Influence of Aquaculture on Winter Sea Duck Distribution and Abundance in South Puget Sound

by

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ABSTRACT

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Shellfish aquaculture is a valuable and expanding industry in Washington State, in particular in South Puget Sound. Concurrently, long-term monitoring efforts throughout Puget Sound reveal varying levels of decline in a significant number of over-wintering sea duck species. However, reasons for these declines are unknown and the need for winter habitat assessments throughout Puget Sound is evident. The overlapping distributions of aquaculture industry and marine bird use in nearshore environments identify a high probability of interaction. This study identified and evaluated associations of four sea duck species/groups, Bufflehead, Scoter, Goldeneye and Merganser, in relation to a changing aquaculture landscape. Findings illustrate that shellfish aquaculture in South Puget Sound is both expanding and intensifying; expanding almost 3 study sites annually by medium and large acreage operations and growing at an annual rate of 127 acres. Our results suggest that sea ducks exhibit species or group-specific responses to aquaculture. Evaluating the location and intensity of aquaculture operations in the South Puget Sound, Bufflehead and Scoter species abundances were positively associated with industry to different degrees. Only Bufflehead, however, maintained significant positive associations over time. Alternatively, Goldeneye and Merganser species abundances demonstrated negative associations with shellfish aquaculture, however responses varied by intensity of culture operations. The influence of shellfish aquaculture on winter sea duck populations is clear, however variability by species demonstrate that while industry may coexist or benefit some, can prove deleterious for others. This study highlights the complexity in defining spatially and temporally dynamic sea duck-aquaculture relations. We recommend continued research to better understand species-specific habitat use and availability in relation to aquaculture development and activity of winter sea duck populations in Puget Sound.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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CHAPTER ONE

LITERATURE REVIEW

Introduction

Long-term monitoring efforts of sea duck populations reveal varying levels of decline, similar to other marine bird species associated with the Washington Coast, and evident in South Puget Sound populations (Fresh et al. 2011, PSAT 2007, Buchanan 2006). Mechanisms causing these declines are largely unknown as habitat use, distribution and ecology of sea ducks has been minimally studied. This lack of knowledge has been recognized by various organizations and monitoring and research efforts have been developed to assist in identifying possible limiting factors. To maintain vulnerable sea duck species, it is vital to understand potential limiting factors across all phases of their annual cycle. Puget Sound provides significant habitat for sea ducks during their non-breeding stages, in particular, related to foraging, resting and molting requirements. Accordingly, it is critical to monitor and assess possible factors influencing habitat use by sea ducks to identify drivers of population density and distribution in Puget Sound. These marine coastal environments are also home to a significant and growing aquaculture industry. This begs the question, could aquatic farm operations play a role in determining sea duck populations in Puget Sound? If so, how are these effects translated into observed sea duck population dynamics? To answer these questions, I will be assessing sea duck distribution and density of nine commonly occurring species in Puget Sound with documented varying levels of long-term decline. I will address principals of species-habitat associations to understand relationships between sea duck populations and presence of aquaculture. This review will provide an exploration of current knowledge, gaps in knowledge, areas of improvement and plans for future efforts concerning sea duck populations and the role of shellfish aquaculture in Puget Sound.

Puget Sound

Puget Sound is the second largest estuary in the United Stated, a complex landscape that supports an abundance of terrestrial, freshwater, estuarine and marine ecosystem species and habitats (Fresh et al. 2011). Puget Sound encompasses 2,800 square miles of inland marine waters, 2,500 miles of shoreline and is fed by 20 major river systems (PSP 2012). Puget Sound is part of the greater Salish Sea, comprising inland marine waters that span international boundaries from the coast of British Columbia extending from Desolation Sound to include the Strait of Georgia and the Strait of Juan de Fuca (PSNERP). Alternatively, the Puget Sound region extends from the Canadian boarder, throughout Puget Sound shorelines and out the Strait of Juan de Fuca to Neah Bay (PSNERP). The nearshore ecosystems that define these shorelines, bracing the terrestrial-marine interface, are among the more complex system types, including coastal riparian, intertidal and subtidal zones. The nearshore is generally defined from the top of shoreline bluffs to the depth of offshore waters where light is no longer able to penetrate waters to productively support plant growth. This area encompasses bluffs, beaches, mudflats, kelp and eelgrass beds, salt marshes, gravel spits and estuaries (PSNERP). While these nearshore environments are critical to many ecological communities, they are also the foundation of many ecosystem goods and services important to Washington's human communities.

The Puget Sound region is a vital resource for Washington, supporting thriving coastal ecosystems, sustaining growing human populations, and providing a foundation for many long-standing cultural traditions. It is no surprise that Puget Sound is recognized as a ‘national treasure’ environmentally, economically, socially and culturally (PSP 2012). While Puget Sound’s coastlines parallel only the western-most third of the state, this area is home to nearly two-thirds of the states population at 4.1 million people (PSP 2012). In a recent report on the state of the sound, it was identified that 70% of all jobs and 77% of total income in the state are derived from the Puget Sound basin (PSP 2012). As Fresh et al. (2011) describe, “the (Puget Sound) region’s location, deep harbors, natural resources and economic and cultural links to the Pacific Rim have made it a global trade center, an economic engine for much of the Pacific Northwest and an important component of the national economy”. Therefore, the sustained health and function of Puget Sound is recognized across disciplines, organizations, and nations (joining coastal waters of Canada in northern-most Washington). Consequently, the cooperation among and within these many facets are essential to maintaining productive operations and results among the myriad of derived resources. One such example is the Puget Sound Partnership (PSP), established in 2007, representing a collaboration of individuals, agencies, and organizations founded on a common goal to “ensure that the Puget Sound forever will be a thriving natural system, with clean marine and freshwaters, healthy and abundance native species, natural shorelines, and place for public enjoyment and a vibrant economy that prospers in productive harmony with a healthy Sound” (PSP 2012).

