused by longer residence times than would occur in a free-flowing estuary, shallow water, high water temperatures, and high nutrient levels from the Deschutes River; this produces large amounts of seasonal organic matter (Roberts et al. 2012). Long flushing times also contribute to problems with fecal coliform (Prescott 1981; Singleton 1982; Singleton and Bailey 1983) and phosphate pollution (Singleton and Bailey 1983; Roberts et al. 2004), both of which often do not meet water quality standards (Hayes et al. 2008) High summer water temperatures and low dissolved oxygen can kill some aquatic organisms such as salmon (Hayes et al. 2008).

Habitat in Capitol Lake supports a variety of wildlife including birds, fish, amphibians, reptiles, and mammals, as is described in Hayes et al. (2008). The freshwater benthos of Capitol Lake is dominated by insects and invertebrates which support a variety of aerial foraging birds such as swallows and swifts, as well as several species of shorebirds and ducks. Aquatic vegetation growth supports a variety of foraging waterbird species, including Pied-billed Grebes (*Podilymbus podiceps*), American Coots (*Fulica americana*), Canada Geese (*Branta canadensis*), and several species of duck. Forage fish, salmonid, centrarchid, and other fish populations support waterbirds such as cormorants, grebes, kingfishers, loons, and terns. Capitol Lake's fish and bird populations also support several species of raptor, including Merlins (*Falco columbarius*), Peregrine Falcons (*Falco peregrinus*), Osprey (*Pandion haliaetus*), and Bald Eagles (*Haliaeetus leucocephalus*). Opportunistic ducks, gulls, and herons also make significant use of the area. While there have been no formal surveys of amphibian, reptile, or most mammal populations on Capitol Lake, anecdotal evidence suggests that at least one species of frog (the invasive American bullfrog [*Lithobates catesbeianus*]), a few species of reptiles, and eleven species of mammals also utilize the area. (Hayes et al. 2008).

Potential Changes under the Deschutes Estuary Restoration Plan

In the 1990's, planners began to consider restoring Capitol Lake and the Deschutes estuary. The plan currently contains three restoration alternatives aimed at solving problems related to the current condition of Capitol Lake: 1) maintenance of a managed lake through dredging, 2) removing the 5th avenue dam and turning Capitol Lake back into an estuary, and 3) removing the 5th avenue dam and turning part of Capitol Lake back into an estuary while retaining a reflection pool on the northeast part of Capitol Lake. Assessments and reports have been generated to evaluate the effects of these options and of retaining the status quo, but a final decision has not yet been made.

The estuary and dual basin restoration plans would have significant impacts on the wildlife and habitat found in the area. In the current situation with Capitol Lake in place, the nutrient loading capacity of both Budd Inlet and Capitol Lake is exceeded (Roberts et al. 2012). However, if Capitol Lake were removed and the Deschutes estuary restored, more of Budd Inlet would meet water quality standards for dissolved oxygen and the area that is currently Capitol Lake would also meet standards under all nutrient loading scenarios that have been analyzed (Roberts et al. 2012).

There would also be additional impacts to the ecosystem, as outlined in Hayes et al. (2008). Under these plans, there would be a major shift in the ecosystem of much of Capitol Lake from a freshwater benthos dominated by insects to a brackish benthos dominated by marine worms, crustaceans, and mollusks. This change is likely to, in turn, reduce the number of aerial foraging birds utilizing the area. Water-associated birds that depend on freshwater aquatic vegetation for foraging are likely to decline in number under these options as well. Populations of bird species that use both freshwater and saltwater environments may not change significantly, but it is difficult to predict the impacts on waterbirds that consume fish because the effects on fish populations are uncertain. Most species of shorebirds, herons, and raptors would likely become more abundant under these options because more foraging habitat would be exposed for longer periods of time. Amphibian use would likely be greatly reduced because the permeable skin of amphibians does not allow them to osmoregulate effectively in waters with increased salinity. Many species of waterbird that primarily utilize salt water and brackish areas in Budd Inlet would likely benefit from the increased foraging area that would be created if the Deschutes estuary is restored (Hayes et al. 2008).

Foraging Behaviors and Food Sources of Capitol Lake and Budd Inlet Species

Water-associated birds can generally be divided into functional groups based on their foraging behaviors and food preferences. The groups that are of particular interest when examining population changes on Capitol Lake and Budd Inlet include surface-feeding ducks, diving ducks, sea ducks, loons, and grebes. Most surface-feeding ducks primarily consume plant matter, while most diving ducks, sea ducks, loons, and grebes primarily consume animal matter (Johnsgard 2017). Ecologically similar species that share the same foraging preferences and life histories may respond to many environmental changes in the same way (Hyrenbach & Veit 2003; Parsons et al. 2008; Trathan et al. 2007; Sandvik & Erikstad 2008). As a group, water-associated birds are phylogenetically diverse, and the species of interest for this analysis come from three different orders of birds: Anseriformes (all ducks), Gaviiformes (loons), and Podicipediformes (grebes).

Surface-feeding Ducks

Surface-feeding ducks, also known as dabbling ducks, belong to the tribe Anatini and are usually found on freshwater ponds, lagoons, marshes, slow-moving rivers, and other shallow wetlands (Johnsgard 2017). While many species occasionally dive for food, they generally forage at or just below the surface by tipping up to reach food sources. For this reason, they are found mainly in shallow areas where food can easily be reached without diving. In general, surface-feeding duck species rely mainly on aquatic vegetation as a food source, but most species also consume some invertebrates (Johnsgard 2010).

Species of surface-feeding ducks commonly found on Capitol Lake include Mallard (*Anas platyrhynchos*), Green-winged Teal (*Anas carolinensis*), American Wigeon (*Anas americana*), Northern Pintail (*Anas acuta*), Northern Shoveler (*Anas clypeata*), Gadwall (*Anas strepera*), Eurasian Wigeon (*Anas penelope*), and Blue-winged Teal (*Anas discors*). There is a range in the dependence of various species on aquatic plants as a food source. American Wigeons graze more than any other North American surface-feeding duck and are highly dependent on vegetative parts of aquatic plants as a food source, with adults consuming very little animal material (Johnsgard 2010). They have been found to occur in the highest densities at sites where the submerged vegetation contains a relatively large amount of water milfoil (*Myriophyllum spp.*) and pondweeds (*Potamogeton spp.*; Johnsgard 2010). Gadwall have also been found to consume mostly vegetative parts of submerged aquatic plants and very little animal matter (Johnsgard 2010; Martin et al. 1951). Green-winged Teals consume a variety of plants and sometimes very small mollusks, but mainly specialize in consuming plant seeds because of their small bill size (Johnsgard 2010). Mallards consume a variety of submerged and emergent aquatic plants and their diets are usually made up of less than 10 percent animal materials such as invertebrates, but they are more unique in their ability to utilize agricultural grain crops in addition to natural aquatic foods (Johnsgard 2010). Northern Pintails consume mainly aquatic vegetation, but have a greater ability to dive in search of food than most surface-feeding ducks and also sometimes feed on grain from agricultural fields (Martin et al. 1951). Blue-winged Teals consume about 75 percent aquatic plants and about 25 percent insects, mollusks, and crustaceans (Johnsgard 2010). Northern Shovelers likely consume more small aquatic animals than any other North American surface-feeding duck, often consuming small crustaceans and insects in addition to aquatic plants (Johnsgard 2010).

Freshwater Diving Ducks

Freshwater diving ducks belong to the tribe Aythyini and differ from the surface-feeding ducks in that they are less adapted to walking on land and more adapted to diving and foraging underwater. Dependence on plant-based versus animal-based food sources varies by species.

Species of freshwater diving ducks that are commonly found on Capitol Lake include Ring-necked Duck (*Aythya collaris*), Canvasback (*Aythya valisineria*), Redhead (*Aythya americana*), Ruddy Duck (*Oxyura jamaicensis*), Greater Scaup (*Aythya marila*), and Lesser Scaup (*Aythya affinis*). Ring-necked Ducks primarily rely on aquatic vegetation as a food source, but also consume significant amounts of insects and mollusks. Canvasbacks and Redheads depend mainly on pondweeds for nutrition in the Puget Sound region. Ruddy Ducks are benthic feeders and consume mainly insects and crustaceans.

Greater Scaup and Lesser Scaup primarily consume animal materials such as mollusks, insects, and crustaceans in the winter, but consume substantial amounts of aquatic vegetation during other times of the year.

Sea Ducks

Sea ducks belong to the tribe Mergini, and although they are marine-adapted, many species can be found in both freshwater and marine environments. All species of sea ducks are strong swimmers and divers, and typically forage for food by diving. In general, sea ducks rely mainly on animal sources of nutrition, including mollusks, crustaceans, fish, and insects. Surf Scoters, in particular, are a candidate indicator species of marine contaminant loads because they often carry significant amounts of heavy metals (Buchanan 2006). All species of sea ducks are migratory to some extent, and they are found in the greatest abundance in the Puget Sound area during the winter season.

Sea duck species commonly found on Budd Inlet and Capitol Lake include Surf Scoter (*Melanitta perspicillata*), White-winged Scoter (*Melanitta deglandi),* Black Scoter (*Melanitta americana*), Bufflehead (*Bucephala albeola*), Hooded Merganser (*Lophodytes cucullatus*), Common Merganser (*Mergus merganser*), Red-breasted Merganser (*Mergus serrator*), Barrow's Goldeneye (*Buchephala islandica*) and Common Goldeneye (*Bucephala clangula*). Barrow's Goldeneyes have been found to eat mainly insects, mollusks, and crustaceans, along with some salmon eggs and aquatic vegetation (Johnsgard 2016). Winter food sources for Barrow's Goldeneyes and Common Goldeneyes are for the most part the same under the same habitat conditions, and Common Goldeneyes eat a wide variety of food (Johnsgard 2016). Bufflehead on freshwater or moderately brackish habitats eat mostly insects and may consume a significant amount of aquatic plant materials and small mollusks in the winter, whereas on saltwater habitats, the major food sources are crustaceans and mollusks, as well as some small fish (Johnsgard 2016). Hooded Mergansers are generalists but tend to eat mostly insects, with some small fish, frogs, tadpoles, mollusks, small crustaceans, and small amounts of plant matter (Johnsgard 2016). Common Mergansers have large regional and habitat-based differences in available food resources and tend to eat mainly fish, especially sculpin, and some salmon eggs in the Pacific Northwest (Johnsgard 2016). Red-breasted Mergansers consume mainly fish, as well as some crustaceans.

All three scoter species are found in areas with sand, mud, and cobble substrates, with Surf Scoters also abundant in rocky areas and White-winged Scoters also abundant over gravel beds (Vermeer & Bourne 1984). Surf Scoters are the most common scoter species in the Puget Sound and are strongly associated with shallow nearshore habitats (Buchanan 2006; Nysewander 2005; Savard et al. 1998). They have several different foraging strategies, consuming mostly bivalves during some parts of the year (Vermeer 1981; Savard et al. 1998; Lacroix et al. 2004), especially blue mussels and clams (Vermeer 1981; Vermeer & Bourne 1984; Lacroix 2001), with some additional crustaceans, insects, and plant matter (Johnsgard 2016). Black Scoters also consume mostly mollusks, especially blue mussels and short razor clams, and the rest of their diet is made up of polychaete worms, crustaceans, and echinoderms (Johnsgard 2016; Vermeer & Bourne 1984). Black Scoters strongly prefer mussels and may compete with Surf Scoters for this resource (Vermeer & Bourne 1984). White-winged Scoters opportunistically forage in various tidal zones and substrate types, consuming mostly mollusks, especially rock clams, manila clams, Pacific littlenecks, oysters, and mussels, and some crustaceans such as barnacles, as well as very small amounts of insects, fishes, and plant matter (Johnsgard 2016; Vermeer & Bourne 1984). Whereas the other two scoter species primarily consume mussels of a similar size, White-winged Scoters eat a lot more snails and clams in addition to consuming larger sized mussels (Vermeer & Bourne 1984). During spring spawning season, many scoters will also feed on herring eggs (Lewis et al. 2006b; Vermeer 1981). Scoter abundance and distribution is closely related to the abundance and distribution of food sources (Lacroix et al. 2005), as is true for many sea ducks (Guillemette & Himmelman 1996).

Loons and Grebes

Loons and grebes are diving birds. The diet of most species consists mainly of fishes, along with some crustaceans, mollusks, and insects. Unlike the previous groupings of ducks, loons and grebes are not closely related, but they share similar habitat and feeding preferences.

The species of loons that are commonly found on Budd Inlet include Common Loon (*Gavia immer*), Pacific Loon (*Gavia pacifica*), and Red-throated Loon (*Gavia stellate*). All three loon species consume mainly fish, but also eat various amounts of crustaceans, mollusks, and insects. The species of loons that co-occur in the Pacific Northwest have differences in bill size and length to avoid niche overlap.

The species of grebes that are commonly found on Budd Inlet include Horned Grebe (*Podiceps auritus*), Red-necked Grebe (*Podiceps grisegena*), and Western Grebe (*Aechmophorus occidentalis*). The species of grebes that co-occur in the Pacific Northwest have substantial differences in body size and bill shape. Western Grebes eat mainly fish, but also occasionally eat crustaceans, polychaete worms, and mollusks. Red-necked

Grebes also eat mostly fish, with some crustaceans, insects, mollusks, and amphibians. Horned Grebes eat mainly insects, along with some fish and crustaceans. Pied-billed Grebes (*Podilymbus podiceps*) are most often found on Capitol Lake, and they are opportunists that eat insects, fish, and other aquatic organisms.

Potential Causes of Changes in Waterbird Abundance

Waterbird population trends vary by functional group. Many seabird species have experienced regional declines, whereas many freshwater ducks have experienced increases at the regional and national scale. Seabird population changes, and especially declines, have been observed throughout the Puget Sound region and in many other parts of the world, but these declines and their causes remain understudied. It can be especially hard to identify causes of decline for species that migrate and utilize different habitats during different parts of the year (Anderson et al. 2009). Several studies link declining marine bird populations and changing distributions to food sources (Lewis et al. 2005; Hyrenbach & Veit 2003), especially reductions in forage fish populations (Sydeman et al. 2015). Other reasons for decline may be related to climate change (Croxall et al. 2012; Hyrenbach & Veit 2003; Sydeman et al. 2015), shoreline development (Croxall et al. 2012), and increased abundance of predators such as Bald Eagles and Peregrine Falcons. Increasing populations of freshwater ducks, on the other hand, may be more closely related to changed hunting policies and wetland restoration efforts (USFWS 2017; Williams et al. 1999).

Food source availability may be one of the most important factors in determining locations and sizes of water-associated bird populations. Studies of marine birds on the open ocean have found that dispersion of food resources and the energy required to capture prey determine which water masses seabirds are able to inhabit (Smith & Hyrenbach 2003), and seabirds with different food sources and foraging behaviors preferentially occupy specific areas (Ballance et al. 1997; Smith & Hyrenbach 2003; Wahl et al. 1989). Population size of predatory marine seabirds tends to be dependent on the abundance of prey species (Sydeman et al. 2015), but the amount of influence exerted by changing prey densities depends on both the amount of change and the availability of alternative prey species (Cairns 1987; Zador & Piatt 1999). However, the nutritional quality of available prey resources is also important, and can sometimes be even more important than the abundance of prey (Österblom et al. 2008; Wanless et al. 2005). The negative effects of low prey quality can be especially detrimental to marine bird species that can only catch one prey animal at a time, while species that can carry multiple prey animals at once may be less affected (Frederiksen et al. 2006). While this hypothesis seems plausible, more data are needed to support it and some studies have shown a lack of support for its conclusions (Hjernquist 2010). Because many marine bird species consume primarily fish, over-fishing is a serious concern as populations of prey fish species decline throughout the world (Hjernquist 2010; Halpern et al. 2008). Research on the relationship between forage fish and seabird populations in California has found that changes in near-shore forage fish populations can have an important influence on seabird abundance, and declining anchovy populations are thought to be responsible for a lot of the long-term seabird declines observed in that region (Sydeman et al. 2015).

Many water-associated birds shift their distributions and have modified their migration patterns to take advantage of abundant food resources. Many seabird species move from their primary wintering locations to consume herring eggs at spawning sites during the spring (Lacroix et al. 2005; Vermeer 1981; Rodway et al. 2003). Sea ducks and diving ducks have altered their distributions to feed on introduced invasive species like zebra mussels (*Dreissena polymorpha*) in North America and Europe (Wormington & Leach 1992; Petrie & Knapton 1999; Mitchell et al. 2000; Mitchell & Carlson 1993; Suter 1982; Burla & Ribi 1998). After the expansion of populations of introduced Asian clams (*Potamocorbula amurensis*) in San Francisco Bay, Lesser Scaup changed their foraging strategy to consume it almost exclusively (Lacroix et al. 2005; Poulton et al. 2002). Surf Scoters have also been observed to congregate at abnormal densities to feed on ephemerally abundant polychaetes (*Ophryotrocha spp.*) off the coast of Vancouver Island, British Columbia (Lacroix et al. 2005). During the breeding season, seabird populations have been shown to change in size and distribution with the availability of food near colonies (Lewis et al. 2005).

Water quality can also be an important factor in determining water-associated bird abundance. Pollutants can impact water-associated bird populations both directly by exposure of the bird to the toxins, and indirectly by reducing productivity in the ecosystem and decreasing the availability of food resources. Many pollutants, especially those that are lipid-soluble, are amplified as they move up the food chain, occurring at the highest concentrations in top predators such as birds (Furness & Camphuysen 1997). Therefore, fish-eating birds are more vulnerable to the effects of many toxins than grazing birds (Dickson & Gilchrist 2001). Filter-feeding benthic organisms such as mussels also contain high concentrations of toxins, which have been passed on to sea ducks that consume them (Dickson & Gilchrist 2001; Henny et al. 1995; Trust et al. 2000). When toxins, such as cadmium, do not directly kill birds, they can still cause retarded growth, anemia, testicular damage, hypertrophy of the heart, and renal dysfunction (Eisler 1985). Phytoplankton are at the bottom of many marine food chains, and decreased primary productivity has been found to occur from exposure to contaminants such as DDT, PCB, or mercury (Wurster 1968; Fisher et al. 1973; Harriss et al. 1970).

Water temperature and salinity fluctuations caused by ocean currents can also alter ecosystem productivity and influence the distribution of water-associated birds (Nelson & Myres 1976; Bary 1963). Climatic oscillations influence seabird distribution and abundance over shorter time periods (Irons et al. 2008), but are not likely to be a major contributing factor to continuous longer term population declines (Paleczny et al. 2015). They may, however, interact with other factors to reduce resilience of populations, causing declines during unfavorable conditions which seabird populations cannot recover from when favorable conditions return due to other constraints (Goya & Garica-Godos 2002; Ainley & Hyrenbach 2010).

Climate change, on the other hand, has the ability to influence a lot of the previously mentioned factors, in many cases exacerbating their effects. Climate modeling has predicted ocean warming and increasing density stratification in most areas (Solomon et al. 2007), with increased upwelling in other places (Bakun 1990). While the effects on marine ecosystems are uncertain, this could lead to reduced nutrient input and primary productivity in some areas and increased nutrient concentrations and productivity in others (Roemmich & McGowan 1995; Sarmiento et al. 2004; Auad et al. 2006; Di Lorenzo et al. 2005). Changes in geographic distribution and abundance of many wildlife species have already been observed in the last few decades (Root et al. 2003; Hickling et al. 2006; Gregory et al. 2009; Lehikoinen et al. 2013), and even more changes are predicted for the coming years (Thomas et al. 2014; Jetz et al. 2007). Changing climate can influence seabird populations directly through physiological effects related to changes in ambient temperature and indirectly by changing the distribution and abundance of food sources and disease (Oswald et al. 2008,2011; Gremillet & Boulinier 2009). Not surprisingly, areas with higher climatic suitability have been found to support larger local populations, and climate change has already had a noticeable detrimental effect on seabirds in the British Isles and elsewhere (Russell et al. 2015; Riou et al. 2011; Thompson & Ollason 2001; Irons et al. 2008). Studies of seabird populations in southern California have found that long-term changes in abundance were related to temperature-driven changes in prey populations (Hyrenbach & Veit 2003; Ainley & Hyrenbach 2010). Additional research in the North Sea related climate, plankton biomass, forage fish abundance, and seabird populations, observing parallel trends between all groups that can be interpreted as evidence for the effects of climate change in that ecosystem (Aebischer et al. 1990). Changes in predator-prey dynamics due to ecosystem shifts, however, remain understudied because most datasets do not include abundance data for both predator and prey species (DeYoung et al. 2008). For freshwater birds, climate change may have additional impacts as important breeding wetlands may dry out in the future (Niemuth et al. 2014).