Sea Ducks in Puget Sound

Puget Sound waters provide habitat to over 70 species of marine bird closely associated with marine environments throughout some or all of their life history, for nesting, wintering and migration. The scope of my work is focused to nine commonly occurring sea duck species of South Puget Sound (WDFW 2010), including: black scoter (*Melanitta nigra*), surf scoter (*M. perspicillata*), white-winged scoter (*M.fusca),* common goldeneye (*Bucephala clangula*), Barrow's goldeneye (*B. islandica*), bufflehead (*B. albedo*), common merganser (*Mergus merganser*), hooded merganser (*Lophodytes cucullatus*), and red-breasted merganser (*M. serrator*). Sea ducks are a typical representation of waterfowl dependent on Puget Sound resources, distinguished by other Anatidae by marine specialized physiological traits. The majority of sea ducks utilizing Washington coastal habitats breed in the Boreal Forests of Canada and Alaska, and migrate south in winter to Puget Sound during non-breeding periods. Wintering periods can be shown to constitute a significant or majority of their life cycle (WDFW 2010), although winter habitat affiliations of sea ducks are poorly known (Esler et al. 2000) Wintering sea duck populations in South Puget Sound are almost exclusively associated with the nearshore environment and are dependent on marine food resources within the intertidal and subtidal habitat (<20m in depth) (Essington et al. 2011). These nine common species can be further subdivided by foraging guild into benthivores (eg. scoter species, goldeneye species, bufflehead) and piscivores (eg. merganser species). Benthivores forage largely on ground dwelling aquatic invertebrates, such as mollusks and crustaceans, although specific variations of prey will occur among species and by seasonal availability (SDJV 2003a-d,f, h, j-k). Piscivores forage primarily on small fish, such as salmon, trout and sculpin, but at times are documented opportunistic feeders, feeding on other available aquatic invertebrates (SDJV 2003e, g, i).

Monitoring Efforts and Trends

Marine birds have been widely used as indicators of estuarine ecosystems (Bower 2009). Monitoring efforts can provide useful indicators of changes in ecosystem condition or health (Gaydos and Pearson 2011), by evaluating population responses to natural and manipulated environments. Birds, and waterfowl in particular, are well known to respond to changes in habitat such as natural or anthropogenic alterations to available prey (Kirk et al. 2007). Prior to the 1970s, marine bird monitoring efforts across Puget Sound were largely restricted to citizen science efforts (Bower 2009). Not until 1978 was the first comprehensive census of marine birds in northern Puget Sound conducted as part of the Marine Ecosystems Analysis (MESA) (Essington et al. 2011), although failing to incorporate the entirety of the Puget Sound region. In 1992, the Washington Department of Fish and Wildlife (WDFW) began collecting summer and winter marine bird population estimates, as part of the Puget Sound Ambient Monitoring Program (PSAMP). Aerial transects were flown both paralleling the shorelines, and extending into open-water throughout the entire Puget Sound and southern shore of the Straight of Juan de Fuca (Nysewander et al. 2005). However, following 1999, summer surveys were eliminated and only winter surveys currently remain. PSAMP still remains the only source of continuous marine bird monitoring efforts in Puget Sound. There are inherent difficulties in both the method and analysis of aerial bird surveys (Butler et al. 1995) and concerted effort must be taken in methodology and monitoring and supplementary analysis. The first report comparing MESA (1978-79) and PSAMP (1991-

1999) surveys documented long-term declines in a large portion of Puget Sound sea duck species with drastic declines in many. Analyses revealed significant declines in 13 of 20 species, or species groups studied (Nysewander et al. 2005). Characteristic of these sharp declines are wintering Scoter populations (black, white-winged and surf), demonstrating declines as great at 56% from 1978-99 and 55% from 1994-2011 (Evenson 2012). While other species documented stable or slowly decreasing long-term trends, such as long-tailed and harlequin duck. Although coupling concerns develop due to occurrence of some species at low densities in restricted locations (WDFW 2010). These initial results from Nysewander et al. (2005) sparked concern over declining marine bird populations, and reinforced involved agencies to address the conservation and management of Puget Sound sea duck populations (eg. Bower 2009, PSP 2012, SDJV 2012, WDFW 2010).

Reasons for these declines in wintering sea duck populations throughout Puget Sound, consistent with other documented trends throughout North America (Bower 2009), remain unanswered. As a result, several knowledge gaps common across sea duck populations have been identified. This may be attributed to the unique challenges of studying sea ducks, such as their broad and remote distributions (SDJV 2012). Foremost, basic biology and ecology of sea ducks is poorly known or unknown (SDJV 2012). Additionally, comprehensive monitoring efforts lack consistency and connectivity throughout different life stages to provide complete detection of population trends (Anderson et al. 2009). Many scientists, conservationists and managers recognize the need for continued research, monitoring and assessment linked throughout the entirety of their life cycles (SDJV 2012). Specifically, a concerted effort must be placed on non-breeding grounds as constrains in these areas may contribute to long-term declines in some species of sea duck (Anderson et al. 2009), especially as some populations spend most of their annual cycle on non-breeding areas (Zydelis et al. 2006). Consistent and coherent work will not only provide insight into Puget Sound's sea duck populations, best directing conservation and management strategies, but will also provide an indicator to ecosystem health and vitality (PSP 2012).

Habitat Use and Requirements

Research on sea duck population dynamics often aim to characterize functional species requirements, identify habitat availability and limitations, and explore patterns of habitat use. This information can then be used to identify possible mechanisms responsible for observed and predicted spatial and temporal trends in sea duck populations. In particular, diet provides a relative value of habitat to birds by quantifying benefits and consequences to local and regional productivity and survivorship (Anderson et al. 2008). This is based largely on the growing body of knowledge exploring the behavioral and functional relationships between predators and their prey (Kirk et al. 2008) by investigating how sea duck populations utilize food resources and respond to both natural and human-induced modifications to occupied habitats and prey landscapes. To answer these questions, research has encompassed three complementary focuses including, foraging dynamics, movement patterns and physiological requirements.

First, explorations in foraging dynamics address behavior responses to food characteristics and availability to infer habitat quality. Sea ducks, like other birds, have been documented to modify foraging behavior and efforts in response to food abundance and quality (Lewis et al. 2008). Foraging theory suggests that fitness consequences of foraging behavior encourage animals to optimize net energy intake when faced with variation in prey attributes or abundance (Kirk et al. 2008, Lewis et al. 2008). Thus, observations in foraging behavior can then be used to infer habitat quality, including possible food limitations (Lewis et al. 2008). Several studies by Kirk et al. (2007, 2008) found that certain prey characteristics (i.e. weaker byssal attachments, thinner shells, easier accessibility) of marine mussels rendered them more susceptible, and in response, surf scoters demonstrated greater level of depletion. Second, complementary studies have been conducted on movement patterns to uncover mechanisms underlying foraging strategies and animal distributions (Kirk et al. 2008). Distribution theories predict that predator densities are closely related to prey landscapes, further suggesting that as a result of individual movements, changes in predator distribution can reflect the underlying differences in the availability or quality of prey within a habitat (Kirk et al. 2008). In addition to habitat quality, animal movement patterns have also been used to estimate minimum space requirements and evaluate flexibility of individuals to habitat change (Kirk et al. 2008 and references therein). Finally, physiological measurements reinforce investigations into foraging dynamics and distribution patterns, by quantifying nutritional requirements and energy balances of sea ducks to determine functional habitat needs (Anderson and Lovvorn 2011). Anderson et al. (2009) explains, that to understand functional dependencies on specific foraging sites requires knowledge of the relative contributions of food to predator conditions. This helps identify critical foraging sites and possible sources of nutritional constraints for sea ducks. Additionally, evaluating physiological measurements in relation to spatial and temporal variability also helps identify distinctions in endogenous versus environmental variables of bird energy statuses (Anderson et al. 2008). Moreover, collaborative methods can be used to infer comprehensive evaluation of habitat for sea ducks, as utilized in Kirk et al. (2008) comparing differing habitat prey landscapes of two heavily used wintering grounds in coastal British Columbia. Results demonstrated that sites of high mussel prey density were consequently significantly depleted, thus encouraging limited site fidelity, larger foraging range size, and less predictable movement and distribution patterns. Alternatively, the site of stable clam availability supported higher site fidelity, small foraging range size and more predictable movement and distribution patterns (Kirk et al. 2008).

As mentioned above, as per investigations in habitat use and requirements, sea duck populations interact intimately with their environment. These interactions can then be monitored and evaluated to conceptualize patterns, evaluate inconsistencies and identify disturbances in functionally critical sea duck habitats. Although a comprehensive assessment of habitat requirements is lacking for Puget Sound sea duck populations, one essential component to quantifying habitat needs is identifying potential stressors and/or limitations (Evenson 2012). Several possible mechanisms responsible for documented populations declines (described in Section 3) in South Sound's wintering sea ducks include: habitat modification and degradation, human activities, disease and contaminants, low recruitment rates, food resource depletion, predation, and larger scale population shifts (Evenson, pers. communication). The continuing focus of this review will concentrate on one practice of human activity, shellfish aquaculture, concurrent with increasing focus and concern of its role in estuarine ecosystems and its growth in nearshore environments in Puget Sound.

Shellfish Aquaculture

History and Status in Washington State

Abundance of shellfish in Puget Sound is a vital resource for Washington, continuing a time-honored cultural tradition, and today providing a thriving economic industry. The aquaculture industry is one of many resource-based business-sectors in the State, securing the economies of many rural western Washington communities and providing the state a significant and indispensable value (PSP 2003c). While recreational harvesting of shellfish still occur in Puget Sound shorelines, and can provide substantial economic value, the industry is most strongly influenced by commercial aquaculture (PSP 2003c).

Aquaculture in U.S. West Coast waters, although occurring since the late 1800s (Dumbauld et al. 2009), is comparatively a young practice in regards to ancient practices in places such as China and Japan, dating as far back as 2,000 years ago (Tidewell 2012). In recognition of Puget Sound's local and abundant marine resource, the 1850s marked the advent of aquaculture (Magoon and Vining 1981). Growth was minimal until the early 1900s, when wild shellfish stocks, heavily depleted from overfishing, were replaced by introduced species for planting, such as the Japanese (or Pacific) oyster (*Crassostrea gigas*) and Manila clam (*Venerupis philippinarum*) (Magoon and Vining 1981, PSP 2003a). By the 1950s, to supplement growing human populations with a quality protein source, the industrialization of aquatic farming escalated and aquaculture on the West Coast has since grown substantially in the following decades (Dumbauld et al. 2009). Currently, aquaculture is a significant and still expanding industry in Washington State, as well as throughout the West Coast of the United States. Washington produces the single largest amount of cultured shellfish in the nation, comprising 85% of total West Coast sales and contributing to a $270 million industry (PSP 2012). Oysters are the largest shellfish crop in the State, followed by clams, mussels, and geoducks (PCSGA 2011).

With such a significant presence of shellfish aquaculture in Washington, many agencies and organizations at different levels are invested in evaluating its role as both a stable human food resource and economic industry, and for its implications to coastal ecosystem functions within Puget Sound. Even State government has taken an active role to protect Washington's shellfish resources with the implementation of the Washington Shellfish Initiative in 2011 to promote sustainable aquaculture economies in agreement with critically functional aquatic ecosystems (WDOE 2012). Industry members have also taken pro-active measures to ensure that Puget Sound nearshore ecosystems continue to support shellfish operations, such as by addressing issues of water quality (PCSGA 2011) and ocean acidification (WABROA 2012). As a recognized water-dependent use of state shorelines, under proper management, aquaculture "can result in long-term over short-term benefits and can protect the resources and ecology of the shoreline" (WDOE 2012).

Method and Operations

The term aquaculture refers to the breeding, rearing and harvesting of aquatic plants and animals for sales in a market economy and does not include the harvest of wild stock. There are two defining characterizations of aquaculture that distinguish it from capture fisheries, intervention and ownership (Lucas and Southgate 2012). As described by the Food and Agriculture Organization of the United Nations (FAO): "farming implies some form of intervention in the rearing process to enhance production…" and subsequently “implies individual or corporate ownership of stock being cultivated” (2006). Aquaculture is a resource dependent activity, operating in freshwater, marine and brackish environments of both natural and man-made systems. The sheltered waters of the Puget Sound region provide an essential resource for marine cultivation in nearshore coastal environments. Aquatic farming practices in Puget Sound are largely comprised of the cultivation of bivalve mollusks (eg. oysters, clams and mussels). Lucas and Southgate (2012) describe that bivalves are an ideal aquaculture species because they can be reared using relatively simple technology (see below). What is more, because bivalves are filter feeders, they readily obtain their energy source from surrounding waters, requiring no additional feed labor following initial placement (Lucas and Southgate 2012).

According to the Pacific Coast Shellfish Growers Association (PCSGA) (2011), regardless of the type of shellfish, planting and harvesting techniques follow similar progressions, proceeding through a stage of seeding, cultivation and harvest. To begin, shellfish seed, or spat, are planted (termed ‘broadcast’) either at the intertidal level, areas alternatively exposed or submerged in tidal waters, or alternatively in subtidal areas, where farms are continually submerged in marine waters. Seedling can be derived from hatchery broodstock, an intensive culture process (i.e. requiring greater labor and capital costs), or alternatively from natural recruitment, an extensive culture process (i.e. where stocking rate is low to moderate and capital is limited) (Lucas and Southgate 2012). Natural recruitment is most widespread, as long as time and locality of recruitment is known and supportive substrate is available, or provided, for settlement (Lucas and Southgate 2012). After a period of growth ranging from 1-6 years, matured shellfish are then harvested, either by hand or mechanically (PCSGA 2011). Although aquaculture farms may follow these similar progressions, this 3-step outline is extremely simplified, and variation does occur during their ocean phase as a reflection of differences in biology and habitat of cultured species, and local factors of farming process such as labor and costs, and market prices (Lucas and Southgate 2012).