Another factor that may influence water-associated bird abundance is the abundance of predators. Local avian predators that kill waterbirds in Budd Inlet and Capitol Lake include Peregrine Falcons (*Falco peregrinus*) and Bald Eagles (*Haliaeetus leucocephalus*). Changes in the abundance of these predatory species, as has occurred in many areas in the past few decades, could influence the abundance of prey species. Peregrine Falcons declined in many parts of the world because of chemical contamination after World War II, but have since recovered throughout North America (Cade et al. 1988; White et al. 2002). On Langara Island, British Columbia, for example, Peregrine Falcon population numbers dropped during the 1950's potentially due to overharvesting, pollution, and declines of prey species such as Ancient Murrelets (*Synthliboramphus antiquus;* Nelson & Myres 1976). Bald Eagle populations have also increased throughout North America (Buehler 2000), and are believed to be responsible for breeding failures, colony abandonment and redistribution of some species of seabirds (Parrish et al. 2001). Similar impacts on seabirds have been documented after recovery of European White-tailed Eagles (*Haliaeetus albicilla*) in Norway and other parts of the northern hemisphere (Hipfner et al. 2012). However, Peregrine Falcons actively drive Bald Eagles out of their nesting areas, so Bald Eagle populations may be smaller in some locations where Peregrine Falcon populations have increased (Hipfner 2005). Some studies of other taxonomic groups have found that the influence of predators can produce variable effects on ecologically similar species (Raimondo et al. 2004; Lawler 1989). As of yet, few studies have investigated the manner in which predator abundance affects multi-species waterbird communities (Robertson et al. 2015; Paine et al. 1990; Yorio & Quintana 1997).

Because many species observed on Budd Inlet and Capitol Lake during the winter are migratory and spend their time elsewhere during other parts of the year, conditions and predators in other locations can also have an important effect on winter abundance. Predators and alteration of ecosystems by introduced mammals on island breeding sites, in particular, have become a concern for global seabird conservation efforts (Hipfner 2010). If breeding is unsuccessful, population declines may also be observed in other parts of the year and are likely to occur throughout the wintering range rather than in localized areas.

Over the same period of time that many seabird populations have been in decline, other water-associated birds, especially freshwater ducks, have seen their populations grow and recover. In 2017, the estimated number of many breeding freshwater duck species in North America was 34 percent higher than the long-term average from 1955 to 2016 (USFWS 2017). Because many waterfowl species are heavily hunted by humans, their abundances can be strongly influenced by hunting practices. The largest increases in duck populations have occurred since around 1991 (USFWS 2017), which was the year that lead shot was banned nationwide. Prior to the ban, lead shot had poisoned millions of waterfowl each year (Bellrose 1959; Feierabend 1983), so it comes as no surprise that populations have begun to rebound. Wetland restoration efforts, which have provided increased food availability and planted cover to protect breeding ducks, have also contributed to increases in waterfowl populations (Williams et al. 1999). However, despite these improvements, some species (most notably Northern Pintail), have population sizes that remain below their historical and expected averages (Williams et al. 1999; USFWS 2017).

Previous Research on Waterbird Population Trends in the Puget Sound Region

A two year marine bird survey was completed by Wahl et al. (1981) for the Marine Ecosystems Analysis (MESA) Puget Sound Project, and it remains the most comprehensive marine bird census that has been undertaken in the northern part of the Salish Sea, if not all of Washington State. Censuses were conducted by aircraft, by boat, by ferry, and on foot. Throughout the study period, researchers observed 116 species of marine birds, with the highest diversity occurring during the fall migration period. Spring migration and herring spawning also attracted large concentrations of birds in some locations, but population size in all areas peaked during the winter, after the arrival of winter residents during late fall (Wahl 1981). The results of this census were subsequently utilized by several other studies to draw conclusions regarding long-term marine bird population trends in the area (Bower 2007; Nysewander et al. 2005).

The Washington Department of Fish and Wildlife (WDFW) was given funding in 1991 to implement the Puget Sound Ambient Monitoring Program (PSAMP), the purpose of which is to design and implement monitoring plans for marine birds, waterfowl, and marine mammals (Nysewander et al. 2005). As part of the PSAMP, summer and winter aerial surveys were conducted each year from 1992 to 1999, covering the entire marine shoreline of greater Puget Sound. Total numbers of birds were generally about three times higher in the winter than in the summer and 68 percent of the winter waterbird observations were waterfowl. Of the total marine birds observed, 37 percent were dabbling ducks and geese, 31 percent were diving ducks/sea ducks, 12 percent were gulls, 11 percent were shorebirds, 5 percent were loons or grebes, 2 percent were alcids, and 2 percent were cormorants. The most commonly recorded species were scoters (*Melanitta perspicillata, M. fusca, and M. nigra*), Dunlins (*Calidris alpina*), gulls (*Larus glaucescens, L. philadelphia, L. canus, L. thayeri*), Snow Geese (*Chen caerulescens*), American Wigeon (*Anas americana*), Bufflehead (*Bucephala albeola*), Mallards (*Anas platyrynchos*), Western Grebes (*Aechmophorus occidentalis*), goldeneyes (*Bucephala islandica and B. clangula*), and scaup (*Aythya marila and A. affinis*). Virtually all of the dabbling ducks belonged to four species, primarily American Wigeon and Mallard with smaller numbers of Northern Pintail and Green-winged Teal. Higher numbers of scoters and goldeneyes were observed in the southern and central parts of Puget Sound than in northern areas, Bufflehead and scaup favored shallower waters in the heads of bays and inlets, and other species had various other geographic distribution patterns. Because the surveys were completed by plane, survey coverage of small, shallow bays and inlets in developed areas was limited and some species may have been undercounted or difficult to identify to the species level.

The PSAMP survey results from 1992 to 1999 were compared with the previously discussed MESA surveys, which took place in part of the study area on nearly identical aerial transects in 1978 and 1979 (Nysewander et al. 2005; Wahl 1981). This comparison found significant decreases for grebes, loons, scoters, scaup, Pigeon Guillemot, Marbled Murrelet, and cormorants. Rhinoceros Auklets, goldeneyes, Bufflehead, and gull species had stable or only slightly decreasing populations, and Harlequin Ducks and mergansers showed some amount of increase in abundance. In the diving duck category, scoters showed a 57 percent decrease and scaup showed a 72 percent decrease. All loon and grebe species showed significant declines, with an 89 percent decrease in Red-necked Grebe, 82 percent decrease in Horned Grebe, 64 percent decrease in Common Loon, and 79 percent decrease for all loons combined. For the alcid species, Pigeon Guillemots showed a 55 percent decline and Marbled Murrelets showed a 96 percent decline. Cormorants also had significant declines, with 62 percent for Double-crested Cormorants and 53 percent for all cormorant species. Other species had changes of up to 55 percent but were not found to be statistically significant at the $\alpha = 0.05$ level. Because the MESA surveys only covered the northern part of the Salish Sea and used other methods in addition to aerial surveys, direct comparisons can only be made for the northern part of the PSAMP survey area in locations where aerial surveys were used in both studies. Another potential limitation to comparison is the type of plane that was used in each survey because a louder plane was used in the PSAMP surveys and may have reduced observability of some of the smaller and warier species, but this difference is probably not significant enough to account for the large decreases in populations that were found.

A Western Washington University study by Bower (2009) aimed at extending and testing the results of the PSAMP/MESA comparison investigated declines in marine bird populations in the Salish Sea by conducting surveys from 2003 to 2005 and comparing the results with those of the previously discussed surveys that were conducted as part of the MESA Puget Sound Project from 1978 to 1979. This comparison found a significant decrease of 28.9 percent for total marine bird abundance, with reductions in 14 of the 37 most common over-wintering species in the Salish Sea and increases in 6 species. Species with the largest declines included Common Murre (*Uria aalge*), Western Grebe (*Aechmophorus occidentalis)*, Red-throated Loon (*Gavia stellate*), and Bonaparte's Gull (*Larus philadelphia*). Of the functional feeding groups represented, benthic feeders, omnivores, pisicivores, and planktivores all included species showing significant declines, but there were no declines observed in herbivorous species. This study also analyzed Christmas Bird Count Data from 11 locations in Washington and Canada in the northern part of the Salish Sea. The analysis found that seven species had declined significantly, including Common Murre, Marbled Murrelet, Greater Scaup, and Lesser Scaup, while three species showed significant increases. Although this study does not include the southern part of the Salish Sea (i.e., South Puget Sound and Budd Inlet), it does provide a table of changes in marine bird abundance by species which can be compared with data collected for the southern part of the Salish Sea to determine if changes in the abundance of particular species are regional or more localized (Bower 2009).

A study by Anderson et al. (2009) focused more narrowly on comparing the results of various marine bird monitoring efforts for Padilla Bay in northern Puget Sound, which is a site that is heavily utilized during the wintering and migration periods. This study evaluates changes in abundance for each species in Padilla Bay using shore-based sampling between the 1978/79 MESA surveys and the 2003-2006 WWU surveys (Wahl et al. 1981; Bower 2007). They found that the combined density of all marine birds in September through mid-May declined from 1978/79 to 2003-2006 in Padilla Bay, especially during early winter and spring migration. Comparison with WDFW aerial survey results showed a similar declining trend (Nysewander et al. 2005). Of the 27 species that were analyzed, six increased and thirteen declined, and declines were observed across foraging and life history groups. They noted declines for Red-throated Loons, three species of grebes, many species of diving ducks, and Brant; increases for Pacific Loons, Common Loons, scoters, and dabbling ducks; and no change for two species of cormorants and Red-breasted Mergansers. Aside from examining trends in depth for a more limited geographic area, another way that this study added to the previously analyzed comparisons of these data sources was by evaluating changes in species assemblages in addition to abundance. They found that species assemblages in Padilla Bay were relatively similar during the late winter period, but somewhat different during the fall migration and early winter periods, and very different during the spring migration period (Anderson et al. 2009).

On the species level, declines in Surf Scoter populations have been observed in some parts of the Pacific Coast. Surf Scoter abundance in Prince William Sound, Alaska has decreased by 83 percent from 1972 to the early 1990s (Agler et al. 1999), and a decrease in abundance was also seen at Southeast Farallon Island, California from 1974 to 1993 (Pyle and DeSante 1994). However, populations at Tomales Bay, California were stable between 1989 and 1996 (Kelly and Tappen 1998). One potential cause of population declines that has been suggested is a change in availability of food resources, especially due to declines in forage fish populations (Agler et al. 1999). In the Puget Sound, declines in Surf Scoter populations have occurred over the same period as declines in herring populations (Buchanan 2006). Another possible explanation that has been suggested is a change in heavy metal contaminants, to which Surf Scoters are especially susceptible. In the Pacific Northwest, cadmium levels in Surf Scoters are generally high (Henny et al. 1991). Cadmium levels in the Queen Charlotte Islands of British Columbia have been found to exceed the amount that could cause kidney damage due to local high contaminant concentrations (Barjaktarovic et al. 2002). High levels of cadmium were also found in Surf Scoters in San Francisco Bay, California (Scheuhammer 1987, Ohlendorf et al. 1991). High concentrations of selenium have also been found in Surf Scoters in coastal California, with concentrations of hepatic selenium and mercury at levels that were found to impair reproduction and neurological function in experiments with Mallards (Hoffman et al. 1998). The toxicity of heavy metals in Surf Scoters is not well understood and requires further study (Ohlendorf et al. 1986). However, despite declines in Surf Scoter populations elsewhere, Surf Scoter abundance has increased in Padilla Bay in northern Puget Sound, suggesting that the local habitat in Padilla Bay may have become more important for scoter populations (Anderson et al. 2009). This suggests the need for smaller-scale analysis to determine critical habitat areas in addition to broader regional-scale studies.

Research on Common Murre (*Uria aalge*) populations on the west coast of North America has found that population trends vary spatially (Carter et al. 2001). Common Murre declines were observed in Washington State from 1979 to 1995, but these declines were much more pronounced in southern colonies than in northern colonies (Carter et al. 2001). From 1996 to 2015, total numbers of Common Murres increased in Washington; these changes, however, were also spatially variable, with increases in populations at northern colonies, and continued declines in southern areas (Thomas & Lyons 2017). These trends show a geographic shift in murre populations. Declines in Washington have been attributed to oil spills, climate oscillations, fishing bycatch, predation, and low food resource availability. A significant amount of murre mortality occurs from fishing by-catch on the Salish Sea (Hamel et al. 2009).

The only waterbird study that has focused specifically on Budd Inlet was completed 15 years ago by the R.W. Morse Company and serves as an inventory of waterbird species in the West Bay area of Budd Inlet (R.W. Morse Company 2002). The study was conducted from October 2001 to June 2002 under contract with the Thurston Regional Planning Council for the purposes of assessing waterbird use of habitat in the West Bay and noting any impacts from the construction of the Fourth Avenue Bridge. This study was designed to detect short-term changes in water-associated bird abundance (over an 8 month period), but the results do not appear to have been statistically analyzed, and therefore serve as a simple inventory of bird species and abundance more than as a rigorous analysis of population trends. While potential longer-term declines in seabird populations that were inferred from Christmas Bird Count data collected prior to the study are noted in the report, they are not analyzed or investigated. However, this study is easily replicable and the original data could be used in comparison with future surveys to contribute to a more rigorous analysis of seabird population trends in Budd Inlet.

Conclusion

No studies to date have assessed waterbird populations and changes in abundance on Capitol Lake and Budd Inlet. My research will evaluate whether or not there has been a significant change in water-associated bird populations on Capitol Lake and Budd Inlet over the past 30 years, and if those changes reflect other estimates of population change in the region. I will also examine the dietary preferences of species to see whether there are any patterns that may help to explain population trends. By answering these questions, my research will build from and expand existing studies of seabird and waterfowl population changes in the Puget Sound region and elsewhere. It is important to determine whether regional trends hold for this area, or if there may be unique population changes due to localized conditions. My research can inform future restoration efforts in Budd Inlet and Capitol Lake and provide the opportunity for important future comparisons.

METHODS

The primary data that were used in my analysis came from annual surveys conducted as part of the Audubon Christmas Bird Count. The Audubon Christmas Bird Count is the longest-running citizen science bird project in the United States and is a tradition that was begun in the year 1900 as a way to transition from hunting birds during the holidays to counting them instead. Data are collected by tens of thousands of volunteers in count circles throughout the nation from December 14 to January 5. The data collected as part of this project show how bird populations have changed in the past 100 years and have been used by researchers and conservationists to assess the long-term health of bird populations and inform strategies for conservation.

Capitol Lake and Budd Inlet fall under a single observer's area for the Christmas Bird Count, which encompasses Capitol Lake and Budd Inlet up to Priest Point Park (Figure 3). The study area is located within the Olympia count circle in Washington State (WAOL; center point located at 47.072247/-122.853297). The same experienced observer has been recording bird count data for this area for the past 31 years from 1987 to 2017. This consistency eliminates potential errors that may be caused by changing observers or survey procedures between years in other areas, which is often a concern when utilizing other Christmas Bird Count data. As such, this dataset provides an excellent opportunity to study changes in local water-associated bird populations during that time period. The data encompass Capitol Lake and Budd Inlet up to Priest Point Park and were collected in mid-December to early January of each year, except for 1990.

All birds within the survey area were recorded over the course of the day on each survey date, while making sure to avoid double counting individuals. The survey route was planned to maximize the probability of tallying as many individuals and species as possible throughout the day. Passerines and other land birds were counted first at daybreak, and Budd Inlet and Capitol Lake were tallied toward mid-day or afternoon. Capitol Lake was generally tallied north to south, or vice versa, in one sweep from the west side. Rarely, in late morning, the Capitol Campus yielded excellent conditions from which to tally the upper lake and that portion of the survey was conducted from there. Bald Eagles have occasionally disrupted tallies on the lake, which then needed to be started from scratch once things settled down. Birds on Budd Inlet were tallied from nearly 20 different locations along the inlet. The borders of the Budd Inlet survey area have changed slightly over the years (to add the area at Priest Point Park), but no changes were made that would significantly alter the abundance of water-associated birds recorded. Binoculars and a spotting scope were used to observe and count birds. The number of hours spent surveying and observed weather conditions which may have influenced bird abundances were also recorded for each survey. In some years, one or two people accompanied the survey, but all birds recorded were seen by the lead observer himself (Keith Brady, pers. comm.).

The 31 year Christmas Bird Count records from Budd Inlet and Capitol Lake were analyzed to determine the directionality and significance of any changes in water-associated bird abundance during the study period. Observation had suggested that there may have been a decline in seabird populations on Budd Inlet and an increase in waterfowl populations on Capitol Lake (Keith Brady, pers. comm.). Generalized linear models (GLMs) using Poisson or quasi-Poisson distributions were used to plot the abundance of each water-associated bird species or functional group of interest against year, in addition to several control variables related to survey conditions. These additional variables included survey date, number of hours spent surveying, mean temperature, precipitation, wind speed, visibility, number of observers, and number of avian predators. The analyses tested the null hypothesis of no relationship between abundance and the potential explanatory factors against the alternative hypothesis of a significant relationship between abundance and time or other survey variables for each species or functional group of interest. Poisson distributions were used for species that did not have overdispersion in their datasets, and quasi-Poisson distributions were used for species that required correction for overdispersion to fit the model. For species with a significant coefficient for year, the average percent increase in abundance per year was calculated by taking the exponential function of the estimated coefficient generated by the GLM. All GLMs were run using R statistical programming software (R Core Team 2018).

Raw data counts for each species were used for analysis. Although many analyses divide the raw data by the number of survey hours to account for effort (Bock & Root 1981), this was deemed unnecessary for this analysis because survey times did not vary greatly and survey routes remained consistent to cover the entire survey area. Most of the variation in survey time was due to difference in effort spent trying to locate passerines, which are irrelevant to this study, whereas effort spent surveying Capitol Lake and Budd Inlet remained consistent from year to year. Time was spent as needed to tally all birds observed on Capitol Lake and Budd Inlet, with more time required in less than ideal weather conditions or to count larger and more diverse flocks of ducks. Therefore, in the first years of surveys, more time was spent surveying Budd Inlet, which had a richer and more abundant water-associated bird presence, and less time was spent during later years after bird presence had decreased. The opposite is true for Capitol Lake, which required less survey time in the early years of the study period when fewer waterfowl were observed, and more time in later years as the presence of ducks increased. Because there was little movement of water-associated birds between areas or into the survey area throughout the day, additional time spent surveying after all birds were counted would not have led to significantly higher numbers recorded per unit effort. Survey times were also recorded as the total number of hours for the day, rather than being broken down into times per survey location, limiting their potential utility for analysis. However, the number of survey hours was still included in the generalized linear models to account for any possible influence.

To control for potential biases in the data due to weather, survey date, or number of surveyors, these factors were statistically analyzed within the generalized linear models to determine if they had a significant influence on the result. In addition to the inclusion of the survey condition variables in the generalized linear models for each species or functional group of interest, each survey variable was also analyzed separately for change over time using simple linear regression.

Weather was the most likely factor that had the potential to bias survey results from year to year. In some years, weather conditions were clear with excellent visibility, whereas in other years surveyors' vision may have been obscured by fog, rain, or snow. In addition to weather notes that were recorded by the surveyor at the time of survey, weather data were obtained from the National Weather Service for each survey date. These data were collected at a weather station located at the Olympia Airport, which is approximately 7 miles from the survey area and has similar weather patterns. Weather conditions at the airport, however, may have been more variable or extreme than those observed closer to the stabilizing influence of the Puget Sound. To control for the potential effects of weather on survey results, water-associated bird abundance and species richness were plotted against temperature, precipitation level, visibility, and windspeed for each survey.