Oysters are sessile, and require a substrate on which to attach for growth, often preferring hard rough surface that is non-greasy and clear of silt and algae (Lucas and Southgate 2012). Spat collectors, or culch, used to culture oysters include lime- or tar-coated wooden sticks, flexible plastic strips, oysters shells, cement tiles, tree branches and bamboo. Similarly, marine mussels non-motile and require firm substrate on which to attach, generally in the form of fibrous material such as rope. Alternative to oysters and mussels, clams are a burrowing species, with developed ventral foot that allow travel throughout particulate tidal beds, from thick mud to sand (Lucas and Southgate 2012). Cultured bivalves can be fundamentally differentiated by operational method: within the seabed; on or just above the seabed; or near the ocean surface. The following discussion outlines common bivalve culture methods, synthesized from descriptions provided by Lucas and Southgate (2012) and PCSGA (2011).

Within the seabed

Bottom-inhabiting clams are cultivated within natural muddy to sandy intertidal seabeds requiring minimal intervention. Occasionally, culture area may require preparation or additional input via seed fertilization and/or disturbance of seabed to loosen substrate and remove potential predators (eg. starfish). Additionally, following seeding, culture method often include protective netting applied to surface of intertidal area to deter predator disturbance (Lucas and Southgate 2012).

On or just above the seabed

Grids of horizontal or vertical stakes (generally wood or bamboo) are used in intertidal oyster and mussel culture, particularly in sheltered muddy coasts with good tidal range. Advantages of this method are that installation, maintenance and harvest can be performed at low tides. Additionally, bivalves can be cultured on racks above the seabed in mesh boxes or baskets, trays and horizontal wooden and asbestos-cement batons.

Surface or suspended culture

Surface methods include hanging bivalves on ropes or in culture units from rafts, longlines and floats. Rafts are rectangular metal, wooden or bamboo frames buoyant provided air-filled drums or floats. Ropes with attached bivalves then hang down from rafts, typically densely packed with attached mussels. Alternatively, longlines are 50+ meter ropes supported by floats at the surface in regular intervals and help in place by terminal anchors. Bivalves are then cultured on vertical ropes suspended from longlines. Attached end structures varying by species, such as cylindrical or pyramid nets, and additional roping. Finally, floats are similar to longline systems, but occur most commonly as large single structures supporting culture system directly below.

Ecosystem Effects of Aquaculture

Puget Sound nearshore environments are among the most complex ecosystems. Already, extensive accumulations of anthropogenic modifications to Puget Sound's coastlines have altered physiochemical and ecological processes that support local human and wildlife communities (Fresh et al. 2011). It is no surprise, that with increasing tidal area devoted to aquaculture practices, concerns have sparked questioning of the ecological role of industry processes to both local environments and extended regional systems. Shellfish aquaculture, with its growing industry, has increasingly been recognized as a possible significant source of additional modification to these nearshore ecosystems, chemically, biologically and physically. Implications of aquaculture activities to ecosystem functioning have been addressed across scales – from local alterations to benthic and water column biological communities and chemical processes, to regional influence on mobile marine animals such as fish and seabirds. As described by Dumbauld et al. (2009), aquaculture effects on the environment can be described, at their most basic level, as a disturbance. Using a definition provided by Picket and White (1985), "a disturbance is any relatively discrete event in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment" (Dumbauld et al. 2009). Although this term may invoke negative qualities, disturbance merely describes influences to species and ecosystems, but leave positive or negative value judgments to readers and managers (Dumbauld et al. 2009). An outline of the most prominent environment effects when addressing the role of aquaculture is described below. As earlier summarized by Dumbauld et al. (2009) these effects can be understandably partitioned into 1) material process effects, 2) physical structure effects, and 3) pulse disturbance effects.

Material process effects

Bivalve mollusks are filter feeders, meaning they filter suspended particulate matter from the water column, ranging in size from bacterioplankton to less mobile zooplankton and include both living and non-living material (Dumbauld et al. 2009). Waste is then expelled in the form of uningested pseudofeces and unassimilated feces, which sink to the seabed as ‘biodeposits’ (Dumbauld et al. 2009). Although these cultured bivalves are exploiting naturally occurring matter, thus not resulting in additional nutrient loading such as with finish culture, presence of aquaculture can adjust material processes and nutrient cycling (Dumbauld et al. 2009). As a result, these changes to physio-chemical characteristics can alter estuarine environments through changes to water quality, sediment properties and resources for primary producers (Dumbauld et al. 2009). The largest question in regards to water quality address particulate matter depletion and bivalve carrying capacity, as it relates to the availability of phytoplankton as food and susceptibility of eutrophication (Dumbauld et al. 2009 and references therein). Concerns of sediment properties largely revolve around accumulation of biodeposits observed under or within aquaculture operations. For example, local concentrations of biodeposits can reduce sediment grain size and increase organic content. In turn, this can also reduce oxygen content and alter nitrogen cycling (Dumbauld et al. 2009) As a result of these physiochemical changes, local alterations have been observed in species richness, composition and dominance such as the displacement of some benthic organisms (eg. urchins), propagation of opportunistic species (eg. marine worms), and/or changes in local infaunal species (Forrest et al. 2009 and references therein). Alternatively, nutrient and light resources to primary producers (eg. eelgrass) may not be substantially affected by introduction of aquaculture. Although eelgrass has shown responses to direct manipulations of nutrients and light, presence of bivalve aquaculture has not demonstrated significant changes in West Coast studies (Dumbauld et al. 2009 and references therein).

Physical structure effects

Shellfish aquaculture can influence local environments through creation of structured habitat, acting as ecosystem engineers or foundation species (Dumbauld et al. 2009). However, it must also be recognized that these artificial structures cannot be directly compared to natural habitats, such as bivalve reef (Dumbauld et al. 2009). It has been documented that aquaculture, as ecosystem engineers, have both positive and negative effects on ecological communities, providing habitat and resources for some species, while simultaneously displacing others (Dumbauld et al. 2009). A major concern on West Coast estuaries occupied by aquaculture structures is displacement or alteration to eelgrass habitat, as these two systems commonly occupy and compete for, similar or adjacent nearshore space (Tallis et al. 2009). The complex structure and invertebrate assemblages of eelgrass communities provide valuable habitat for fish and wildlife and are a major source of detrital carbon for estuarine foodwebs in this region (Simenstad and Fresh, 1995). Studies of this relationship along West Coast estuaries demonstrate variable results. One study by Ruesink and Rowell (in prep) as described by Dumbauld et al. (2009) found that geoduck clams at a south Puget Sound aquaculture site reduced eelgreass density by roughly 30% during summer months, although this difference neutralized during winter months when shoot densities thinned naturally in control plots. Alternatively, concluding this same assessment of West Coast studies, Dumbauld et al. (2009) found that eelgrass could coexist with shellfish cultured at low densities used in on-bottom aquaculture on soft sediments.

Off-bottom aquaculture structures have been demonstrated to introduce novel habitat in some estuarine environments. For example, applied aquaculture structures, such as stakes and racks, can introduce new attachment sites for growth by wild mussels

(Kirk et al. 2008). Structures may also provide refuge for structure-oriented feeders and crevice-dwelling fish (Dumbauld et al. 2009). In turn, this could provide additional food resources for large mobile predators, such as crabs, fish and birds. Most studies outlined in Dumbauld et al. (2009) document that while aquaculture structures demonstrate increased community level effects (abundance and diversity) of some fish and invertebrates compared to open un-structured seabeds, values were still lesser when compared to adjacent eelgrass habitats.

Pulse disturbance effects

Pulse disturbances are short discrete events. In regards to aquaculture, harvest practices have been characterized as pulse disturbances with direct implications to sea grass beds and nearshore sediments. The implications of these disturbances vary by harvest method, scale of operation and environmental characteristics. Present studies of harvest method reveal that on-bottom culture has more clearly demonstrated physical effects during shellfish harvesting (Forrest et al. 2009), generally believed that alternative off-bottom methods express less-intensive environmental implications. Additionally, while cultured species can be harvested either by mechanical or physical hand method, hand methods are considered less intensive to tidal ecosystems (Simenstad and Fresh 1995). Harvest activities have been shown to both directly affect seagrass and associated organisms, and indirectly affect, through secondary implications, availability of epifaunal and infaunal prey resources (Simenstad and Fresh 1995). A synthesis of west coast aquaculture operations by Dumbauld et al. (2009) described that mechanical harvest methods, including intensive mechanical dredging and suction, resulted in immediate eelgrass declines of 42% and 96%, respectively. The greatest source of variation in these studies was believed a result of site-specific recovery responses. whereby the first dredging study reported a recovery time of 4 years, while the following suction study reported a recovery time of 2 years. Across studies, recovery time varied as a result of habitat characteristics, such as seagrass species, sediment attributes, disturbance size, intensity and treatment responses by industry (Dumbauld et al. 2009).

Policy and Regulations

Following Washington State Authoritative Code definitions, aquaculture means "the culture and/or farming of food fish, shellfish, and other aquatic plants and animals in fresh water, brackish water or salt water areas. Aquaculture practices may include but are not limited to hatching, seeding or planting, cultivating, feeding, raising, harvesting of planted crops or natural crops so as to maintain an optimum yield, and processing of aquatic plants or animals" (WAC 332-30-106). To reiterate, for the purposes of this review, aquaculture is restricted to the cultivation and commercial harvest of shellfish in marine nearshore tidelands. There are numerous organizations that play a role in the monitoring and regulation of shellfish aquaculture, operating under the jurisdiction of local, state, federal and tribal governments. As outlined in PCSGA (2011), the types of regulation pertaining to shellfish aquaculture include: animal health, economic development, trade and marketing; environmental quality and health; land use and shorelines management; navigation and navigable waters; public health and food safety; resource use; and wildlife and habitat conservation. These regulations can be largely divided into those pertaining directly to the cultivation and commercial harvest of shellfish, and those pertaining to activities associated with shellfish aquaculture.

National and Federal

In 2005, the US Food and Drug Administration in collaboration with the Interstate Shellfish Sanitation Conference created the National Shellfish Sanitation Program (NSSP). The NSSP is a federal/state cooperative program aimed to promote and improve the sanitation of bivalve shellfish. The NSSP has since undergone multiple revisions to maintain most up-to-date research and effective strategies. Another central force of federal action pertaining to aquaculture comes from the US Army Corps of Engineers (ACOE) operating under the Clean Water Act (Section 404) and Rivers and Harbors Act (Section 10) (Dumbauld et al. 2009). Similarly, the National Oceanic and Atmospheric Administration (NOAA) recognize the broad suite of economic, social and environmental benefits provided by our nation's coastal shellfish populations (NOAA 2011). In 2011, NOAA released the National Shellfish Initiative in conjunction with National Aquaculture Policy focused on increasing bivalve shellfish populations through commercial production and conservation activities (NOAA 2011). To achieve this, NOAA acknowledged and promoted increased collaboration with public and private partners to address marine planning and permitting, environmental research, restoration and farming techniques and coordinated and innovative financing (NOAA 2011).

State

In 1997, the Washington's Shorelines Management Act was adopted to "prevent the inherent harm in an uncoordinated and piecemeal development of the state's land. " Further, to ensure that "the interests of all the people be paramount in the management of shorelines of statewide significance" including Puget Sound shorelines and waters (WDOE 2012). Under this act shellfish aquaculture is defined as a water-dependent use, and further described as a preferred use following that operations and activities aare consistent with the control of pollution and prevention of damage to the natural environment (WDOE 2012).

Succeeding national and federal initiatives, Washington State has also taken additional action to protect and enhance shellfish resources with the creation of Washington Shellfish Initiative in 2011. Like the national initiative, Washington recognizes the benefits of shellfish protection, restoration and enhancement efforts to increase recreation and jobs and ensure a healthier Puget Sound (WSI 2011). Dominant jurisdiction operating over Washington’s shellfish resources and aquaculture is two-fold, fulfilling both state wildlife and sanitation requirements. The Washington Department of Fish and Wildlife (WDFW) operates under wildlife and habitat conservation policies to regulate commercial fishery and aquaculture activities through aquatic farm registration requirements. It is required that all aquatic farmers must first register their operations with WDFW. However, prior to 2008, all operations could be registered under a single application with no itemization of specific operations and activities (Galivan, P. pers. communication). Additionally, the Washington State Department of Health authorizes shellfish aquaculture activities to ensure safe growing and consumption of cultivated product (DOH 2012). DOH issues shellfish operation license for acting farm in addition to harvest site certificate per intended site of harvest. While the majority of shellfish aquaculture activities occur on privately owned tidelands, still approximately 30% of intertidal lands and nearly all subtidal lands are owned by the State and regulated by Department of Natural Resources (DNR). DNR may hold contractual agreements of leased aquatic lands with growers, and although the agency does not have a regulatory role in aquaculture practices, it does actively enforce written lease conditions.

Policy Gaps and Needs

Consequently, there are many overlapping jurisdictions that may cause for complex permitting pathways (PCSGA 2011) for both the subjective farm and regulatory organizations. Acting agencies across regulatory levels acknowledge the necessity of addressing the complexity of aquaculture policy and planning to effectively maintain the viable economic contribution of shellfish aquaculture while continuing to meet the various stewardship responsibilities (Dewey et al. 2008). In 2007, Washington State Legislation passed house bill 2220 in regards to shellfish aquaculture in coastal waters. This bill took action to confront three major needs in aquaculture policy and process: 1) create a Shellfish Aquaculture Regulatory Committee representing a wide range of perspectives and interests; 2) increase scientific research and advisory action on expanding geoduck aquaculture in Puget Sound; and 3) expand information required of aquaculture farms on WDFW registration documents (HB 2220).