Survey date is another factor that could potentially have influenced the abundance or variety of species observed at any given time. Numbers of water-associated birds utilizing Budd Inlet and Capitol Lake fluctuate throughout the season as species and individuals move between areas or undertake yearly migrations. Many of the water-associated bird species of interest are migratory and are found in the highest density in the Puget Sound region during certain parts of the winter. Survey dates were assigned numbers from 1 to 20, with 1 being the earliest survey date (December 14) and 20 being the latest survey date (January 5). Intermediate numbers represent survey dates in between. These numbers were plotted against water-associated bird abundance and species richness for each year to determine whether or not survey date influenced the results.

The number of surveyors varied by survey, with the lead observer recording data either alone or with one or two other people. This is not likely to have influenced the results because the lead observer remained the same at each survey, with the exception of one survey in 2002, and was responsible for counting and recording all observations himself. However, the number of surveyors was plotted against the water-associated bird abundance and species richness data as well to be sure that additional observers did not provide assistance to or distraction from the count.

The number of predators present during a particular survey also has the potential to bias results. Avian predators that take a significant amount of waterfowl as part of their diets include Bald Eagles and Peregrine Falcons. Abundance of these species was recorded during each survey and analyzed to assess change over time and potential influence on water-associated bird species richness or abundance.

After assessing the significance of trends using the generalized linear models, chi square tests of independence were used to assess the population trends (increasing, decreasing, or no significant change) in relation to habitat specialization and feeding guild for each species of interest. Three categories of habitat specialization (Budd Inlet specialist, generalist, and Capitol Lake specialist) and five feeding guilds (herbivore, benthivore, piscivore, insectivore, and opportunist) were used in two separate chi square tests of independence run in R (R Core Team 2018). These tests allowed for better comparison of population trend results by habitat specialization and food preference so that detected patterns may be used to help explain some of the population changes.

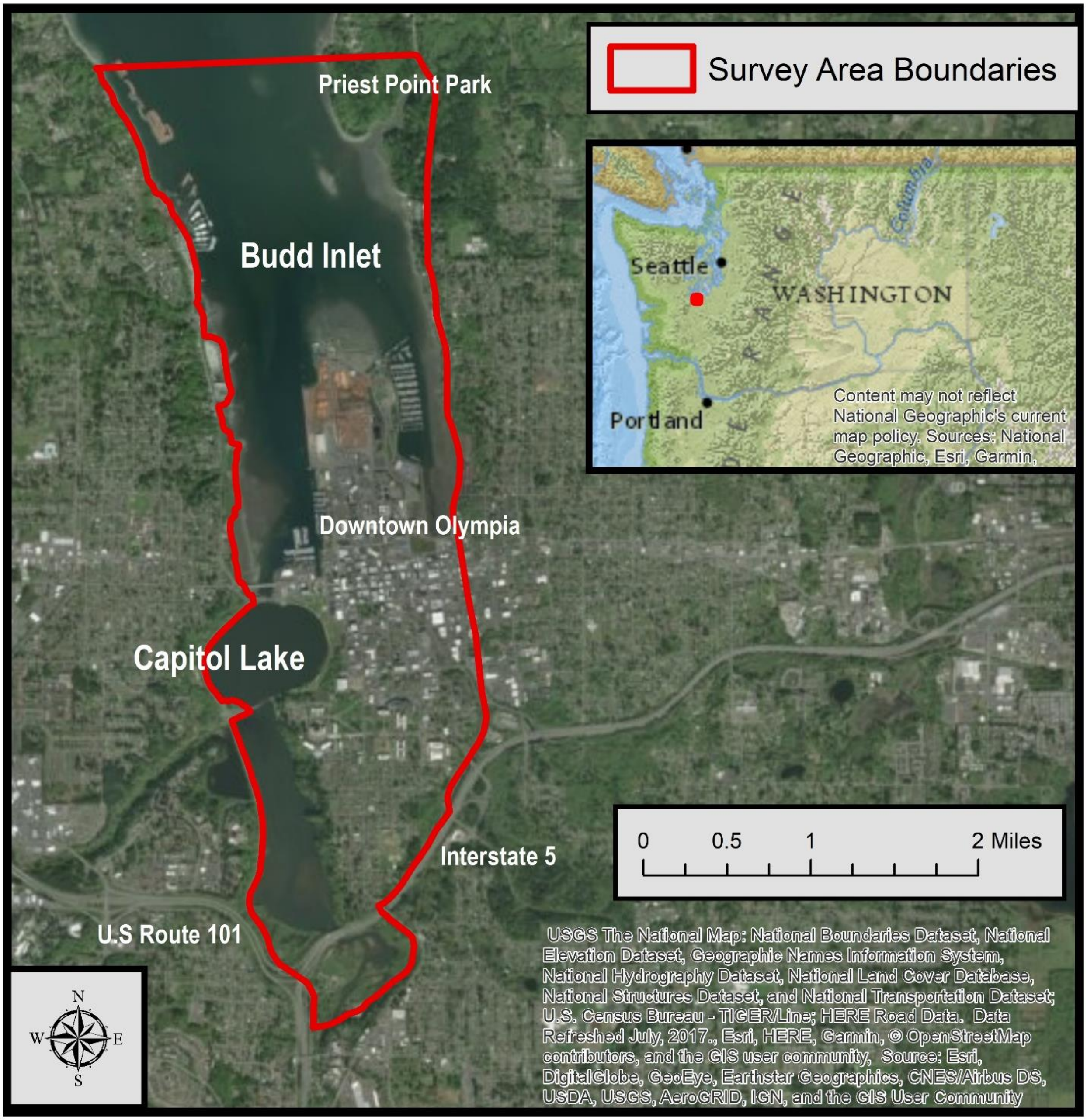

Figure 3. Map of the survey area boundaries. The survey area encompassed Capitol Lake and Budd Inlet north to Priest Point Park in Olympia, WA.

RESULTS

The population trends for water-associated birds on Budd Inlet and Capitol Lake were analyzed using generalized linear models. The results of the generalized linear models are broken down into sections and tables based on water-associated bird functional groups and utilization of habitat. These groupings include general trends, habitat-based trends, surface-feeding ducks, freshwater diving ducks, sea ducks, loons, and grebes. These sections are followed by a separate section that describes the results for potential biasing factors that were included as control variables in the models. In the concluding section, the results of the chi square tests of independence, to test for an association of population trend with habitat specialization and (separately) feeding guild, are presented.

General Trends

Total bird richness in the survey area, including land birds, had a small, nearly significant increasing trend over time (0.7%/year; $0.05 < p < 0.10$; Table 1; Figure 4). Overall water-associated bird species richness did not change significantly over time. Total water-associated bird abundance had a near-significant increase over time (1.7%/year; $0.05 < p < 0.10$; Table 1; Figure 4). Number of survey hours had a significant relationship with total bird richness, but not water-associated bird richness (Table 1). None of the other survey condition factors had a significant relationship with total bird richness, water-associated bird richness, or total water-associated bird abundance.

Habitat-based Trends

To assess habitat-based trends, water-associated bird species of interest were separated into groups based on their utilization of Capitol Lake and Budd Inlet. Generalized linear models were used to determine the significance of trends in abundance and species richness for the habitat-based groups during the study period.

The Capitol Lake users group included all species that are either specialized to the habitat found in Capitol Lake or are users of both Capitol Lake and Budd Inlet. This group had a significant increase in both abundance of water-associated bird species of interest (4.6 %/year) and species richness (1.7%/year) during the study period (Table 2; Figure 5). The Capitol Lake specialists group included species that utilize Capitol Lake exclusively or almost exclusively and are rarely found on Budd Inlet. This group had an even larger significant increase in both abundance (6.5%/year) and species richness (2.7%/year; Table 2; Figure 5). There was also a significant positive relationship between abundance of Capitol Lake specialists and visibility conditions (Table 2).

The Budd Inlet users group included all species that are either specialized to the habitat found in Budd Inlet or are users of both Budd Inlet and Capitol Lake. This group did not show a significant trend for abundance or species richness (Table 3; Figure 6). The Budd Inlet specialists group included species that utilize Budd Inlet exclusively or almost exclusively and are rarely found on Capitol Lake. This group had a significant decrease in abundance (-5.2%/year) but no significant trend for species richness (Table 3; Figure 6).

Surface-feeding Ducks

Abundance data for seven species of surface-feeding ducks were analyzed using generalized linear models to determine the significance of change in abundance over time (Table 4; Figure 7). Of these seven species, five species showed a significant increase in abundance over time (all $p < 0.05$): American wigeon (9.3 %/year), Gadwall (9.7%/year), Green-winged Teal (5.8%/year), Northern Pintail (11.3%/year), and Northern Shoveler (11.1%/year; Table 4; Figure 7). Mallard and Eurasian Wigeon did not have a statistically significant trend in abundance over time (Table 4; Figure 7). However, Eurasian Wigeon was not recorded in any surveys prior to 2002, but was recorded in almost every year thereafter (Figure 7). Two additional surface-feeding duck species were recorded too infrequently to be included in the species-level analysis (Eurasian green-winged teal and Blue-winged teal), with Eurasian green-winged teal occurring once in 2005 and Blue-winged teal occurring once in 2011. Total abundance of surface-feeding ducks showed a highly significant increase of 7.2 percent per year ($p < 0.01$; Table 4; Figure 7). In addition to change over time, the abundance of one surface-feeding duck species was significantly related to survey date (Northern Shoveler), three species were significantly related to survey hours (Northern Shoveler, Gadwall, Green-winged Teal), three species were significantly related to temperature (Green-winged Teal, Mallard, Northern Pintail), one species was significantly related to precipitation (Gadwall), two species were significantly related to visibility (Gadwall, Northern Shoveler), two species were significantly related to number of observers (Gadwall, Green-winged Teal), and no species were significantly related to wind speed or number of predators (Table 4).

Freshwater Diving Ducks

Abundance data for six species of freshwater diving ducks were analyzed using generalized linear models to determine the significance of change in abundance over time (Table 5; Figure 8). Greater Scaup and Lesser Scaup abundances were analyzed together due to difficulty distinguishing between species due to survey conditions in some years. Of the five species-level models analyzed, three species showed a significant change in abundance over time (all $p < 0.05$). Two species increased in abundance over time: Canvasback (11.6%/year) and Ring-necked Duck (11.2%/year; Table 5; Figure 8). Ruddy Duck abundance decreased significantly by -14.1 percent per year (Table 5; Figure 8). Redhead and Scaup species did not show a significant change in abundance over time (Table 5; Figure 8). The aggregated total abundance for the freshwater diving duck group had a near-significant increase over time (3.9%/year; $0.05 < p < 0.10$; Table 5; Figure 8). In addition to change over time, the abundance of one freshwater diving duck species was significantly related to wind speed (Ring-necked Duck) and one group of species was significantly related to visibility (Scaup spp.; Table 5). No species were significantly related to survey date, number of survey hours, temperature, precipitation, number of observers, or number of predators. Total abundance of all freshwater diving ducks in each survey year was significantly related to visibility conditions (Table 5).

Sea Ducks

Abundance data for nine species of sea ducks were analyzed using generalized linear models to determine the significance of change in abundance over time (Table 6; Figure 9). Of these nine species, four species showed a significant change in abundance over time (all $p < 0.05$) and one species showed an almost significant change in abundance over time ($0.05 < p < 0.10$; Table 6; Figure 9). Black Scoter and White-winged Scoter decreased in abundance over time (-37.2%/year and -16.4%/year, respectively), but there was no significant change in abundance over time for Surf Scoters (Table 6; Figure 9). Bufflehead, Common Goldeneye, and Common Merganser did not have a significant change in abundance over time (Table 6; Figure 9). Barrow's Goldeneye decreased in abundance over time (-8.7%/year). Hooded Merganser had a significant increase in abundance over time (3.9%/year; $p < 0.05$) and Red-breasted Merganser had a near-significant increase in abundance over time (6.3%/year; $0.05 < p < 0.10$; Table 6; Figure 9). There was no significant change in abundance over time for the aggregated total abundance of sea ducks over time (Table 6; Figure 9). In addition to change over time, the abundance of one sea duck species was significantly related to survey date (Common Merganser), two species were significantly related to survey hours (Black Scoter and Common Merganser), one species was significantly related to precipitation (Red-breasted Merganser), and one species was significantly related to wind speed (Common Merganser; Table 6). No species were significantly related to temperature, visibility, number of observers, or number of predators. Total abundance of all sea duck species in each survey year was not significantly related to any of the factors included in the model (Table 6).

Loons

Abundance data for three species of loons were analyzed using generalized linear models to determine the significance of change in abundance over time (Table 7; Figure 10). Of these three species, one species showed a significant decrease in abundance over time: Red-throated Loon (-20.3%/year; Table 7; Figure 10). Common Loon and Pacific Loon did not show a significant change in abundance over time, but both species had negative year coefficients and the total number of loons decreased significantly over time (-13.0%/year; Table 7; Figure 10). No loon species were significantly related to any of the survey condition variables that were included in the model (Table 7).

Grebes

Abundance data for five species of grebes were analyzed using generalized linear models to determine the significance of change in abundance over time (Table 8; Figure 11). None of these species or the aggregate total of grebe abundance showed a significant change over time (Table 8; Figure 11). In addition to change over time, the abundance of one grebe species was significantly related to precipitation and visibility (Pied-billed Grebe) and no species were significantly related to any of the other survey variables (Table 8).

Potential Biases

Survey conditions that may have influenced the results of the abundance and species richness counts were included in the generalized linear model for each species or functional group analyzed (Tables 1-8). Of the 29 water-associated bird species that were included in the analysis, two species were significantly related to survey date, five species were significantly related to number of survey hours, three species were significantly related to temperature, three species were significantly related to precipitation levels, two species were significantly related to wind speed, four species were significantly related to visibility conditions, two species were significantly related to number of observers, and no species were significantly related to number of avian predators (Tables 1-8).

In addition to determining relationships between survey conditions and species trends, survey conditions were assessed using simple linear regression to determine whether or not they had changed throughout the duration of the study period (Table 9). There was no trend over time in recorded temperature, precipitation, wind speed, or visibility conditions (Table 9). Some of the manipulated survey conditions, however, did change over time. The number of observers that participated in each survey was highest toward the beginning of the study period, when there were often two or three observers present, and lower in more recent years, in which surveys were often conducted solo or with two observers (Table 9). Survey date has also changed over time, with surveys now occurring earlier than they did at the beginning of the study period (Table 9). On average, surveys in the second half of the study period from 2003 to 2017 occurred 5 days earlier than surveys in the first half of the study period from 1987 to 2002. Additionally, the number of avian predators that were observed during the surveys increased significantly over time (Table 9).

Trends in Abundance by Habitat Specialization and Feeding Guild

A species' degree of habitat specialization (Budd Inlet specialist, Capitol Lake specialist, or generalist species) was significantly associated with its trend in abundance (declining, increasing or no significant change; χ^2 (4) = 13.6, $p < 0.01$; Figure 12). Budd Inlet specialists had more species than expected with declining trends, and fewer species than expected with increasing trends. Capitol Lake specialists had more species than expected with increasing trends, and fewer species than expected with declining or stable trends. Generalists had a disproportionately high number of species with no significant trends and a disproportionately low number of species with decreasing trends (Figure 12).

Similar to the habitat specialization results, a species' feeding guild (herbivorous, benthivorous, piscivorous, insectivorous, or opportunistic) was significantly associated with its trend in abundance (χ^2 (8) = 20.0, $p < 0.05$; Figure 13). More herbivores than expected had increasing trends, and fewer herbivores than expected had decreasing or stable trends. More benthivores than expected had declining trends, while fewer had increasing trends. For both piscivores and insectivores, more species than expected had no significant trends in abundance. Fewer opportunistic species had declining trends than would be expected if trends were proportional across feeding guilds (Figure 13).

Table 1. Results for general trends in species richness and all species abundance using a GLM based on the Poisson or quasi-Poisson distribution. The table includes regression coefficients for change by year and in relation to survey variables including date, number of hours, mean temperature, precipitation, wind speed, visibility, number of observers, and number of predators. Significant change ($p < 0.05$) is denoted in red using the * symbol, highly significant change ($p < 0.01$) is denoted in red using the ** symbol, and near significant change ($0.05 < p < 0.10$) is denoted in orange using the · symbol. Parentheses around numbers in the percent change per year column represent near significant estimates ($0.05 < p < 0.10$). Model Dispersion (Disp.), Null Deviance (Null Dev.) and Residual Deviance (Res. Dev.) are also reported for each model.

Response Variable	Change (%/Yr)	Year	Date	Hours	Temp.	Precip.	Wind Sp.	Vis.	Obs.	Pred.	Disp.	Null Dev.	Res. Dev.
All Bird Richness	(0.7)	0.007·	0.011	0.081*	-0.004	-0.003	-0.011	0.003	-0.016	0.012	1	30.6	4.9
		(0.004)	(0.007)	(0.036)	(0.004)	(0.067)	(0.01)	(0.014)	(0.05)	(0.022)			
Waterbird Richness	-	0.007	0.01	0.068	-0.006	0.03	-0.007	0.018	0.027	-0.013	1	14.5	6.5
		(0.005)	(0.009)	(0.047)	(0.005)	(0.086)	(0.013)	(0.019)	(0.066)	(0.03)			
Waterbird Abundance	(1.7)	0.017·	0.01	-0.05	0.002	-0.077	-0.031	0.032	0.198	-0.003	270.4	9321.9	5510.1
		(0.009)	(0.017)	(0.086)	(0.01)	(0.174)	(0.025)	(0.034)	(0.12)	(0.054)			

Table 2. Results for species that utilize and/or specialize in habitat found in Capitol Lake using a GLM based on the Poisson or quasi-Poisson distribution. The table includes regression coefficients for change by year and in relation to survey variables including date, number of hours, mean temperature, precipitation, wind speed, visibility, number of observers, and number of predators. Significant change ($p < 0.05$) is denoted in red using the * symbol, highly significant change ($p < 0.01$) is denoted in red using the ** symbol, and near significant change ($0.05 < p < 0.10$) is denoted in orange using the · symbol. Model Dispersion (Disp.), Null Deviance (Null Dev.) and Residual Deviance (Res. Dev.) are also reported for each model.

Response Variable	Change (%/Yr)	Year	Date	Hours	Temp.	Precip.	Wind Sp.	Vis.	Obs.	Pred.	Disp.	Null Dev.	Res. Dev.
Abundance - Capitol Lake users	**4.6**	0.045**	-0.021	0.009	0.004	0.11	-0.048	0.087	0.011	0.052	370.8	19095.1	7488.6
		(0.015)	(0.031)	(0.165)	(0.017)	(0.283)	(0.04)	(0.057)	(0.196)	(0.084)			
Abundance - Capitol Lake specialists	**6.5**	0.063**	-0.045	0.071	0.016	0.339	-0.074	0.143*	0.02	0.058	303.4	19723.5	6470.6
		(0.018)	(0.039)	(0.213)	(0.021)	(0.328)	(0.047)	(0.067)	(0.23)	(0.097)			
Richness - Capitol Lake users	**1.7**	0.017*	0.002	0.017	-0.003	-0.022	-0.007	0.035	0.052	-0.017	1	16.5	5.9
		(0.008)	(0.015)	(0.074)	(0.008)	(0.134)	(0.02)	(0.028)	(0.102)	(0.045)			
Richness - Capitol Lake specialists	**2.7**	0.027*	-0.006	0.06	-0.004	0.059	-0.028	0.061	0.06	-0.042	1	26.6	8.3
		(0.011)	(0.02)	(0.102)	(0.011)	(0.183)	(0.027)	(0.038)	(0.134)	(0.06)			

Table 3. Results for species that utilize and/or specialize in habitat found in Budd Inlet using a GLM based on the Poisson or quasi-Poisson distribution. The table includes regression coefficients for change by year and in relation to survey variables including date, number of hours, mean temperature, precipitation, wind speed, visibility, number of observers, and number of predators. Significant change ($p < 0.05$) is denoted in red using the * symbol, highly significant change ($p < 0.01$) is denoted in red using the ** symbol, and near significant change ($0.05 < p < 0.10$) is denoted in orange using the · symbol. Model Dispersion (Disp.), Null Deviance (Null Dev.) and Residual Deviance (Res. Dev.) are also reported for each model.