Sea Ducks and Aquaculture

Shellfish aquaculture and sea duck populations occupy similar intertidal and subtidal habitat within coastal ecosystems. The question reasonably follows, could the significant and expanding aquaculture industry, such as in Puget Sound, influence functional habitat use by wintering sea ducks? As a result, are trends in population distribution and density of sea duck correlated to changing aquaculture landscapes? Research demonstrates that aquaculture can directly modify habitat chemically, biologically and physically and these modifications have the capacity to reverberate indirectly through ecosystem processes. Further still, these implications may cascade to higher trophic levels - influencing larger mobile epibenthic predators, such as sea ducks.

As a result, studying the response of sea ducks may provide an indicator of the environmental response of estuarine ecosystems to commercial aquaculture. Previous investigations into the relationship between sea ducks and shellfish aquaculture have documented positive, negative, and neutral responses, as outlined in the next section.

Sea Duck Responses to Aquaculture

Positive

One key beneficial role of aquaculture for sea ducks is the addition of new prey resources. Several studies show that off-bottom aquaculture farm structures may provide novel recruitment surface for wild mussel species, as a result providing additional prey populations for predatory sea ducks (Zydelis et al. 2009, Kirk et al. 2007). A study in Desolation Sound, B.C., found that densities of wild mussels were much greater on floating aquaculture structures than measurements taken in adjacent unstructured intertidal areas (Tallis et al. 2009, Zydelis et al. 2009). What is more, structure – grown mussel species displayed altered morphological traits, such as weaker byssal attachment, and more fragile and thinner shells, making them a more advantageous foraging decision for sea ducks (Kirk et al. 2007, Zydelis et al. 2009). This translated into observed positive relationships between sea duck densities and off-bottom aquaculture sites in winter habitats of sea ducks in coastal BC (Zydelis et al. 2009). For some industry members, these events represent a mutually advantageous relationship where bird populations are supplied valuable prey resources and in turn, clear aquaculture structures of nuisance mussel species (Kirk et al. 2007). Additionally, one study by Caldow et al. (2003) comparing bird assemblages in experimental areas of greater intertidal mussel density (to represent areas of artificial increase in mussel species for cultivation) and adjacent unaltered intertidal areas, demonstrated an increase in some opportunistic nearshore bird species due to increased habitat complexity. In other cases, on-bottom aquaculture farms (i.e. clams) provide prey by way of cultivated species (Price and Nickum 1995). However, this negatively affects shellfish growers' stock and is often prevented by application of anti-predator nets or physical deterrents within culture areas (Lucas and Southgate 2012).

Negative

Aquaculture could negatively impact sea duck populations in Puget Sound through direct habitat exclusion or alterations (Dumbauld et al. 2009); introduction of invasive and/or non-native marine invertebrate species (Tallis et al. 2009), displacing historical prey choice (Caldow et al. 2003); and introduction of toxins, parasites and disease with consequential contamination and bioaccumulation in sea ducks (Buchanan 2006). The most studied source of detriment to sea duck populations from aquaculture is degradation or alteration of critical foraging habitat (Connolly and Colwell 2005). Studies by Simenstad and Fresh (1995) and later supported by Tallis et al. (2009) demonstrate the negative impacts of on-bottom aquaculture methods, including dredging, harrowing and leveling of intertidal areas for farming. Artificial application of additional substrate and subsequent mechanical harvest of cultured shellfish (i.e. dredging) can displace nearshore birds by direct disturbance, and alteration or exclusion of valuable eelgrass habitats and prey landscapes (Simenstad and Fresh 1995). Additionally, major findings by Bendell-Young (2006) reported that areas along the coast of B.C. with greatest intensity of aquatic farming demonstrated a decrease in species richness, altered bivalve composition, abundance and distribution, and change in community intertidal structure. Bendell-Young (2006) continued, that the consequences of aquaculture could potentially restrict access to sea ducks during key over-wintering periods, exacerbating already declining West Coast populations.

Neutral

In a study by Zydelis et al. (2006), efforts found that in Baynes Sound, supporting 50% of B.C.'s aquaculture, despite extensive clam and oyster farming, wintering scoter densities were largely a variable of natural environmental attributes, including extent of intertidal zone and substrate type. Zydelis et al. (2006), also noted that this could be attributed to the significant and stable source of natural clam prey populations documented in Baynes Sound, thus exclusion from some areas (i.e. anti-predator netting and direct disturbance) did not result in significant displacement. This supports the suggestion that the aquaculture industry and sea duck populations may be capable of mutual sustainability. An earlier study by Caldow et al. (2003) also demonstrated neutral effects of aquaculture on some marine bird assemblages where alternative habitat is readily available. As demonstrated, some undetectable responses of sea duck populations to nearshore aquaculture practices were a result of greater variables at play, covariation of environmental and aquaculture variables and limited data availability. The abundance of neutral responses seen in studies directly assessing the affect of aquaculture on nearshore birds suggests a need to continue comprehensive monitoring efforts at greater spatial and temporal scales to tease out the effect of natural environmental differences (Forrest et al. 2009) and variability among site-specific studies (Caldow et al. 2003).

Conclusions

Puget Sound is an unparalleled resource in Washington and along the US West Coast, ecologically and economically, providing for the productive and expanding shellfish aquaculture industry, and supporting vital nearshore ecosystems. Consistent with expansion, there is increasing evidence of threatened components of Puget Sound's nearshore ecosystems (Fresh et al. 2011, PSP 2012), such as declining sea duck populations (Buchanan 2006, WDFW 2010). Although documentation still remains limited in explorations linking the ecological role of aquaculture to nearshore bird populations, concurrent use of nearshore habitats is evident. The question remains, how and to what degree does shellfish aquaculture play in determining habitat use and distribution of winter sea duck populations in Puget Sound (Evenson 2012).

It is important to recognize the inherent variability of outcomes in studies addressing environmental effects of shellfish aquaculture and its role in sea duck population patterns. Continued work is required to characterize and project the ecological importance of the intertidal zone (Bendell-Young 2006), the role of aquaculture in those coastal ecosystems (Dumbauld et al. 2009) and the wider implications of aquaculture for wintering sea duck populations. There is no single driver of documented declines in winter bird populations, but instead investigations must explore all facets of dynamic estuarine ecosystems and assess the role of human impacts. For example, research efforts must address historically underrepresented over-wintering areas (SDJV 2012), as a substantial portion of a species' annual cycle is spent in non-breeding areas (Gaydos and Pearson 2011). Additionally, monitoring and assessment efforts must continue to address smaller scale local systems, such as critical habitat areas, while maintaining connectivity to larger scale systems, such as regional population trends (Anderson et al. 2009). Anderson et al. (2009) elaborates “identifying causes of population decline is especially difficult for species that migrate substantial distances among distinct habitat used over an annual cycle because it is unclear how changes in resources versus non-local factors have contributed to declines”.