Response Variable	Change (%/Yr)	Year	Date	Hours	Temp.	Precip.	Wind Sp.	Vis.	Obs.	Pred.	Disp.	Null Dev.	Res. Dev.
Abundance - Budd Inlet users	-	0.002	0.025	0.035	-0.014	-0.055	-0.018	0.009	0.144	-0.022	112.0	3757.3	2365.2
		(0.012)	(0.02)	(0.097)	(0.012)	(0.208)	(0.03)	(0.04)	(0.144)	(0.066)			
Abundance - Budd Inlet specialists	5.2	-0.053*	0.03	0.207	-0.012	0.25	-0.055	-0.005	0.236	-0.192	77.4	7248.8	1454.9
		(0.02)	(0.031)	(0.146)	(0.019)	(0.313)	(0.049)	(0.067)	(0.244)	(0.113)			
Richness - Budd Inlet users	-	-0.008	0.017	0.099	-0.003	0.115	-0.01	0.011	-0.027	-0.003	1	12.3	4.8
		(0.009)	(0.015)	(0.078)	(0.009)	(0.142)	(0.023)	(0.032)	(0.113)	(0.051)			
Richness - Budd Inlet specialists	-	-0.019	0.023	0.194	-0.006	0.185	-0.024	0.011	-0.06	-0.012	1	24.2	8.9
		(0.012)	(0.021)	(0.105)	(0.012)	(0.201)	(0.03)	(0.045)	(0.154)	(0.071)			

Table 4. Results for surface-feeding duck species using a GLM based on the Poisson or quasi-Poisson distribution. The table includes regression coefficients for change by year and in relation to survey variables including date, number of hours, mean temperature, precipitation, wind speed, visibility, number of observers, and number of predators. Significant change ($p < 0.05$) is denoted in red using the * symbol, highly significant change ($p < 0.01$) is denoted in red using the ** symbol, and near significant change ($0.05 < p < 0.10$) is denoted in orange using the · symbol. Model Dispersion (Disp.), Null Deviance (Null Dev.) and Residual Deviance (Res. Dev.) are also reported for each model.

Species	Change (%/Yr)	Year	Date	Hours	Temp.	Precip.	Wind Sp.	Vis.	Obs.	Pred.	Disp.	Null Dev.	Res. Dev.
American Wigeon	9.3	**0.089***	-0.054	-0.121	0.029	0.164	-0.091	0.09	-0.332	0.185	271.2	16709.1	6180.2
Anas americana		(0.027)	(0.064)	(0.351)	(0.034)	(0.5)	(0.069)	(0.095)	(0.352)	(0.136)			
Eurasian Wigeon	-	0.063	-0.445	-1.468	0.231	2.038	-0.849	0.556	-1.23	1.004·	5.1	131	43.7
Anas penelope		(0.083)	(0.441)	(1.62)	(0.166)	(2.64)	(0.522)	(0.628)	(1.21)	(0.558)			
Gadwall	9.7	**0.093***	0.014	**0.754***	-0.003	**1.21***	-0.106	**0.283****	**0.864****	-0.093	27	1571.6	489.1
Anas strepera		(0.026)	(0.049)	(0.319)	(0.025)	(0.498)	(0.063)	(0.099)	(0.295)	(0.143)			
Green-winged Teal	5.8	**0.057***	0.029	**0.501***	**-0.053***	0.129	-0.071	0.125	**0.824****	-0.159	9.1	477.0	204.1
Anas carolinensis		(0.022)	(0.043)	(0.235)	(0.019)	(0.621)	(0.059)	(0.086)	(0.273)	(0.132)			
Mallard	-	0.018	-0.001	0.094	**-0.03***	0.05	-0.03	0.08	0.322·	-0.03	32.3	1172.5	634.1
Anas platyrhynchos		(0.014)	(0.027)	(0.13)	(0.013)	(0.284)	(0.038)	(0.053)	(0.178)	(0.08)			
Northern Pintail	11.3	**0.11***	0.029	0.033	**-0.1***	-2.679	-0.058	0.14	0.268	-0.362	6.4	287.6	119.6
Anas acuta		(0.044)	(0.098)	(0.404)	(0.039)	(2.58)	(0.115)	(0.161)	(0.638)	(0.285)			
Northern Shoveler	11.1	**0.11***	**-0.258***	**1.256***	-0.045	1.274	-0.172	**0.383***	0.846	-0.195	13.5	693.4	245.7
Anas clypeata		(0.05)	(0.117)	(0.543)	(0.043)	(1.02)	(0.121)	(0.169)	(0.539)	(0.244)			
Total	7.2	**0.07****	0.001	0.054	0.001	0.16	-0.053	0.071	0.015	0.079	270.8	14560.4	5862.8
		(0.02)	(0.041)	(0.23)	(0.022)	(0.38)	(0.05)	(0.072)	(0.254)	(0.107)			

Table 5. Results for freshwater diving duck species using a GLM based on the Poisson or quasi-Poisson distribution. The table includes regression coefficients for change by year and in relation to survey variables including date, number of hours, mean temperature, precipitation, wind speed, visibility, number of observers, and number of predators. Significant change ($p < 0.05$) is denoted in red using the * symbol, highly significant change ($p < 0.01$) is denoted in red using the ** symbol, and near significant change ($0.05 < p < 0.10$) is denoted in orange using the · symbol. Parentheses around numbers in the percent change per year column represent near significant estimates ($0.05 < p < 0.10$). Model Dispersion (Disp.), Null Deviance (Null Dev.) and Residual Deviance (Res. Dev.) are also reported for each model.

Species	Change (%/Yr)	Year	Date	Hours	Temp.	Precip.	Wind Sp.	Vis.	Obs.	Pred.	Disp.	Null Dev.	Res. Dev.
Canvasback	**11.6**	0.11*	0.12	-0.319	0.003	-1.95	0.123	-0.192	0.458	-0.017	22.1	905.7	441.8
Aythya valisineria		(0.04)	(0.074)	(0.329)	(0.042)	(1.31)	(0.091)	(0.125)	(0.531)	(0.228)			
Redhead	-	0.61	-0.844	1.356	-0.089	4.37	-0.552	0.874	-2.11	0.329	1.99	50.8	29.2
Aythya americana		(0.146)	(0.547)	(1.063)	(0.11)	(3.081)	(0.518)	(0.723)	(2.33)	(0.653)			
Ring-necked Duck	**11.2**	0.106*	-0.197	-0.347	0.079	1.194	-0.321*	0.24	-0.694	0.254	82.6	4681.6	1394.5
Aythya collaris		(0.041)	(0.127)	(0.557)	(0.057)	(0.731)	(0.132)	(0.173)	(0.521)	(0.209)			
Ruddy Duck	**-14.1**	-0.152**	0.034	0.317	0.009	-0.123	0.108	0.242·	-0.224	0.206	23.0	1670.2	460.4
Oxyura jamaicensis		(0.033)	(0.047)	(0.218)	(0.019)	(0.554)	(0.087)	(0.137)	(0.368)	(0.175)			
Scaup spp.	-	0.039	-0.106	0.237	0.014	0.717	-0.112	0.291*	0.292	-0.075	234.2	8481.1	4379.3
Aythya affinis/marila		(0.03)	(0.069)	(0.327)	(0.031)	(0.538)	(0.083)	(0.119)	(0.383)	(0.175)			
Total	(3.9)	0.034·	-0.057	0.121	0.01	0.473	-0.083	0.192*	0.144	-0.044	162.7	7177.4	3222.5
		(0.02)	(0.042)	(0.212)	(0.02)	(0.343)	(0.052)	(0.076)	(0.252)	(0.113)			

Table 6. Results for sea duck species using a GLM based on the Poisson or quasi-Poisson distribution. The table includes regression coefficients for change by year and in relation to survey variables including date, number of hours, mean temperature, precipitation, wind speed, visibility, number of observers, and number of predators. Significant change ($p < 0.05$) is denoted in red using the * symbol, highly significant change ($p < 0.01$) is denoted in red using the ** symbol, and near significant change ($0.05 < p < 0.10$) is denoted in orange using the · symbol. Parentheses around numbers in the percent change per year column represent near significant estimates ($0.05 < p < 0.10$). Model Dispersion (Disp.), Null Deviance (Null Dev.) and Residual Deviance (Res. Dev.) are also reported for each model.

Species	Change (%/Yr)	Year	Date	Hours	Temp.	Precip.	Wind Sp.	Vis.	Obs.	Pred.	Disp.	Null Dev.	Res. Dev.
Black Scoter	-37.2	-0.465**	0.175	1.667**	-0.035	1.155	-0.166·	-0.401·	-1.17	0.099	1	677.0	4.1
Melanitta americana		(0.073)	(0.115)	(0.632)	(0.042)	(0.893)	(0.085)	(0.236)	(0.766)	(0.212)			
Surf Scoter	-	0.024	0.059·	-0.071	0.006	-0.064	-0.041	0.128·	0.212	-0.217·	23.8	1143.3	528.6
Melanitta perspicillata		(0.02)	(0.032)	(0.164)	(0.02)	(0.353)	(0.05)	(0.066)	(0.247)	(0.115)			
White-winged Scoter	-16.4	-0.179*	-0.041	0.198	-0.04	0.723	-0.158	0.134	0.571	-0.23	64.6	3931.7	738.8
Melanitta deglandi		(0.065)	(0.079)	(0.359)	(0.079)	(0.918)	(0.12)	(0.169)	(0.592)	(0.291)			
Bufflehead	-	0.022	-0.073·	0.029	0.002	-0.161	-0.022	0.006	-0.129	0.082	98.8	3845.6	1904.0
Bucephala albeola		(0.019)	(0.042)	(0.203)	(0.021)	(0.356)	(0.049)	(0.071)	(0.256)	(0.105)			
Common Goldeneye	-	0.001	0.002	-0.027	0.016	0.051	-0.04	0.044	0.012	0.067	15.2	325.1	288.8
Bucephala clangula		(0.018)	(0.033)	(0.171)	(0.02)	(0.319)	(0.049)	(0.068)	(0.234)	(0.105)			
Barrow's Goldeneye	-8.7	-0.091**	.02	0.168	0.0002	-0.039	0.005	-0.107	-0.137	-0.077	33.2	2809.8	596.3
Bucephala islandica		(0.024)	(0.035)	(0.167)	(0.022)	(0.338)	(0.057)	(0.079)	(0.298)	(0.133)			
Common Merganser	-	0.033	0.233**	-0.685*	-0.031	-2.158	0.215*	0.038	-0.25	0.069	15.0	2293.1	252.7
Mergus merganser		(0.042)	(0.059)	(0.278)	(0.036)	(1.332)	(0.094)	(0.103)	(0.506)	(0.227)			
Hooded Merganser	3.9	0.038**	-0.003	0.165	-0.016	-0.13	0.023	0.096·	0.014	0.074	4.6	278.4	87.9
Lophodytes cucullatus		(0.013)	(0.025)	(0.136)	(0.012)	(0.261)	(0.033)	(0.048)	(0.163)	(0.071)			
Red-breasted Merganser	(6.3)	0.061·	0.103	0.49	-0.031	1.149*	-0.163·	-0.013	0.142	-0.167	13.0	491.2	286.0
Mergus serrator		(0.033)	(0.065)	(0.318)	(0.036)	(0.525)	(0.078)	(0.121)	(0.378)	(0.181)			
Total	-	-0.002	0.026	-0.008	-0.005	-0.119	-0.007	-0.011	0.064	-0.013	109.1	3158.2	2274.2
		(0.014)	(0.024)	(0.114)	(0.014)	(0.234)	(0.035)	(0.047)	(0.173)	(0.078)			

Table 7. Results for loon species using a GLM based on the Poisson or quasi-Poisson distribution. The table includes regression coefficients for change by year and in relation to survey variables including date, number of hours, mean temperature, precipitation, wind speed, visibility, number of observers, and number of predators. Significant change ($p < 0.05$) is denoted in red using the * symbol, highly significant change ($p < 0.01$) is denoted in red using the ** symbol, and near significant change ($0.05 < p < 0.10$) is denoted in orange using the · symbol. Model Dispersion (Disp.), Null Deviance (Null Dev.) and Residual Deviance (Res. Dev.) are also reported for each model.

Species	Change (%/Yr)	Year	Date	Hours	Temp.	Precip.	Wind Sp.	Vis.	Obs.	Pred.	Disp.	Null Dev.	Res. Dev.
Common Loon	-	-0.076	-0.059	0.806	-0.045	1.777	-0.184	0.199	-0.704	-0.476	1.2	42.2	20.7
Gavia immer		(0.06)	(0.125)	(0.585)	(0.043)	(1.156)	(0.2)	(0.303)	(0.905)	(0.431)			
Pacific Loon	-	-0.19	-0.545	1.524	-0.055	-1.863	-0.794	1.03	2.889	-2.00	6.1	29.7	15.6
Gavia pacifica		(0.254)	(0.738)	(2.656)	(0.267)	(15.448)	(0.991)	(1.51)	(4.6)	(2.825)			
Red-throated Loon	-20.3	-0.227**	-0.019	0.543	-0.046	1.284	-0.2	-0.046	-0.612	-0.184	1.8	93.7	29.3
Gavia stellata		(0.074)	(0.099)	(0.46)	(0.048)	(0.882)	(0.153)	(0.222)	(0.705)	(0.333)			
Total	-13.0	-0.14**	-0.034	0.489	-0.03	1.212·	-0.184	0.009	-0.415	-0.264	2.1	103.1	42.4
		(0.044)	(0.072)	(0.319)	(0.035)	(0.654)	(0.118)	(0.166)	(0.525)	(0.246)			

Table 8. Results for grebe species using a GLM based on the Poisson or quasi-Poisson distribution. The table includes regression coefficients for change by year and in relation to survey variables including date, number of hours, mean temperature, precipitation, wind speed, visibility, number of observers, and number of predators. Significant change ($p < 0.05$) is denoted in red using the * symbol, highly significant change ($p < 0.01$) is denoted in red using the ** symbol, and near significant change ($0.05 < p < 0.10$) is denoted in orange using the · symbol. Model Dispersion (Disp.), Null Deviance (Null Dev.) and Residual Deviance (Res. Dev.) are also reported for each model.

Species	Change (%/Yr)	Year	Date	Hours	Temp.	Precip.	Wind Sp.	Vis.	Obs.	Pred.	Disp.	Null Dev.	Res. Dev.
Eared Grebe	-	0.015	0.01	0.265	0.069	0.85	-0.313·	0.081	0.705	-0.306	1.8	54.4	27.6
Podiceps nigricollis		(0.065)	(0.134)	(0.677)	(0.086)	(1.466)	(0.173)	(0.278)	(0.868)	(0.412)			
Horned Grebe	-	-0.03	0.063	0.547·	-0.019	0.86	-0.17·	0.086	0.335	-0.276	17.1	795.1	290.4
Podiceps auritus		(0.035)	(0.062)	(0.303)	(0.034)	(0.681)	(0.092)	(0.134)	(0.43)	(0.209)			
Pied-billed Grebe	-	0.03	0.002	0.254	-0.023	-1.866*	0.046	0.166*	0.333	-0.008	2.3	119.9	49.9
Podilymbus podiceps		(0.02)	(0.042)	(0.2)	(0.018)	(0.881)	(0.057)	(0.075)	(0.254)	(0.135)			
Red-necked Grebe	-	-0.094	-0.047	0.284	0.013	-1.209	0.058	-0.206	0.108	-0.248	1.9	65.1	33.5
Podiceps grisegena		(0.056)	(0.086)	(0.41)	(0.059)	(1.343)	(0.14)	(0.195)	(0.775)	(0.325)			
Western Grebe	-	-0.142	0.094	0.81	-0.053	-0.801	0.121	-0.21	0.79	-0.286	304.2	1966.4	413.2
Aechmophorus occidentalis		(0.303)	(0.421)	(2.333)	(0.275)	(7.205)	(0.616)	(0.949)	(4.214)	(1.53)			
Total	-	-0.04	0.047	0.513	-0.033	0.123	-0.055	-0.0001	0.647	-0.297	40.0	1909.8	449.6
		(0.037)	(0.061)	(0.295)	(0.036)	(0.803)	(0.094)	(0.131)	(0.47)	(0.219)			

Table 9. Results for change in each survey variable over time, using simple linear regression with each survey variable as the dependent variable and year as the independent variable. The table includes estimated regression coefficients for the 'year' term. Significant change ($p < 0.05$) is denoted in red using the * symbol and highly significant change ($p < 0.01$) is denoted in red using the ** symbol. R^2 and adjusted R^2 are also reported for each regression.

Survey Variable	Estimate	R2	Adj. R2
Mean Temperature	-0.037 (-0.148)	0.002	-0.033
Survey Date	**-0.374**** (0.08)	0.438	0.418
Precipitation	0.003 (0.012	0.002	-0.033
Wind Speed	0.005 (0.077)	0.0001	-0.036
Visibility	0.011 (0.044)	0.002	-0.033
Observers	**-0.034*** (0.013)	0.204	0.175
Predators	**0.059*** (0.029)	0.135	0.104

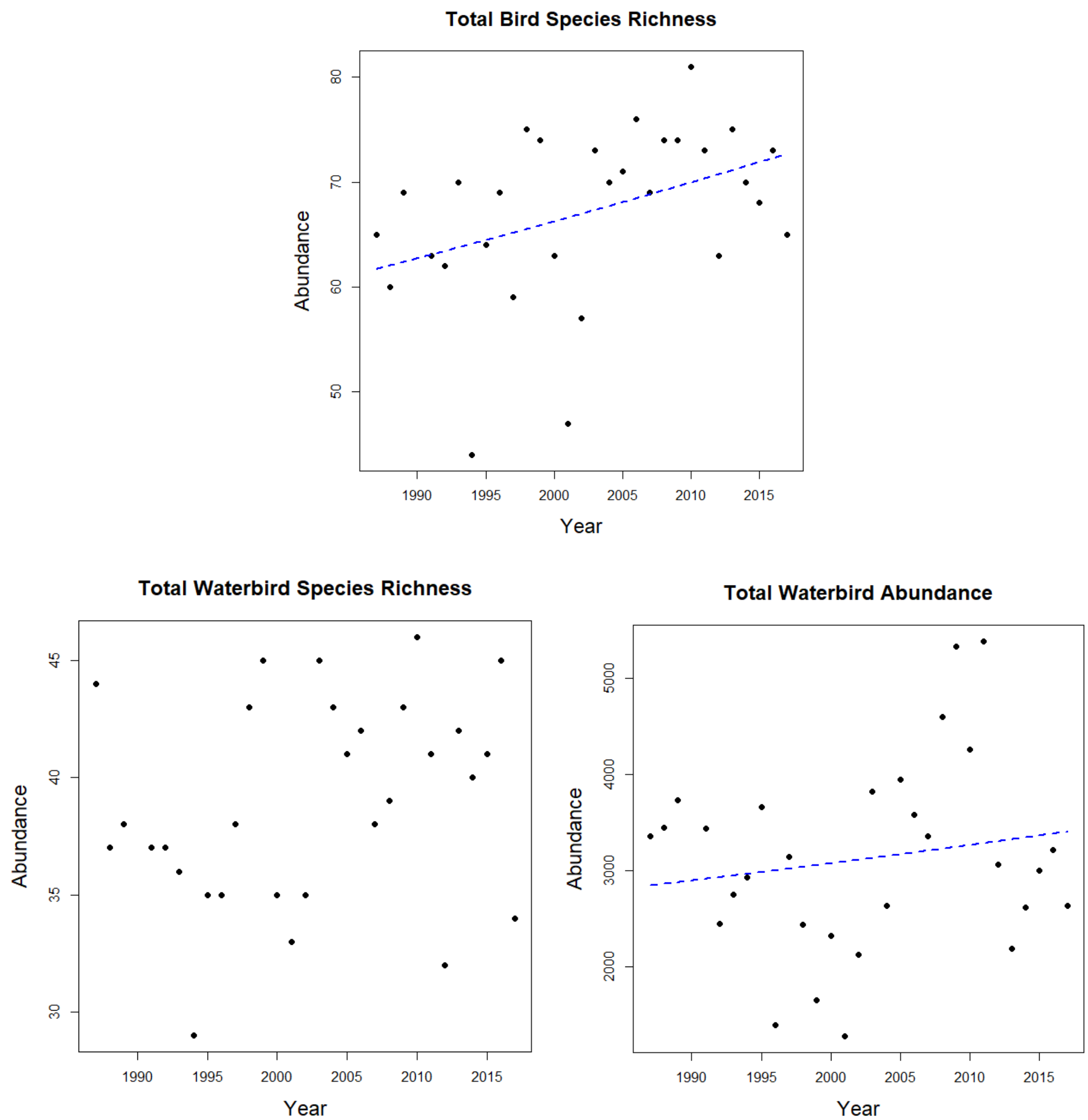

Figure 4. General trends in total bird species richness, total water-associated bird species richness, and total water-associated bird abundance in each survey year. Dotted lines represent near-significant coefficient estimates for 'year' ($0.05 < p < 0.10$) based on Poisson or quasi-Poisson regression.

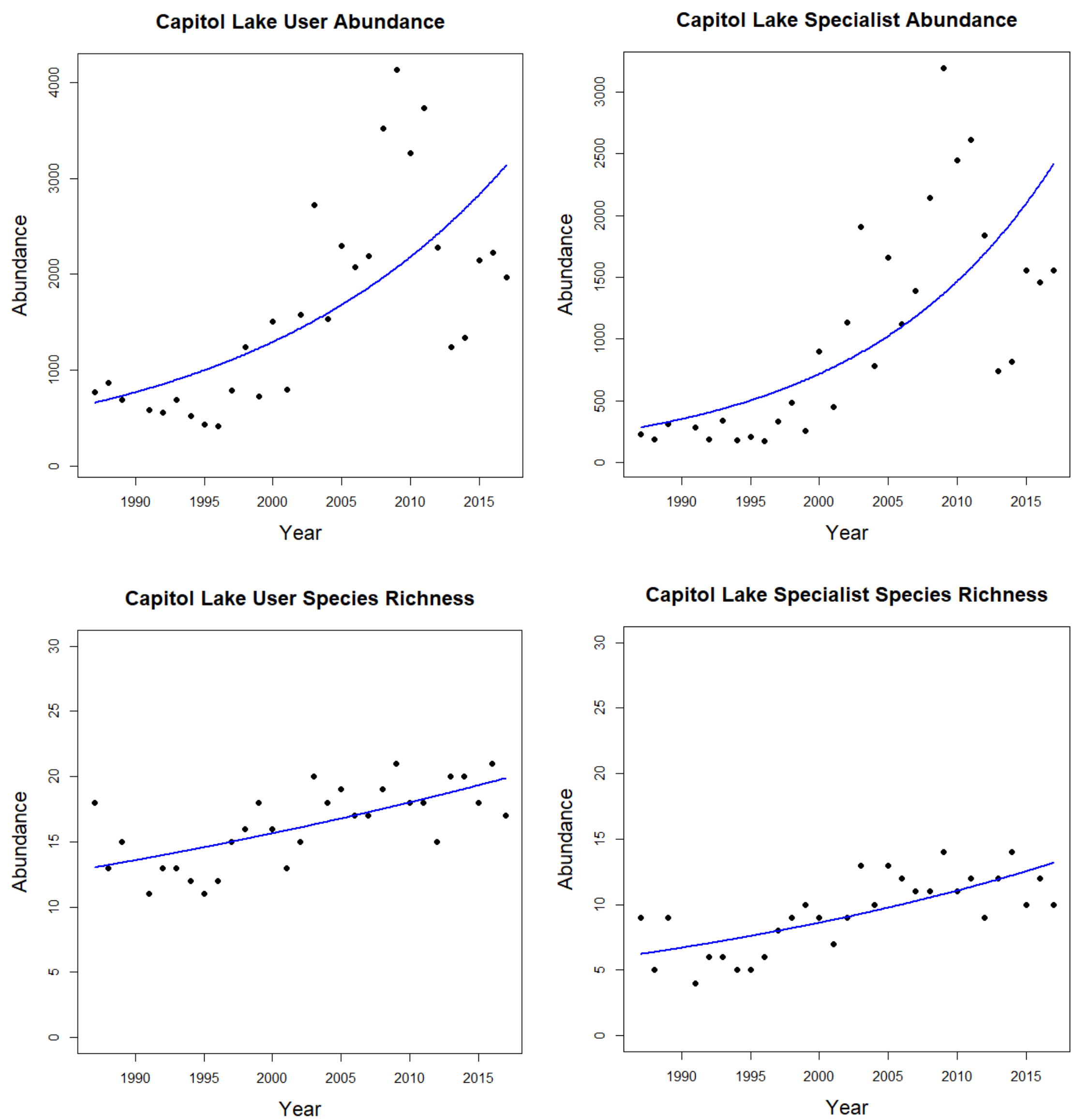

Figure 5. Abundance and species richness trends for Capitol Lake users and Capitol Lake specialists. Solid lines represent significant coefficient estimates for ‘year’ (at $p < 0.05$) based on Poisson or quasi-Poisson regression.

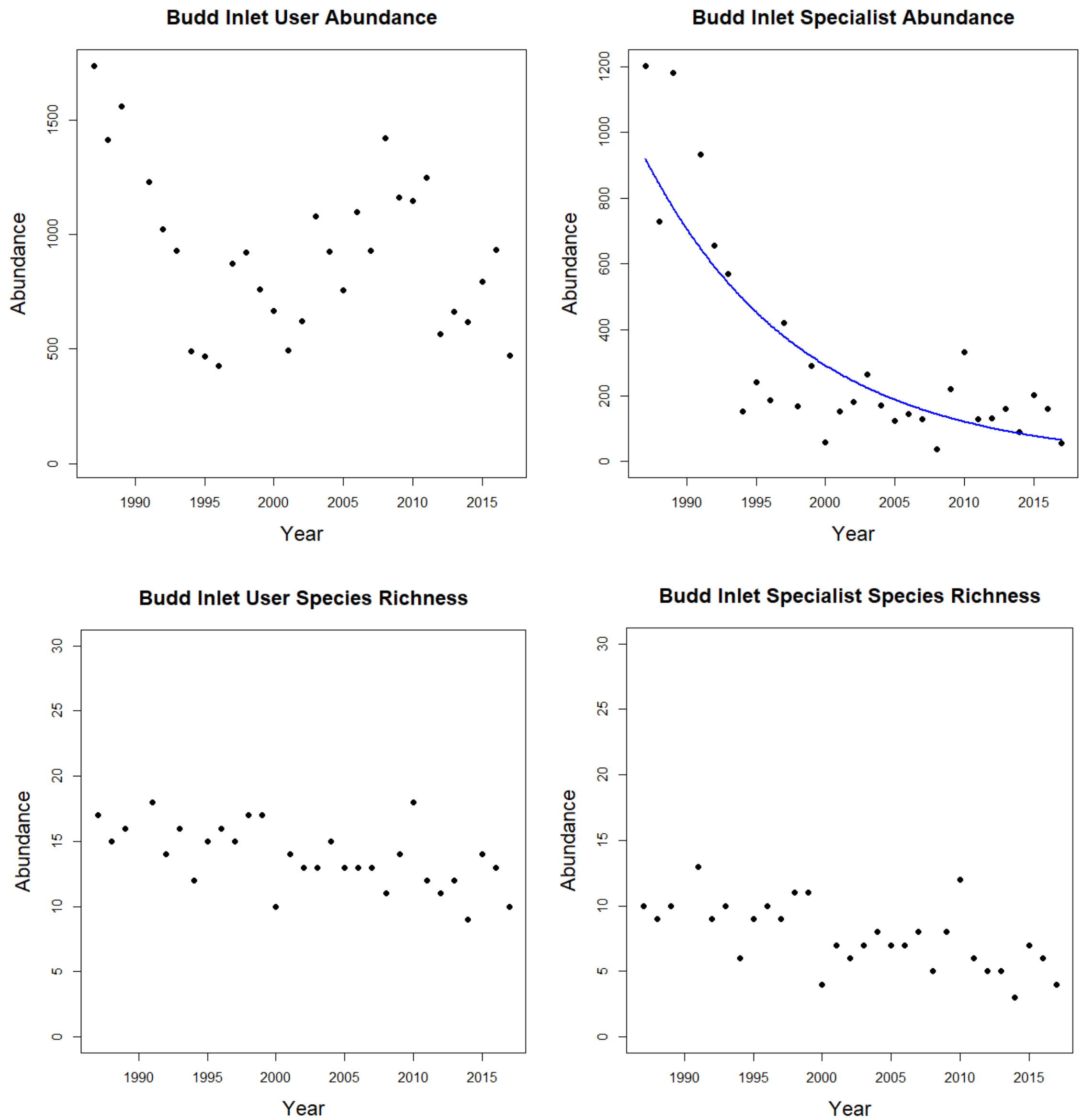

Figure 6. Abundance and species richness trends for Budd Inlet users and Budd Inlet specialists. Solid lines represent significant coefficient estimates for 'year' (at $p < 0.05$) based on Poisson or quasi-Poisson regression.

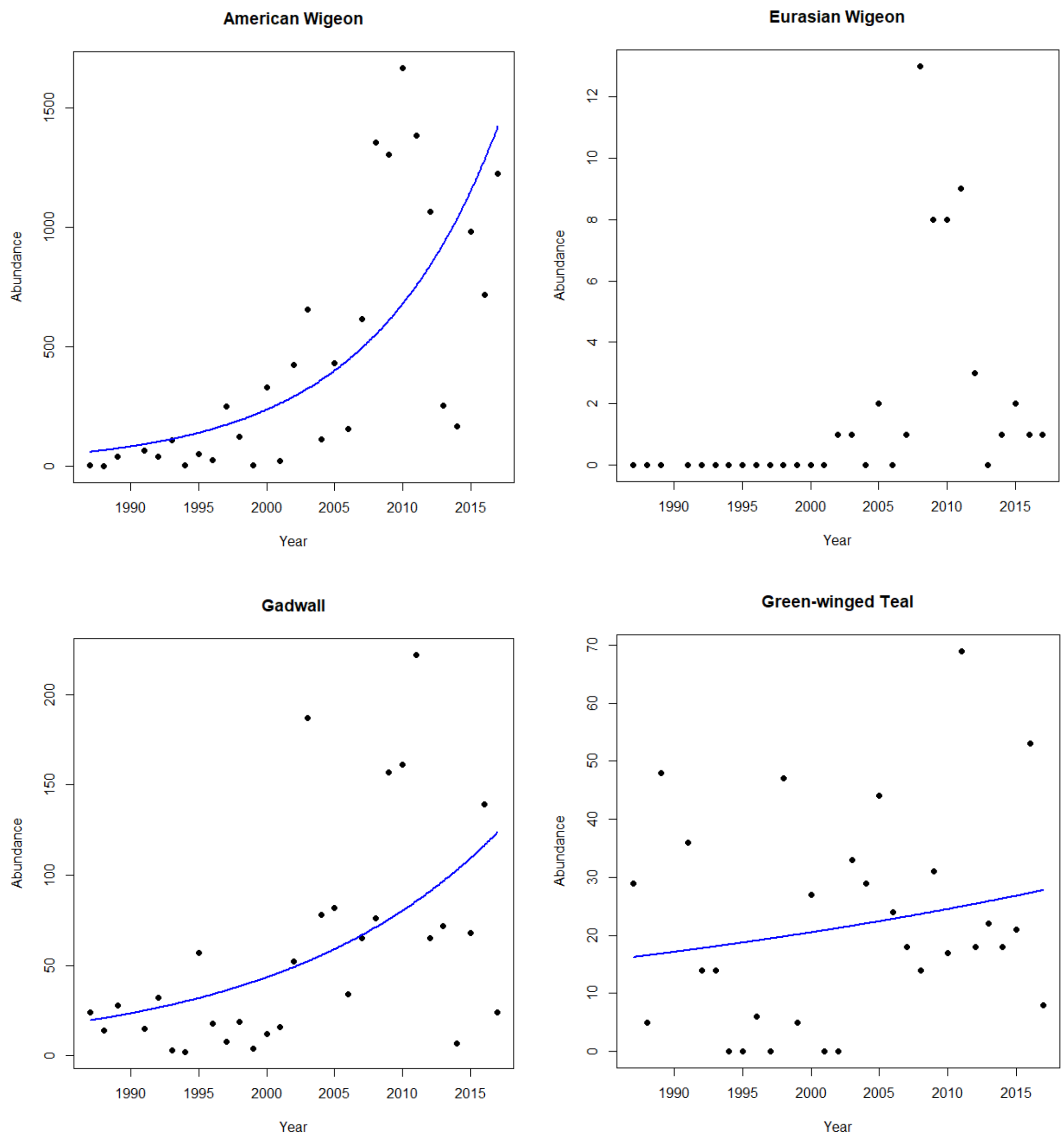

Figure 7 (continued on next page). Abundance of the surface-feeding duck species in each survey year. Solid lines represent significant coefficient estimates for 'year' (at $p < 0.05$) based on Poisson or quasi-Poisson regression.

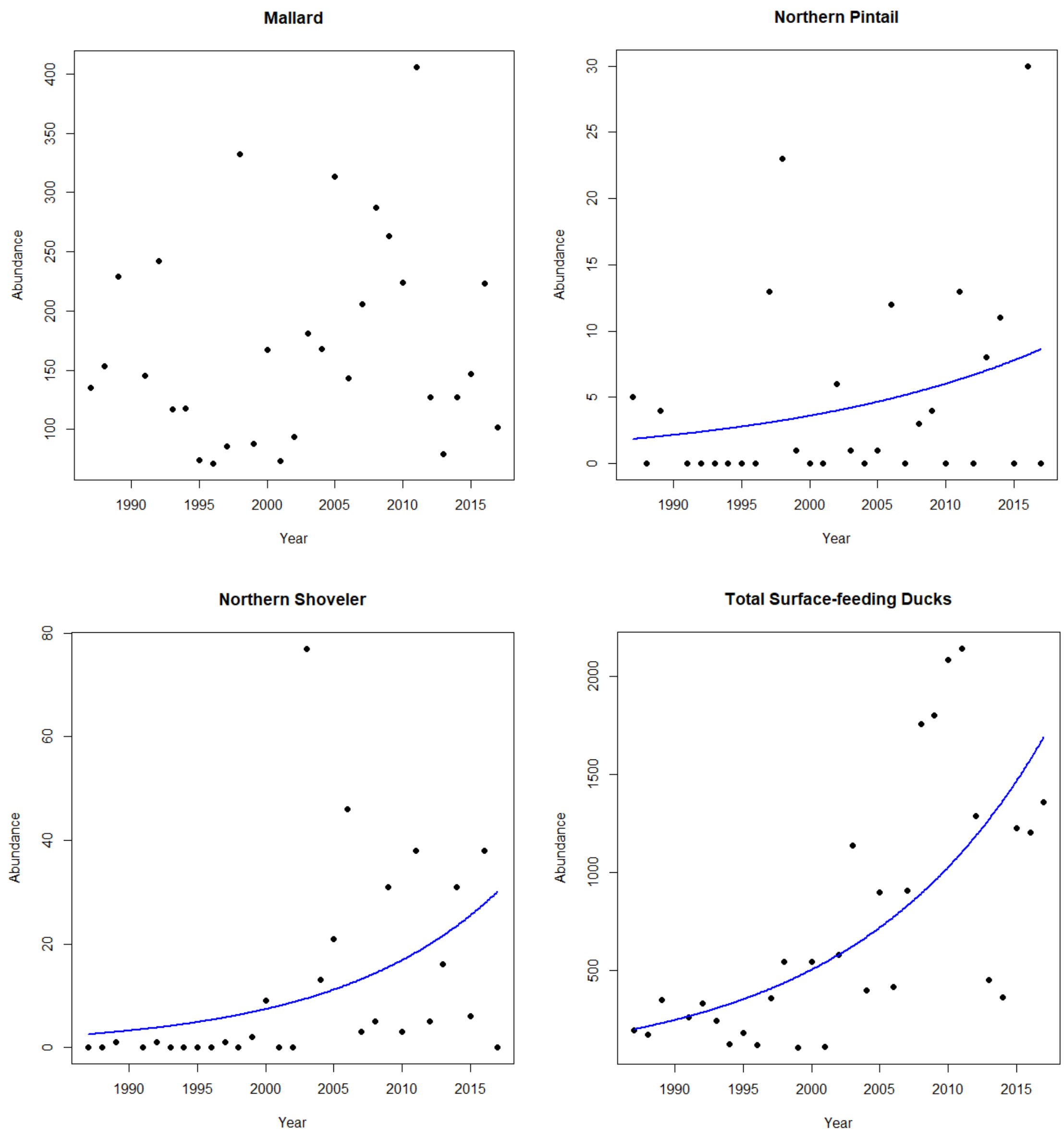

Figure 7 (continued from previous page). Abundance of the surface-feeding duck species in each survey year. Solid lines represent significant coefficient estimates for 'year' (at $p < 0.05$) based on Poisson or quasi-Poisson regression.

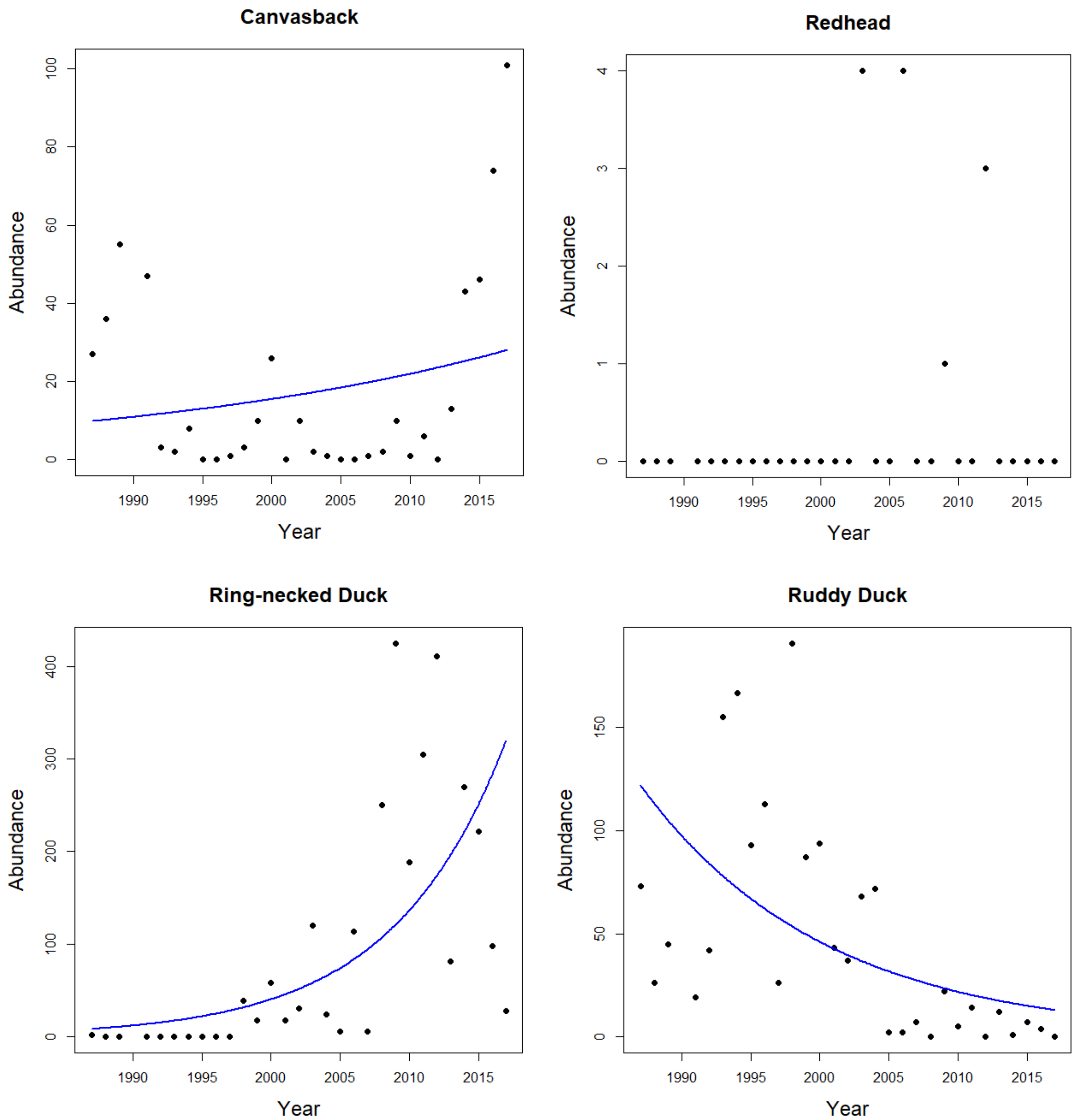

Figure 8 (continued on next page). Abundance of the freshwater diving duck species in each survey year. Solid lines represent significant coefficient estimates for 'year' (at $p < 0.05$) based on Poisson or quasi-Poisson regression. Dotted lines represent near-significant coefficient estimates for 'year' ($0.05 < p < 0.10$) based on quasi-Poisson regression.