There is an increasing demand for integrated approaches to managing coastal ecosystems. Decisions affecting coastal resources are fragmented among many organizations, often proving inefficient, resulting in conflict among sectors, and contributing to management gaps and overlaps (PCSGA 2011). Alternatively, collaborative work among different organizations including governmental (e.g. WDFW, DNR, NOAA) tribal, non-governmental, universities, independent research institutions and aquaculture industry members (e.g. SDJV, PSP, PSNERP, PSI, PCSGA), addressing aquacultures impact to nearshore ecosystems are necessary to effectively create and execute productive and sustainable outcomes. In a similar vein, collaborative working relationships among organizations have also been promoted in sea duck conservation and management objectives outlined by SDJV (2012) and WDFW (2010), to better coordinate monitoring and assessment efforts and identify key research links throughout regional populations. In this way, the best solutions to define sea duck – aquaculture relationships can only be achieved through interdisciplinary, interorganizational and international approaches to research, conservation, management, and industry actions.

CHAPTER TWO

MANUSCRIPT

Introduction

The Puget Sound region is an unparalleled resource in Washington State – supporting productive marine ecosystems, providing thriving coastal economies and defining many social and cultural identities and traditions. In particular, the nearshore environments that blanket Puget Sound shorelines contain some of the most abundant marine resources and highlight the complexity of balancing productive market economies with maintaining functional coastal ecosystems. Shellfish aquaculture is a historically significant and expanding industry in Puget Sound, dependent on these nearshore environments. Further, the Sound's complex of bays and inlets provide important habitat to more than 70 species of bird critically dependent on marine resources for a significant portion of their life-histories (Essington et al. 2009). Consequently, this interface of overlapping, and at times competing use necessitates comprehensive monitoring and assessment efforts to identify and evaluate wildlife responses to a variable network of natural and anthropogenic landscapes.

Aquaculture – as used here, the aquatic farming of marine bivalve shellfish – is a long-standing coastal activity in Puget Sound. The extensive sheltered bay and inlets provide productive grounds for the artificial cultivation of shellfish, predominantly comprised of clams, oysters, geoducks and mussels. Over the last several decades, in response to growing human population demands and aided by the advancements of culture method and operation (Magoon and Vining 1981), aquaculture has seen a substantial growth in industry. Currently, aquaculture in Washington provides the

Nation's top production of cultured clams, oysters and mussels, and further supports the state with an annual $270 million industry (PSP 2012). The valued economy and tradition of shellfish aquaculture in Washington is clearly recognized with National and State initiatives in place to encourage the growth and vitality of industry (PSP 2012). Since the farming of shellfish as a water-dependent use relies on functional marine environments, it is recognized that this may also provide industry incentive to adhere to and encourage issues of water quality and pollution in their tidelands (PCSGA 2011). However, as the support and growth of shellfish aquaculture continues to expand in Puget Sound, it is important that industry and resource management agencies are able to clearly define the ecological role of operations on nearshore habitat and wildlife.

Sea ducks in Puget Sound are a characteristic marine bird – as a species intimately associated with the nearshore environment. The complex of estuaries that make up Puget Sound define important habitat for over-wintering populations. However, varying levels of long-term decline in many wintering sea ducks have sparked concerns by conservation and management agencies (Essington et al. 2009). This concern is exacerbated "given the number of sea duck species for which basic biology is poorly known or unknown, their broad and remote distributions, and the unique challenges of studying sea ducks" (SDJV 2012). Consequently, reasons for these declines are largely unknown. A key step in understanding and mitigating declining populations is the development of a comprehensive assessment of habitat use, needs and availability, in particular in Puget Sound (WDFW 2012). Because sea ducks that utilize Puget Sound do so for a significant portion of their annual cycles (Gaydos and Pearson 2011), the importance of quantifying the extent of impacts to non-breeding areas is a vital first step to describing population dynamics and habitat use (SDJV 2012). One facet of defining the habitat use, needs and availability of sea ducks is to identify and evaluate possible limiting factors. As the nearshore environments of Puget Sound provide for both thriving aquaculture industries and critical winter sea duck habitats, the probability for interaction is high. As a result, concern to identify overlapping distributions and competing uses is of reasonable consequence.

Past studies evidencing implications of this overlap have documented varying levels of positive, negative and neutral sea duck – aquaculture relations. Shellfish aquaculture may negatively influence marine birds species by direct exclusion or modification to habitat (Simenstad and Fresh 1995), alteration of biological communities (Bendell-Young 2006), or by the physical presence and disturbance associated with culture operations (Forrest et al. 2009) However, several studies documenting positive associations of sea ducks and shellfish aquaculture describe advantageous bird responses to novel prey sources provided by industry operations through the introduction of structure-grown mussels (Kirk et al. 2007), natural dispersal of planted shellfish seed (Caldow et al. 2003, Zydelis et al. 2006), or direct consumption of cultivated species (Zydelis et al. 2009). Alternatively, lack of response to aquaculture by overlapping bird species suggests alternative forces describing species behavior and fitness and overall population dynamics (Zydelis et al. 2006, 2009). Overall, several studies suggest responses to aquaculture are species specific (Caldow et al. 2003), most likely a reflection of variable behavior, feeding and habitat associations among subjects (Connolly and Colwell 2005).

Previous studies suggest sea ducks respond in varied ways to shellfish aquaculture; these findings highlight the need to continue and advance research efforts. As this valued industry further expands its role in nearshore ecosystems of Puget Sound, it is important to assess the wider ecological influences to overlapping marine bird populations. Further, it is advantageous to expand the scope of past studies to incorporate broad-scale spatial and temporal variability to better understand sea duck population dynamics and assist in the mitigation of observed population declines. Our research explored how location and extent of an expanding shellfish aquaculture industry affects winter sea duck populations in South Puget Sound. Our objectives were to 1) define the nature and degree of sea duck-aquaculture relations; 2) describe how responses vary among sea duck species, and 3) explore how these relations trend over time in response to a changing aquaculture landscape.