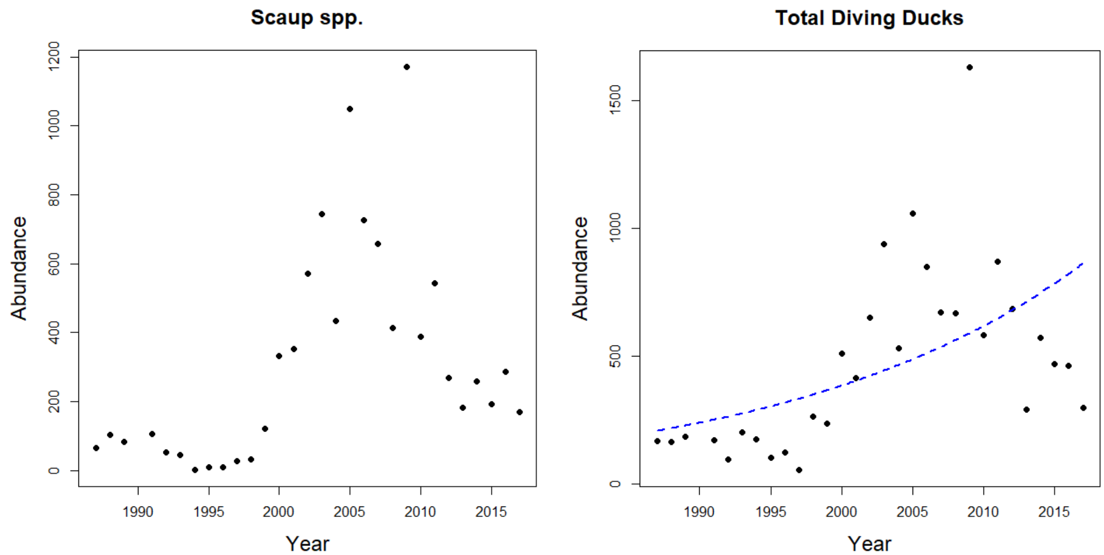

Figure 8 (continued from previous page). Abundance of the freshwater diving duck species in each survey year. Solid lines represent significant coefficient estimates for 'year' (at $p < 0.05$) based on Poisson or quasi-Poisson regression. Dotted lines represent near-significant coefficient estimates for 'year' ($0.05 < p < 0.10$) based on quasi-Poisson regression.

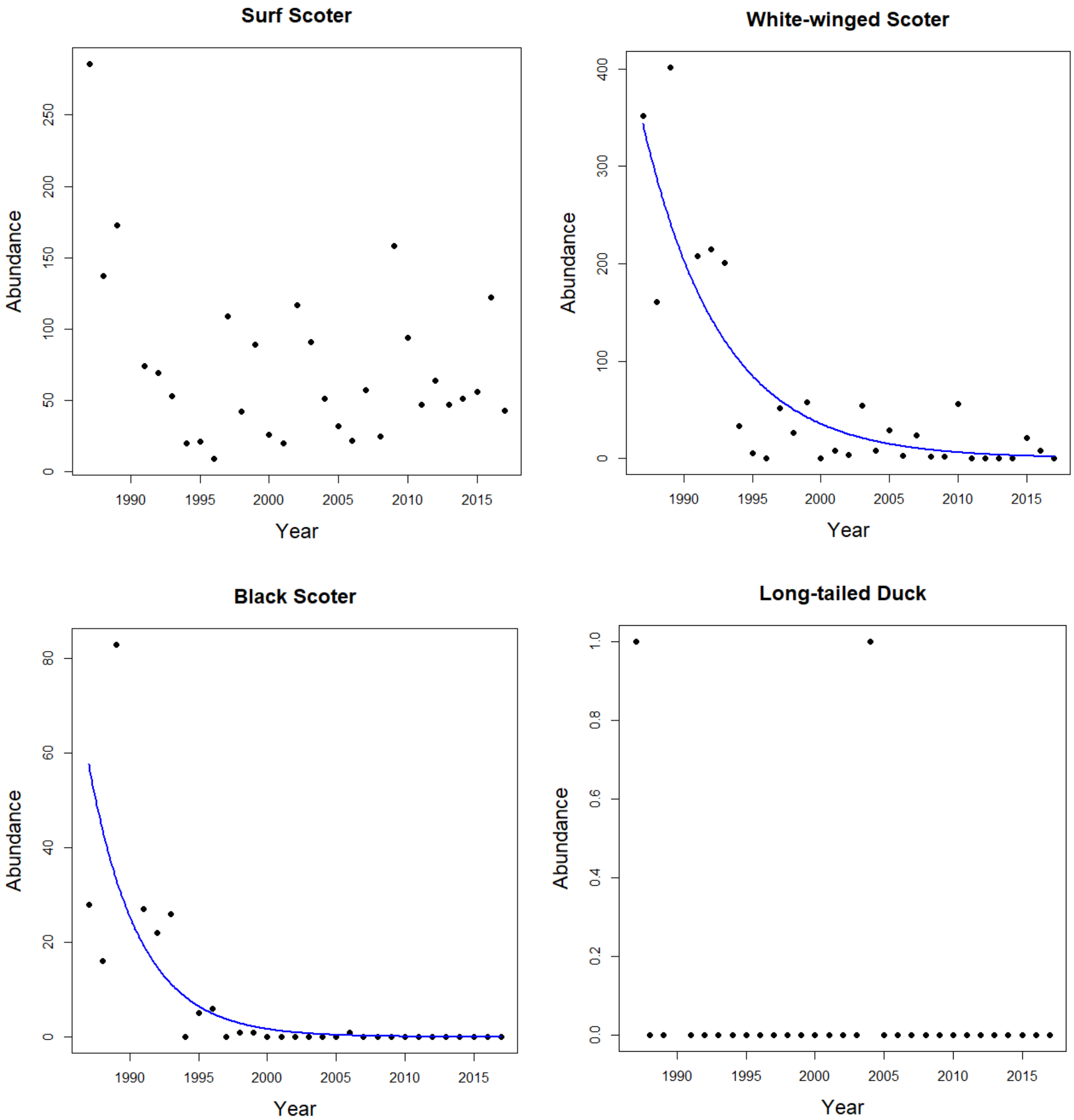

Figure 9 (continued on next two pages). Abundance of the sea duck species in each survey year. Solid lines represent significant coefficient estimates for ‘year’ (at $p < 0.05$) based on Poisson or quasi-Poisson regression.

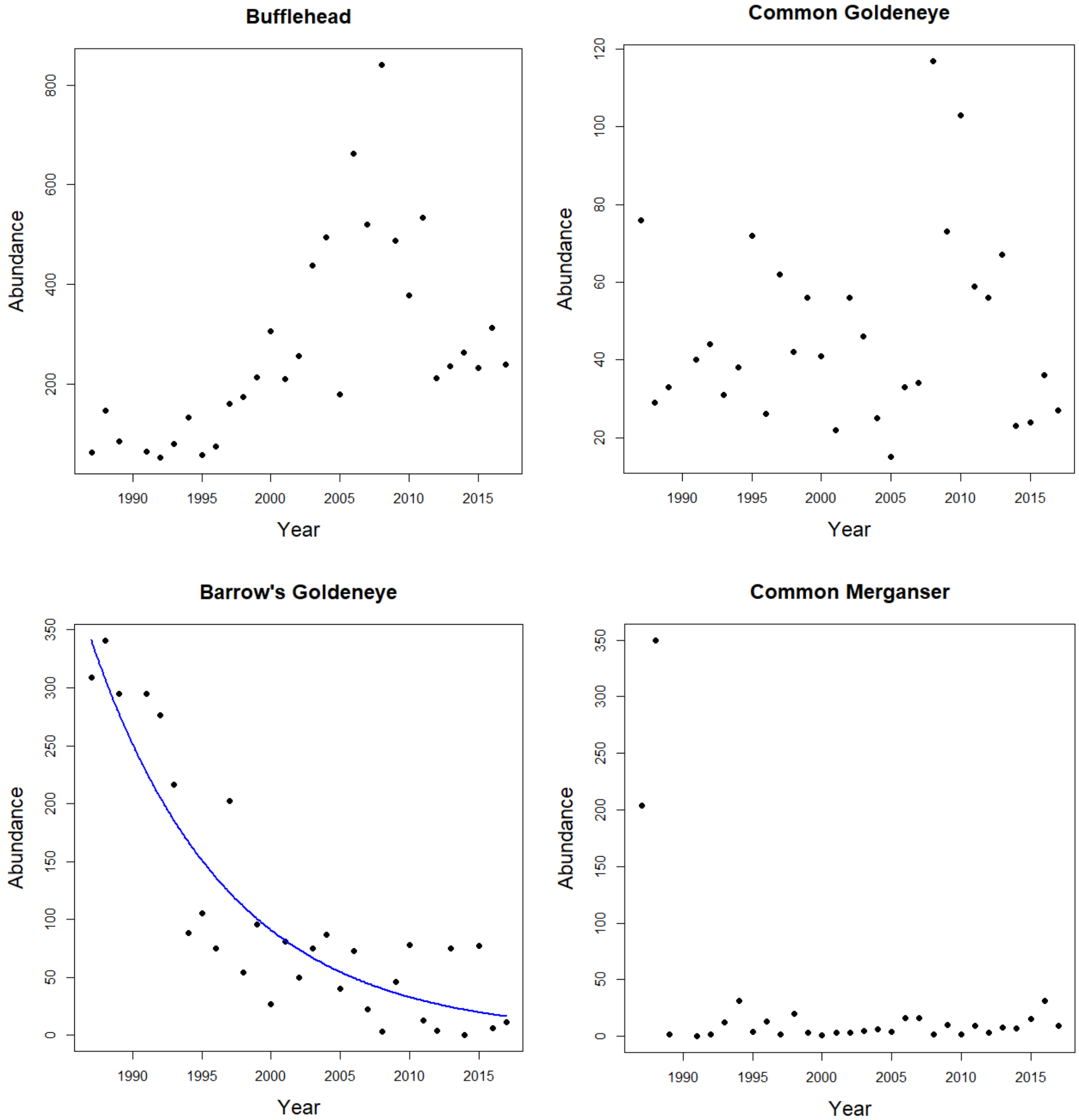

Figure 9 (continued from previous page). Abundance of the sea duck species in each survey year. Solid lines represent significant coefficient estimates for 'year' (at $p < 0.05$) based on Poisson or quasi-Poisson regression.

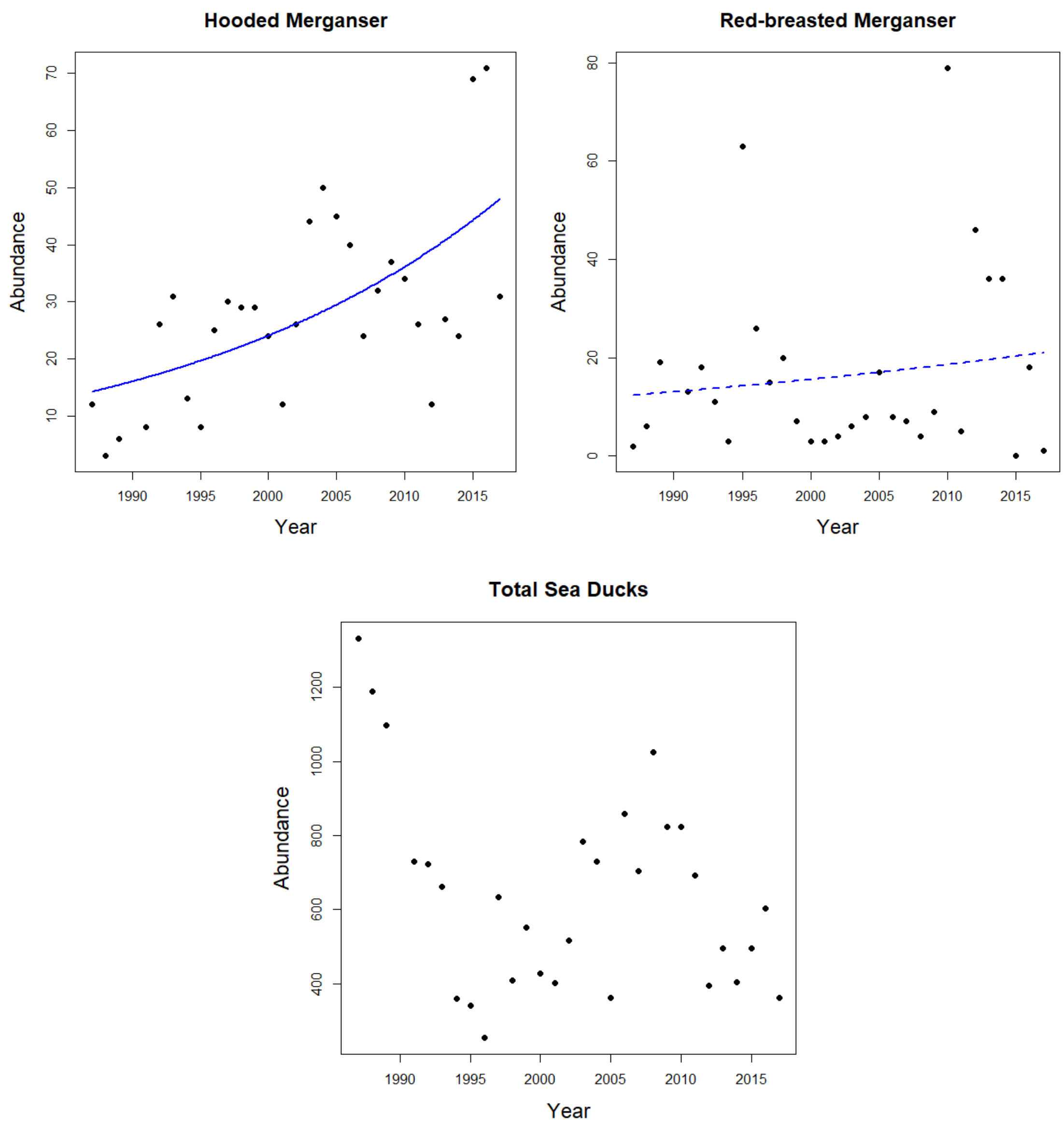

Figure 9 (continued from previous page). Abundance of the sea duck species in each survey year. Solid lines represent significant coefficient estimates for 'year' (at $p < 0.05$) based on Poisson or quasi-Poisson regression.

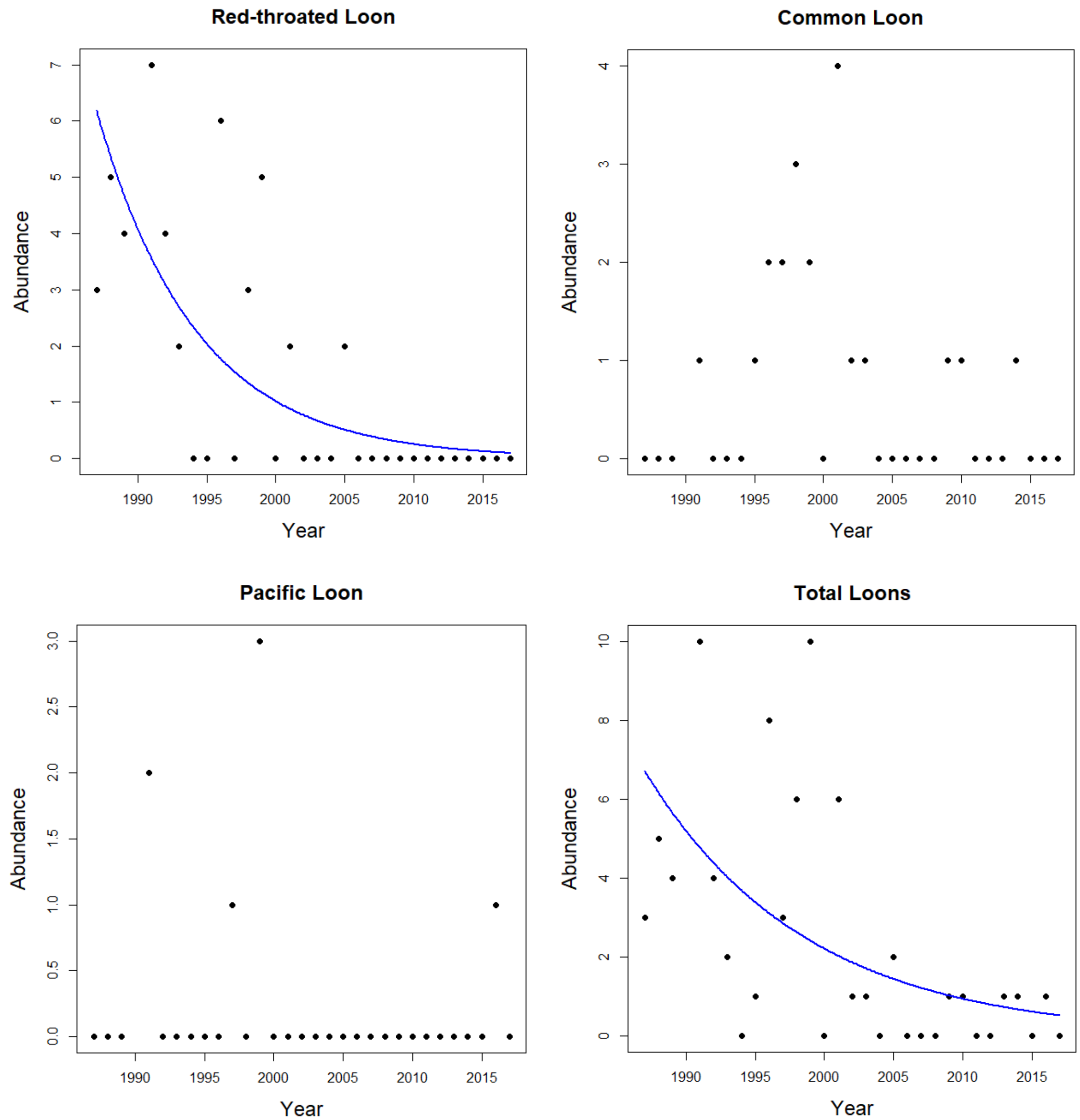

Figure 10. Abundance of the loon species in each survey year. Solid lines represent significant coefficient estimates for 'year' (at $p < 0.05$) based on Poisson or quasi-Poisson regression.

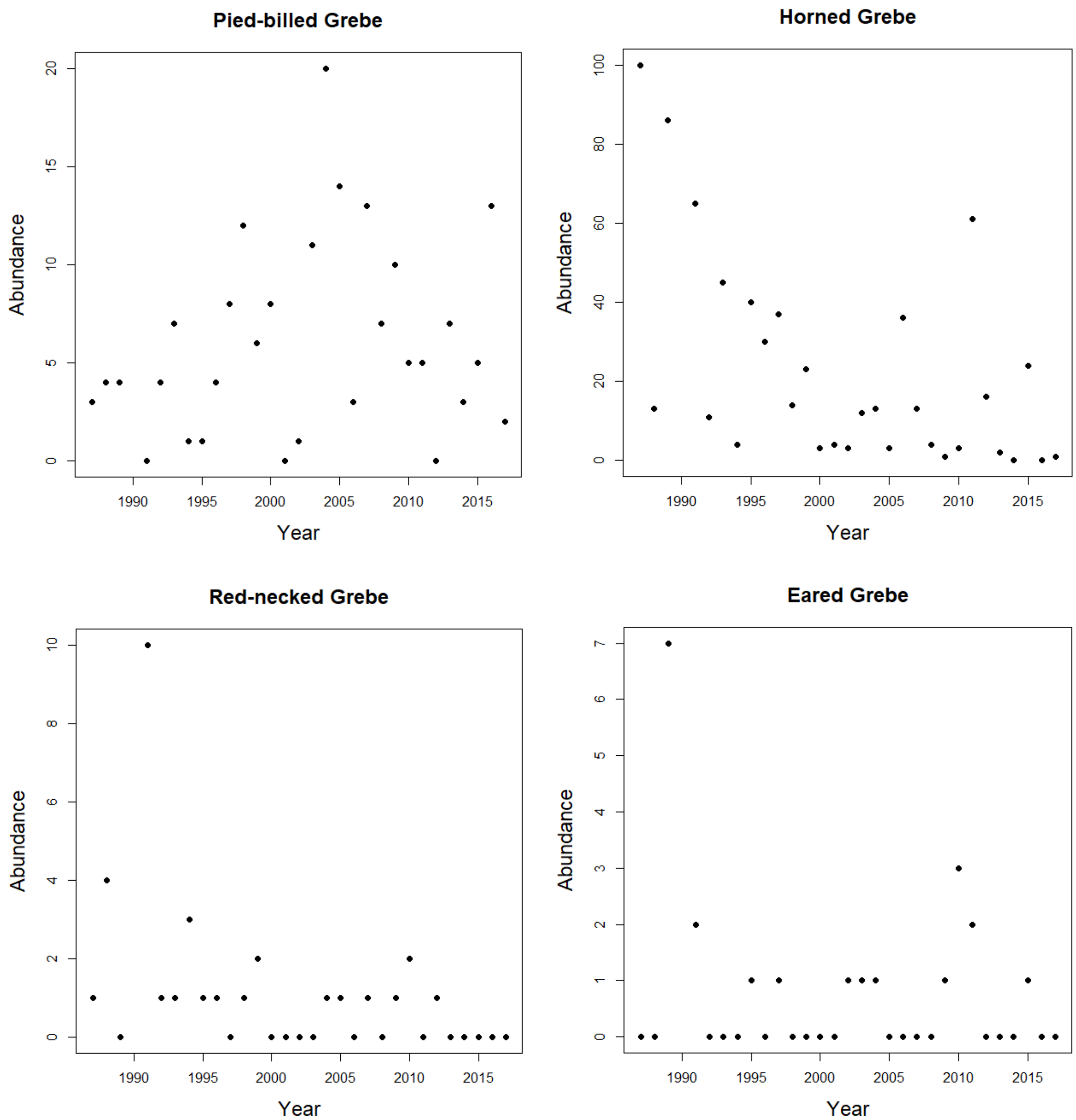

Figure 11 (continued on next page). Abundance of the grebe species in each survey year. Solid lines represent significant coefficient estimates for 'year' (at $p < 0.05$) based on Poisson or quasi-Poisson regression.

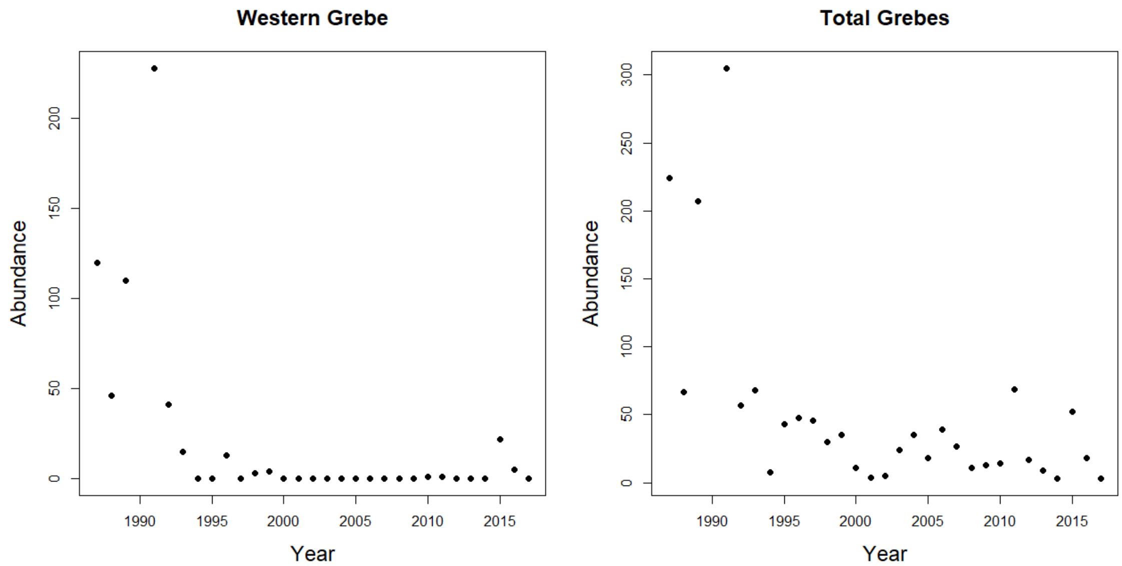

Figure 11 (continued from previous page). Abundance of the grebe species in each survey year. Solid lines represent significant coefficient estimates for 'year' (at $p < 0.05$) based on Poisson or quasi-Poisson regression.

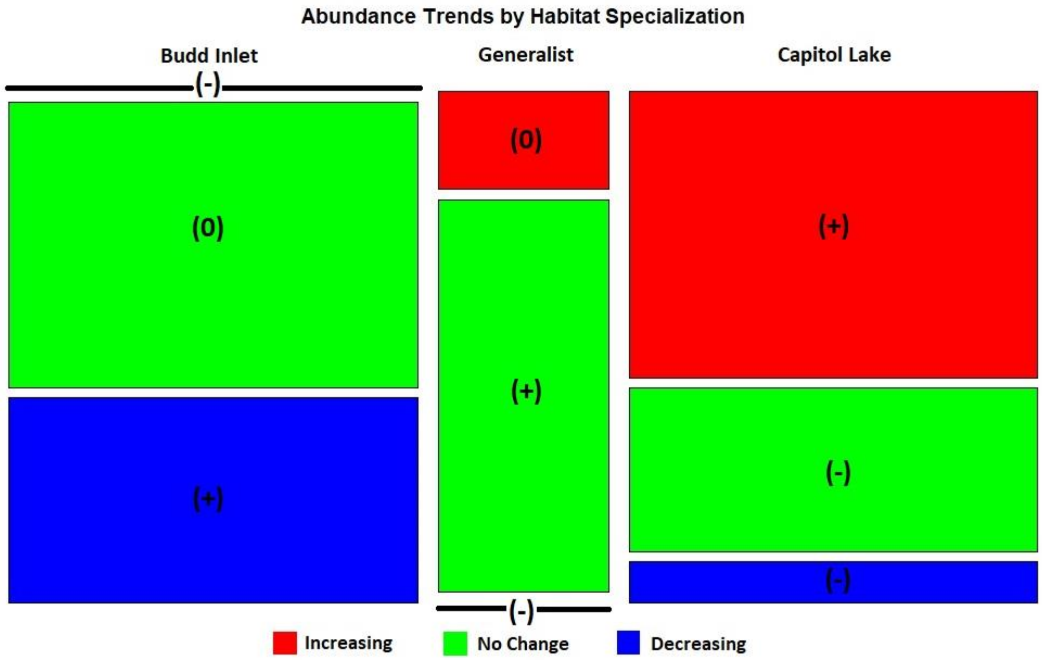

Figure 12. Counts of species by their trend in abundance (increasing, no significant change, or decreasing) and habitat specialization (Budd Inlet specialists, generalists, Capitol Lake specialists). Red blocks represent the number of species in each category with an increasing trend, green blocks represent the number of species with no change in abundance over time, and blue blocks represent the number of species with a decreasing trend. If there are no species in a specific trend x specialization category, it appears as a black line. The (-) symbol represents abundance-habitat specialization combinations with fewer species than expected (residuals < - 0.5), the (0) symbol represents combinations with approximately the same number of species as expected (- 0.5 < residuals < 0.5), and the (+) symbol represents combinations with more species than expected (residuals > 0.5), based on a chi-squared test of independence.

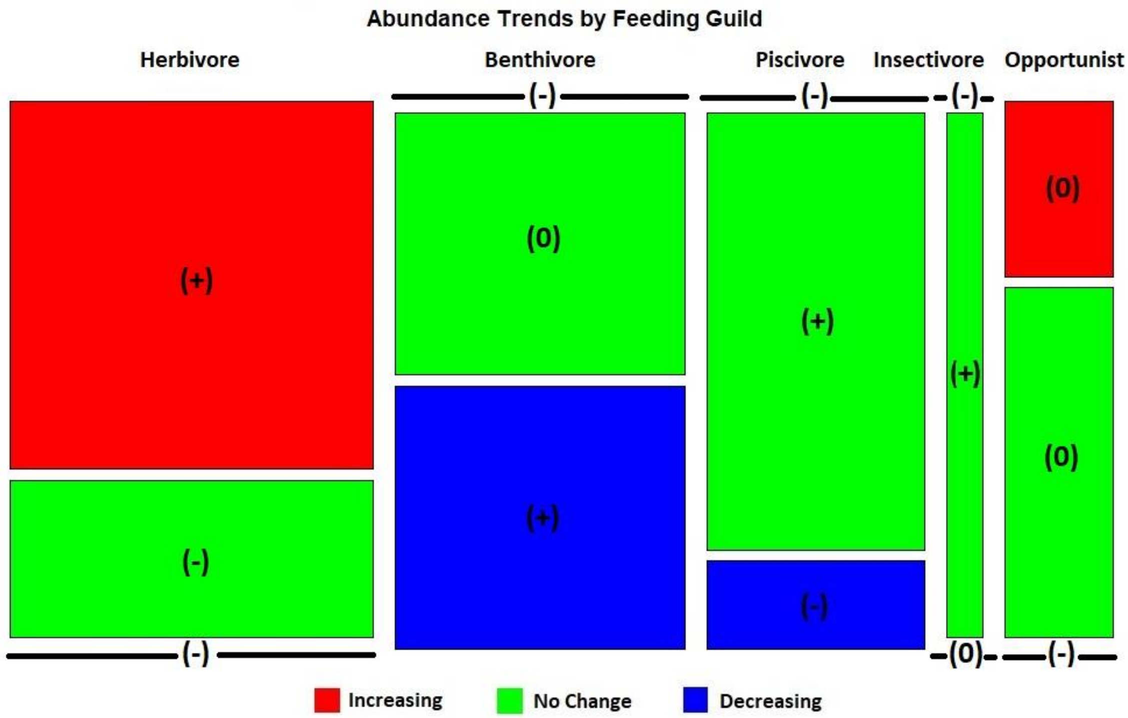

Figure 13. Counts of species by their trend in abundance (increasing, no significant change, or decreasing) and preferred feeding guild (herbivore, benthivore, piscivore, insectivore, opportunist). Red blocks represent the number of species in each category with an increasing trend, green blocks represent the number of species with no change in abundance over time, and blue blocks represent the number of species with a decreasing trend. If there are no species in a specific trend x feeding guild category, it appears as a black line. The (-) symbol represents abundance-feeding guild combinations with fewer species than expected (residuals < - 0.5), the (0) symbol represents combinations with approximately the same number of species as expected (- 0.5 < residuals < 0.5), and the (+) symbol represents combinations with more species than expected (residuals > 0.5), based on a chi-squared test of independence.

DISCUSSION

The overall trends for water-associated bird abundance and species richness show a pronounced shift in the utilization of the survey area by waterbirds over the course of the study period. Many species that utilize Budd Inlet have experienced significant declines, while many species that utilize Capitol Lake have experienced significant increases. These trends are most evident for species that have a high degree of specificity for one habitat type or the other, rarely if ever utilizing the opposite habitat. Capitol Lake specialists have increased in abundance by 6.5 percent per year and increased in species richness by 2.7 percent per year (Table 2; Figure 5), while Budd Inlet specialists have decreased in abundance by 5.2 percent per year, although species richness remained unchanged (Table 3; Figure 6). When generalist species that are able to utilize habitat in both Budd Inlet and Capitol Lake are included in the analysis, there is still a significant increasing trend in abundance and species richness of species that utilize Capitol Lake (Table 2; Figure 5), but there is no longer a significant trend for species that utilize Budd Inlet (Table 3; Figure 6). This suggests that generalist species may have been able to shift their utilization to Capitol Lake as conditions deteriorated in Budd Inlet, increasing in abundance or remaining stable as the abundance of species that are limited to using only the habitat types found in Budd Inlet has declined. More species than expected that specialize in Budd Inlet have had decreasing population trends, and more species than expected that specialize in Capitol Lake have had increasing trends, while populations of most generalist species have experienced no significant changes (χ^2 (4) = 13.6, $p < 0.01$; Figure 12).

Total water-associated bird abundance and species richness over the entire survey area did not change significantly over time (Table 1; Figure 4), suggesting that the gains in abundance and richness on Capitol Lake were significant enough to compensate for the losses in abundance and richness on Budd Inlet, balancing out the changing trends when considering the aggregate totals for the survey area. This underscores the value of analyses focused on specific locations and species, as anyone looking for trends at a broader scale using overall Christmas Bird Count data would not necessarily detect them.

Population changes for functional groups and species of interest were examined at a finer scale by analyzing trends by group for surface-feeding ducks (Table 4; Figure 7), freshwater diving ducks (Table 5; Figure 8), sea ducks (Table 6; Figure 9), loons (Table 7; Figure 10), and grebes (Table 8: Figure 11), and for each individual species that was included within each group. These trends show which groups and species are the drivers of the broader-scale changes that were previously discussed, and they can provide some insight into which aspects of the available habitat in Budd Inlet and Capitol Lake may have changed over the course of the study period. Because food source availability is a likely cause of changes in abundance, the abundance trends were also analyzed by feeding guild to find patterns in population trends that may be related to food preference (Figure 13).

Surface-feeding Ducks

Surface-feeding ducks were the group with the largest increasing trend (Table 4; Figure 7), strongly reflecting the preference of most species in this group for the habitat and food sources found in Capitol Lake. The total abundance for the group had a highly significant increase of 7.2 percent per year ($p < 0.01$; Table 4; Figure 7). This trend was driven primarily by increasing abundances for five of the seven surface-feeding duck species analyzed: American Wigeon (9.3%/year), Gadwall (9.7%/year), Green-winged Teal (5.8%/year), Northern Pintail (11.3%/year), and Northern Shoveler (11.1%/year; Table 4; Figure 7). All five of these species show a very strong preference for the habitat found in Capitol Lake, are rarely found on Budd Inlet (Keith Brady, pers. comm.), and primarily consume vegetation and insects (Johnsgard 2010). Both of these food sources have proliferated in Capitol Lake in recent years due to explosions in the growth of many pondweed species (CH2MHill 2001; Hayes et al. 2008; Roberts et al. 2012). Eurasian Wigeon has similar habitat and food preferences and although Eurasian wigeon did not show a significant trend when analyzed by the model, it should be noted that this species was not recorded in any surveys in the first half of the study period prior to 2002, but was recorded in almost every year thereafter (Table 4; Figure 7). This may reflect both an increase in abundance of the species generally within the region due to increased migration, as well as more favorable habitat conditions in Capitol Lake. Two rare species with similar habitat and food preferences (Eurasian Green-winged Teal and Blue-winged Teal) were also only observed during the second half of the study period. Green-winged Teal is the species with an increasing abundance trend that utilizes Budd Inlet in addition to Capitol Lake the most (Keith Brady, pers. comm.), and it is also the species with the slowest rate of increase in abundance over time (Table 4; Figure 7). Mallard is the only surface-feeding duck species that utilizes Capitol Lake and Budd Inlet approximately equally (Keith Brady, pers. comm.), and Mallards showed no significant change in abundance over time, remaining at a moderate level of abundance throughout the study period (Table 4; Figure 7). This suggests that if Mallards benefited from improved conditions on Capitol Lake, this may have been balanced by deteriorating conditions on Budd Inlet. All of the surface-feeding duck species were analyzed as part of the herbivore feeding guild. Herbivores had a disproportionately greater number of species with increasing trends (χ^2 (8) = 20.0, $p < 0.05$), further suggesting that increased food availability may be the driver of population trends in this group.

Populations of surface-feeding ducks have also been increasing on a larger scale, as recorded in annual breeding surveys conducted by the U.S Fish and Wildlife Service (USFWS 2017). The abundance data from these surveys show an increasing trend for many of the waterfowl species, but these trends do not match up exactly with the trends observed for Capitol Lake and Budd Inlet in several ways. The first is that all of the species trends in the U.S. Fish and Wildlife Service report have been increasing since at least around 1991 (earlier for some species; USFWS 2017). That was the year that lead shot, which previously poisoned millions of waterfowl each year (Bellrose 1959; Feierabend 1983), was banned nationwide, allowing populations to begin to rebound. Increases in abundance of surface-feeding ducks on Capitol Lake, in contrast, did not begin until very late in the 1990's (Figure 7). The second is that the U.S. Fish and Wildlife Service data show a large increase in Mallard populations which was not seen in the Capitol Lake surveys (Figure 7; USFWS 2017). The third is that Green-winged Teal abundance on Capitol Lake and Budd Inlet did not increase as much as would be expected given the increases observed by the U.S. Fish and Wildlife Service for the general breeding population (Figure 7; USFWS 2017). Finally, the U.S. Fish and Wildlife Service data do not show the dramatic increase in American Wigeon populations that was recorded on Capitol Lake (Figure 7; USFWS 2017). American Wigeon abundances according to the U.S. Fish and Wildlife Service surveys are currently slightly higher than, but comparable to, their levels in the late 1990's, and the overall population declined during many of the years when increases were observed on Capitol Lake (USFWS 2017). These discrepancies make it unlikely that the entirety of the population trends observed on Capitol Lake can be attributed to the broader scale population increases. The cause of the increased occurrence of surface-feeding ducks on Capitol Lake, then, is probably attributable to a combination of both increasing general population trends and more favorable local habitat conditions.

Freshwater Diving Ducks

Freshwater diving ducks are also found almost exclusively on Capitol Lake, with some occurrences in Budd Inlet. Two of the freshwater diving duck species showed a significant increase in abundance over time: Canvasback (11.6%/year) and Ring-necked Duck (11.2%/year; Table 5; Figure 8). Similar to the surface-feeding ducks that had increasing trends, both of these species consume mostly pondweeds and other aquatic vegetation, which have proliferated on Capitol Lake in recent years (CH2MHill 2001; Hayes et al. 2008; Roberts et al. 2012). Redhead also shares these habitat and feeding requirements, and although they were not observed in high enough numbers to register as a significant increasing trend using the model, they were never observed in the survey area prior to 2003 (Figure 8). These species were also analyzed as part of the herbivore feeding guild, which had a disproportionately high number of species with increasing trends ($\chi^2(8) = 20.0$, $p < 0.05$), further suggesting that increased food availability may explain the population trends in these species. Another interesting change within this group is that at the beginning of the study period, Canvasbacks were found with approximately equal likelihood on Capitol Lake and Budd Inlet, and in more recent years are found only on Capitol Lake (Keith Brady, pers. comm.), suggesting that the habitat in Budd Inlet may no longer be able to support their populations. Abundance of Canvasbacks also declined sharply after the first few years of the study period (possibly reflecting deteriorating conditions in Budd Inlet) before increasing again in the four most recent years (possibly reflecting improved conditions in Capitol Lake; Figure 8). Ruddy Duck was the only freshwater diving duck species that decreased in abundance over time (-14.1%/ year; Table 5; Figure 8), and it is also the only species that consumes primarily insects and crustaceans, with little to no plant matter. As a benthic feeder, it may also be affected by issues with sediment toxicity and low dissolved oxygen in Capitol Lake (Roberts et al. 2012). More benthivores than expected were found to be declining across the study area (χ^2 (8) = 20.0, $p < 0.05$), suggesting that benthic food sources may have been affected by environmental contamination or other influences. The scaup species group, including Greater Scaup and Lesser Scaup, did not show a significant change in abundance over time (Table 5; Figure 8). It is possible that some of the population trends that may have been observed were obscured by the relationship between recorded scaup abundance and visibility conditions, as this was a significant correlation established by the model (Table 5). Greater Scaup and Lesser Scaup abundances were analyzed together because of difficulty distinguishing between species due to survey conditions in some years (Keith Brady, pers. comm.). However, if the species had been analyzed separately, it is likely that there would have been a significant increasing trend at least for Lesser Scaup. Lesser Scaup were only recorded once prior to 1997, in a trend that appears very similar to that which was seen for Ring-necked Duck. Scaup consume primarily mollusks, making them unique within the freshwater diving duck tribe in terms of their feeding preferences. The aggregated total abundance for the freshwater diving duck group had a near-significant increase over time (3.9%/year; Table 5; Figure 8), but the negative influence of the Ruddy Duck trend seems to largely balance out the increasing trends for other species when the total numbers are analyzed.

The annual breeding surveys conducted by the U.S. Fish and Wildlife Service also include freshwater diving ducks and there are similarities as well as differences between the broader continental scale trends and the trends that were observed on Capitol Lake (USFWS 2017). Large scale increases have been observed for Canvasback populations (USFWS 2017), which is a species that also increased on Capitol Lake (Table 5; Figure 8. However, the increase in Canvasback on Capitol Lake has largely occurred within the last five years (Figure 8), while the larger scale increase has occurred over a much longer period (USFWS 2017). No significant trend was detected for Redhead on Capitol Lake (Table 5; Figure 8), even though a fairly large increase has occurred in the larger scale population (USFWS 2017). In contrast, Ring-necked Duck has increased dramatically on Capitol Lake (Table 5; Figure 8), while there has been no significant change between current Ring-necked Duck population size and the 1990-2016 average in the breeding population as a whole (USFWS 2017). Another difference between the Capitol Lake data and the U.S. Fish and Wildlife Service data is that the U.S. Fish and Wildlife Service data show a decline in scaup populations (USFWS 2017), while scaup populations on Capitol Lake did not have a significant trend (and had the trend for Lesser Scaup been significant, as discussed previously, it would have been in the opposite direction; Table 5; Figure 8). Because there are both similarities and differences between the trends observed on Capitol Lake and the larger scale breeding population trends recorded by the U.S Fish and Wildlife Service, it is likely that the cause of the population trends on Capitol Lake is related to a mix of factors including both increasing general population size and changes in local habitat suitability.

Sea Ducks

As a group, sea ducks can commonly be found on both Capitol Lake and Budd Inlet, though all of the sea duck species utilize Budd Inlet to some extent. As such, there was no significant change in the aggregated total abundance of sea ducks over time (Table 6; Figure 9). However, several species within the sea duck tribe are exclusive to Budd Inlet and have never been recorded on Capitol Lake during the surveys (Keith Brady, pers. comm.). These species include Surf Scoter, White-winged Scoter, Black Scoter, Barrow's Goldeneye, and Red-breasted Merganser.

Black Scoter and White-winged Scoter had very large decreases in abundance over time (-37.2%/year and -16.4%/year, respectively), but there was no significant change in abundance over time for Surf Scoters (Table 6; Figure 9). What is particularly striking is that Black Scoter went from being fairly common in the early years of the study period (1987 to 1993), with more than 80 individuals counted in one year and an average of around 30 individuals counted in each year, to only being observed rarely in extremely low numbers during the rest of the study period (Figure 9). Single individuals were observed only three times during the last 20 years, and no Black Scoters have been recorded in any surveys since 2006 (Figure 9). White-winged Scoters followed a very similar pattern, with large numbers typically upwards of 200 individuals recorded from 1987 to 1993, followed by a drop off in which fewer than 60 individuals were recorded for all the remaining years of the study period (Figure 9). However, White-winged Scoters' decline is not quite as dramatic as that of the Black Scoter, as low numbers of White-winged Scoters have continued to be observed in recent years (Figure 9). Barrow's Goldeneye also decreased in abundance over time (-8.7%/year; Table 6; Figure 9). All of these species are benthic feeders (Bower 2009), so one possible reason for their declines may be related to toxic sediments and low dissolved oxygen in Budd Inlet (NewFields 2015; Roberts et al. 2012). A disproportionate number of benthivores were found to be declining (χ^2 (8) = 20.0, $p < 0.05$), suggesting that benthic food sources may also be in decline. Red-breasted Merganser is unique within this group as the only Budd Inlet specialist with an increasing trend in abundance over time (6.3%/year), and it is also the only one that is not a benthic feeder (Table 6; Figure 9).

Species that utilize Capitol Lake in addition to Budd Inlet include Bufflehead, Common Goldeneye, Common Merganser, Hooded Merganser, and Long-tailed Duck. Bufflehead, Common Goldeneye, and Common Merganser did not have a significant change in abundance over time (Table 6; Figure 9). However, one interesting thing to note is that despite the lack of a significant trend over time, more than 200 Common Mergansers were recorded in the first year of surveys (1987) and 350 Common Mergansers were recorded in 1988, after which their numbers dropped off to below 40 for the remainder of the study period (Figure 9). The model did register a significant relationship between Common Merganser abundance and several of the survey conditions (survey date, survey hours, and wind speed; Table 6). Survey date, especially, may have masked any effect of any potential change over time in the model, as the first two years of surveys were also completed at the latest dates. It is unclear whether the sudden drop off in Common Merganser numbers after the first two years was actually caused by the change to earlier survey dates, or by some other change in conditions that occurred at that time. Hooded Merganser was the only sea duck species with a significant increase in abundance over time (3.9%/year; Table 6; Figure 9). It is also the only sea duck species that is an opportunist, feeding on many types of organisms and plants, so it may have more flexibility in shifting to alternative food sources if some sources decline. To emphasize this, all of the opportunist species across the study area had either stable or increasing populations, more than expected by chance ($\chi^2(8) = 20.0$, $p < 0.05$; Figure 13). Long-tailed Duck was recorded too infrequently to be included in the analysis, but its observations do not seem to support any larger pattern as it was recorded once at the beginning of the study period (1987) and once later in study period (2005; Table 6; Figure 9).

Bower (2009) provides a similar type of analysis for many of these species in the northern part of the Salish Sea (though no surveys were conducted south of Discovery Bay) by comparing winter population estimates from 1978-1980 with more recent population estimates from 2003-2005. Although this study period does not line up perfectly with the study period used for the Budd Inlet and Capitol Lake surveys, it does cover a broad enough span of years that it can be used as a comparison, since it would have been able to detect population levels before and after the years in which the largest sea duck population changes were observed in Budd Inlet and Capitol Lake. Bower (2009) calculated decreases in the populations of all three scoter species, Barrow's Goldeneye, Red-breasted Merganser, Bufflehead, Common Goldeneye, and Long-tailed Duck, with the only increase for Common Merganser. Hooded Merganser was not included in the analysis. While the declines reported by Bower (2009) for scoters and Barrow's Goldeneye are not surprising given the data recorded on Budd Inlet and elsewhere, the decline reported by Bower (2009) for Red-breasted Merganser is in contrast to the increase observed on Budd Inlet (Table 6; Figure 9). Common Goldeneye, Bufflehead, and Long-tailed Duck also did not show the same declines in the Budd Inlet/Capitol Lake study area that were observed by Bower (2009), and Common Merganser did not show the dramatic increase in population in the Budd Inlet/Capitol lake study area that was observed by Bower (2009; Table 6; Figure 9). The comparison to Bower (2009)'s analysis suggests that there are different population trends for overwintering birds in the northern part of the Salish Sea than in Budd Inlet, which is much farther south in Puget Sound and may be subject to different environmental conditions even if birds found the two locations from the same breeding populations.

Loons and Grebes

All three species of loons are found exclusively on Budd Inlet and consume a similar diet of fish, with some insects, crustaceans, and mollusks. Although Red-throated Loon is the only species that showed a significant decrease in abundance over time using the model (-20.3%/year), both Common Loon and Pacific Loon had negative year coefficients and the total number of loons decreased significantly over time, albeit to a lesser extent (-13.0%/year; Table 7; Figure 10). Bower (2009)'s analysis showed a similar level of decrease for Red-throated Loon, along with an even larger decrease for Pacific Loon, and a large increase for Common Loon, suggesting that loon populations except for

Red-throated Loon in Budd Inlet have not changed in size in the same ways as loon populations further north in the Salish Sea. The loon species were included in the piscivore feeding guild for further analysis, which had more species than expected with no significant population trends (χ^2 (8) = 20.0, $p < 0.05$; Figure 13), reflecting the mix of population trends within this group. Piscivore is a broad term, and some of the variety in trends for this feeding guild may be a result of different types of fish that are eaten by different species and the greater ability of some species to utilize other types of food if their preferred fish are scarce. However, there may also be additional factors unrelated to diet that make some species more susceptible to decline than others, and declines may be caused by problems either locally in Budd Inlet or elsewhere in their range.

None of the grebe species showed a significant trend using the generalized linear models, which was very surprising given the appearance of the data for some species (Table 8; Figure 11). It should be noted that this may be an issue of inadequate model fit rather than a true lack of a trend. Removing just a few survey variables (which likely did not influence the abundance counts) results in a highly significant trend for year for some species, so it is possible that a model fitting approach would have better represented the data for this group. Bower (2009)'s analysis of grebe population changes in the northern part of the Salish Sea suggest that populations may have decreased for Red-necked Grebe, Horned Grebe, and Western Grebe in other habitats in the region. It should be noted that the lack of significant trends for this group may have also influenced the results of the chi square independence test for the piscivore, insectivore, and opportunist feeding guilds, as at least one grebe species was included in each group (χ^2 (8) = 20.0, $p < 0.05$; Figure 13). However, even without the inclusion of the grebe species trends, it is unlikely that there would have been a disproportionate level of increase or decline for any of those feeding guild categories.

Other Water-associated Bird Species

Several other water-associated bird species and groups are commonly recorded during the surveys but were not included in the species-specific analyses. These include geese, swans, alcids, cormorants, herons, gulls, shorebirds, and coots. These groups and species were excluded from analysis because they either did not appear to exhibit any interesting trends over time, or because they were recorded too infrequently to provide adequate data for a time series analysis. However, there are a few potential trends worth noting with regard to several of these species.

Within the goose group, Canada Goose was the only species that was commonly recorded, but there was a great deal of variability in abundance from year to year. Cackling Goose was only recorded three times, all of which were in the second half of the study period (2005, 2009, and 2013). Similarly, Greater White-fronted Goose was only recorded after 1999 and has become more common in recent years. In the opposite trend, individual Snow Geese were recorded in the first two years of surveys, but never again after that. Snow Geese and Greater White-fronted Geese were never observed in numbers greater than one or two individuals. The arrival of Trumpeter Swan is also interesting, as this species was never recorded prior to 2010, but has become an almost annual occurrence since 2014. Only two individuals have been recorded in any given year, and it is possible that the same pair is returning to Capitol Lake year after year.

Alcids are another group that have potentially interesting population trends in the greater Puget Sound region (Bower 2009). However, alcids are typically found further out in the ocean, and because the survey area only includes the southern part of Budd Inlet, these species were recorded infrequently and in low numbers in this dataset. Common Murre was recorded once in 1999 and Ancient Murrelet was recorded once in 2011. Pigeon Guillemot was recorded twice in the early survey years, then disappeared, with a small spike of reoccurrence from 2004 to 2010. Rhinoceros Auklet was recorded sporadically throughout the study period, with especially high numbers in 1996.

Influence of Survey Conditions and Other Potential Limitations

None of the survey conditions included in the model seemed to have a large degree of influence on the results, as only a few species were found to have a significant relationship with any given survey variable. Given this result, it is unlikely that any of the manipulated survey conditions, such as number of observers or number of survey hours, had an effect on the recorded abundances. Traditional analysis of Christmas Bird Count data uses count per party-hour as a way of accounting for the influence of effort on counts (Bock & Root 1981). This was not done for this analysis because survey times did not vary much from year to year and survey routes were consistent (Keith Brady, pers. comm.), but survey hours were included in the model to account for any possible influence. As the number of survey hours was rarely a significant factor in the models, this deviation from traditional CBC analysis appears justified. Further, in the analysis of the general trends, survey hours had a positive relationship with total bird richness, but not with water-associated bird richness, which supports the surveyor's claim that any additional time spent surveying in certain years was used to search for passerines rather than waterbirds, thus not affecting the water-associated bird count results (Keith Brady, pers. comm.).

The number of observers that participated in each survey changed throughout the study period. It was highest toward the beginning of the study period, when there were often two or three observers present, and lower in more recent years, in which surveys were often conducted solo or with two observers. Because of this, it is unclear whether relationships between species abundance and number of surveyors detected by the model may be more reflective of change over time rather than the number of surveyors. Because the lead observer saw and recorded all birds himself during the surveys, it is unlikely that additional observers would have provided a significant increase in the number of birds observed (Keith Brady, pers. comm.). This is reflected in the fact that there was a significant relationship of counts to the number of observers present in only two species' models.

Similarly, survey date has also changed over time, with surveys now occurring earlier than they did at the beginning of the study period. On average, surveys in the second half of the study period from 2003 to 2017 occurred 5 days earlier than surveys in the first half of the study period from 1987 to 2002. In particular, the first three surveys occurred later than almost all of the following surveys, between December 30 and January 2. Survey date has the potential to affect the abundance or species richness of water-associated birds present because species migrate into the area at different times. However, most migrations take place during the spring and fall and would be complete by December, so it is unlikely that the change in survey date was responsible for a significant portion of the observed trends. One species for which survey date may have played a significant role is Common

Merganser. Common Mergansers tend to accumulate throughout the winter, congregating in larger flocks later in the season, so the significant model result for survey date might be a valid explanation in this case (Keith Brady, pers. comm.). It is unclear whether reductions in Common Merganser numbers after the first two survey years are more closely related to the change to earlier survey dates or to some other factor that changed at that time.

One limitation of this study is that it is based on a dataset for which surveys were conducted on only one day each year. While this has been sufficient to capture trends for many species, the data do contain a significant amount of variability from year to year. When species were absent or observed in low numbers during years that occurred between years when the same species were present in large numbers, it is probable that those species were present in the area and utilized the habitat found in the study area on some days of that winter, but may have simply not been observed in the study area on the particular day that was surveyed. It is possible that without this variability in the data, trends may have been detected for additional species.

Recommendations for Further Research

Several opportunities exist for further research on the population trends of water-associated birds in Budd Inlet and Capitol Lake. The first is to investigate the reasons for the population changes that have been documented. This research could test hypotheses related to explanations such as changes in food source availability, water quality, predation pressure, or other factors. It would also be useful to analyze trends within the greater Puget Sound region over the same time period to determine whether there have been simultaneous declines in seabird populations elsewhere in the region, or simply a geographic shift away from Budd Inlet. This could be done by tallying the Christmas Bird Count results for species of interest from all count circles overlapping Puget Sound in each survey year and analyzing that dataset using a model that includes independent variables that, as much as possible, represent the same factors that were accounted for in this analysis. Although these regional counts lack some of the consistency of the smaller dataset that was used for this analysis, they can help to show which local trends may mirror the trends observed at the regional scale for various species and which trends may have occurred due to localized conditions.

Another opportunity for further research is to continue monitoring the population trends of the water-associated bird species that are documented here to determine if they continue or change in the future. This can be done simply by continuing the annual surveys of Budd Inlet and Capitol Lake using the same protocols and survey area boundaries to develop a longer-term dataset. An additional source of data on water-associated bird populations in the West Bay portion of Budd Inlet is available in the form of an 8 month survey conducted from mid-November through mid-June of 2002 for the Thurston Regional Planning Council (R.W. Morse Company 2002). This survey was conducted by the same observer who provided the Christmas Bird Count data analyzed here, and it could easily be replicated and used as a baseline to analyze the changes that have occurred since then. This could be beneficial for providing additional evidence of the trends shown in this analysis, as well as for determining whether similar trends have occurred during other parts of the year.

Continued monitoring of water-associated bird populations in the Capitol Lake and

Budd Inlet area will be especially important if Capitol Lake is removed and the Deschutes estuary is restored. The large abundances of surface-feeding ducks that currently utilize the freshwater habitat found in Capitol Lake will likely be forced to find alternative foraging locations if the restoration plan is implemented, potentially reducing their abundance in the area. It will also be interesting to see if seabird populations on Budd Inlet which are currently in decline might benefit from the additional foraging habitat that would be provided by a more natural estuarine system. One water-associated bird group that is especially expected to benefit from the restoration of the mud flats in the Deschutes estuary is the shorebirds, which most commonly forage while walking across exposed tidal flats and in shallow water. Shorebirds were not given much attention in this analysis because their abundance trends during the study period were not particularly striking, but it will be important to document population changes for this group after restoration efforts occur. The dataset used in this analysis provides a baseline for the current conditions prior to restoration and can be used to compare current abundances and population trends with those observed in future surveys following the implementation of the restoration plan.

CONCLUSION

It is clear that the water-associated bird life on Capitol Lake and Budd Inlet during the winter has changed significantly over the past 30 years. The abundance of seabirds on Budd Inlet that could be observed in the early years of the study period has largely disappeared, and many species that were once abundant now occur only sporadically or in very low numbers, if they are seen at all. At the same time, utilization of Capitol Lake by ducks, especially those that feed on aquatic vegetation, has taken off. The reasons for these trends are not well understood, but there are some likely causes that would benefit from further study.

The abundance trends show a disproportionate level of decline for Budd Inlet specialists and a disproportionate level of increase for Capitol Lake specialists, while the abundance of generalist species has remained relatively stable. This points to key differences in the way these two connected ecosystems are changing. Across the survey area, many of the population changes appear to be attributable to the feeding preferences of various species, with disproportionate increases for herbivores and disproportionate declines for benthivores, while members of other feeding guilds have maintained more stability. These patterns may be helpful in determining which parts of the ecosystem are in trouble, and which ones may be less affected by changes in the environment.

The declining population trends for seabirds on Budd Inlet are particularly concerning, because seabird populations have been struggling worldwide. Seabirds are often viewed as indicator species, and declining populations could indicate dangerous changes in the ecosystem and environment as a whole. Further research can determine if local conditions in Budd Inlet are especially detrimental to seabirds and their food sources, or if conditions elsewhere along their migratory routes are to blame.

Additionally, further research should continue to regularly document population changes on Budd Inlet and Capitol Lake so that any new patterns can be detected. Monitoring will be especially important if the Deschutes estuary is restored, as the restoration plan is likely to result in changed habitat for some species. Capitol Lake specialists, whose populations are for the most part doing very well under current conditions, would largely be forced to find alternative foraging areas if Capitol Lake is removed. At the same time, the additional marine habitat may provide additional food resources for some of the Budd Inlet specialists that are currently in decline, especially if restoration also leads to improved water quality. This scenario could lead to some species returning to Budd Inlet in higher numbers in the future.

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