Methods

Study Area

Puget Sound is the second largest estuary in the United State, draining 19 major river basins and comprising 2,800 square miles of marine waters. Extending inland from the Pacific Ocean on the west to the Canadian border to the North, the sound is bordered by roughly 2,500 miles of shoreline. The Puget Sound is also home to nearly two-thirds of the total state population of Washington, and consequently human activities heavily impact these coastal environments (Fresh et al. 2011). This interface of terrestrial and aquatic ecosystems makes up the Sound's nearshore environments, including the coastal-most upland riparian area, through the intertidal and extending just beyond the subtidal zone (Fresh et al. 2011). Due to its vast and complex structure, the Sound is often divided into six subregions for monitoring and research efforts. Following delineations outlined by the Puget Sound Assessment and Monitoring Program (PSAMP), our research is focused on describing aquaculture and sea duck characteristics in South Puget Sound, encompassing the southern-most inland waters, south of the Tacoma Narrows to Olympia, WA. With such a large estuarine system, variation in the biophysical environment exists, often extending in a North-South gradient. South Puget Sound is more sheltered from the influence of the ocean than its corresponding central and northern regions, characterized by shallower waters, weaker circulation and less saline conditions than the northern exposed region (Gustafson et al. 2000).

These shallow bays and inlets that make up South Puget Sound provide suitable muddy to sandy sediments for both the cultivation and natural propagation of bivalve shellfish (Simenstad and Fresh 1995). Currently, Washington State shellfish aquaculture operations produce the nation's greatest number of farmed oysters, clams and mussels (PCSGA 2011). Puget Sound holds the second greatest concentrations of shellfish aquaculture operations in Washington, following closely behind the outer coast (PCSGA 2011). Since its industry inception in the mid 1900s, aquaculture operations have expanded substantially to meet growing human demand (Magoon and Vining 1981). Within Puget Sound, individual shellfish operations can vary by species cultured and method of culture as a result of local regulations, environmental conditions, and market demands (PCSGA 2011).

Study Organisms

Shellfish

Cultured clam species predominantly include Manila (*Venerupis philippinarum)*, with additional farming of Butter (*Saxidomus gigantean*) and Littleneck (*Protothaca staminea*). Two main forms of clam cultivation are in operation in Puget Sound, ground and bag culture. Ground culture involves species grown directly in the intertidal substrate, and often covered by protective netting to prevent loss by predation (i.e. crabs and ducks) (PCSGA 2011). Alternatively, bag culture includes clams grown in bags set directly in the intertidal beaches or suspended from racks or trays within both the intertidal and subtidal zones (PCSGA 2011). Harvesting of clams in South Puget Sound is most often conducted by hand rake methods. More recently, Geoduck clams (*Panopea generosa*) have also become a significant subject of aquaculture activity in Washington State. Geoduck farms are typically located low in intertidal zones, utilizing a network of PVC pipes buried vertically into the substrate. Seeds are then added to each pipe and protective netting is placed individually over each tube or completely over the entire operation. Geoducks are harvested using a pump and hose, pressure-injecting water into each pipe to loosen the clam from the substrate for collection (PCSGA 2011). Cultivated mussel species include Blue (*Mytilus trossulus*) and Mediterranean or Gallo (*Mytilus galloprovincialis*). The majority of West Coast mussels are grown suspended from rafts or surface long-lines in the subtidal zones. These rafts are typically constructed of lumber, galvanized steel and plywood and afloat via plastic barrels or foam. Raft structures may also periodically utilize protective netting. Surface long-lines are commonly made of heavy plastics or nylon suspended by floats or buoys anchored and attached at intervals. Bags or lines are removed and harvested when appropriate market size is reached (PCSGA 2011). Oyster culture provides the greatest source of variation in species farmed, including Pacific (*Crassostrea gigas*), Native (*Ostrea lurida*), Kumanoto (*Crassostrea sikamea*), Eastern or American (*Crosostrea virginica*) and European flat (*Ostrea edulis*). Consequently, oyster culture also demonstrates greatest variability in operational methods among both ground and suspended culture, including bag, rack and bag, long-line and stake culture. Variation in oyster cultivation method most often depends on the target market, farmed for half-shell, ornamental or shucked meat (PCSGA 2011).

Sea Ducks

In addition to the economic values provided, Puget Sound provides abundant habitat for marine birds of the US West Coast, and is one of the most important wintering areas in the eastern Pacific (Nysewander et al. 2005). The Puget Sound supports approximately 70 species of marine bird that depend on the marine environment for all or a significant portion of their life histories (Essington et al. 2009). In particular, the sheltered inland marine waters of South Puget Sound provide substantial nearshore habitat for over-wintering populations of sea ducks – a group of diving duck intimately associated with the marine environment. Nine species commonly occur within Puget Sound, including: black scoter (*Melanitta nigra*), surf scoter (*M. perspicillata*), white-winged scoter (*M.fusca),* common goldeneye (*Bucephala clangula*), Barrow's goldeneye (*B. islandica*), bufflehead (*B. albedo*), common merganser (*Mergus merganser*), hooded merganser (*Lophodytes cucullatus*), and red-breasted merganser (*M. serrator*). Further description of these nine species is provided in Table 1, Appendix A. Sea ducks, as game species managed under state and federal migratory waterfowl regulations are subject to monitoring and management efforts to maintain sustainable population numbers (WDFW 2010). However, as described, habitat assessments are limited, thus identification of possible sources of limitation and stress are lacking (Evenson 2012).

Data Sets

Bird Survey Data

The Washington Department of Fish and Wildlife conducts annual aerial surveys of marine birds throughout Puget Sound, as part of the Marine Bird and Mammal Component of the Puget Sound Ambient Monitoring Program (PSAMP). Surveys began in 1992, including both parallel nearshore (<20m) and zig-zag off-shore (>20m) transects, estimated to cover 16% to 19% and 3% to 4.5% of total area, respectively (Nysewander et al. 2005). Efforts were taken to minimize possible sources of variation inherent in aerial surveys of waterfowl (Butler et al. 1995) by using experienced pilot biologists and observers, consistent timing and trajectory, and using the same aircraft throughout. The floatplane flew at 80-90 knots at an altitude of approximately 65 meters above sea level. Two observers positioned on each side of the aircraft recorded occurrence, species, GPS location and time within a 50 m wide search area (Nysewander et al. 2005). Separate databases were obtained through DFW for each winter survey season: 1994-95, 1995-96, 1996-97, continuous to 2012-13. For analysis purposes, each season was identified by its December year (eg. 1994-95 renamed to 1994). Within each year, anecdotal observations of bird counts while off transect were removed from representation and analysis. Bird surveys from the first 2 years were removed from analysis to eliminate variation, as method and operations were still developing at its onset. Therefore, bird survey data was pulled from the 1994/1995 winter season to the most current 2012/2013 winter season. Survey data was used to examine several parameters of sea duck populations, including counts, density indices and associated confidence limits. WDFW identifies our focal sea duck species by the following codes: Surf Scoter (SUSC), Black Scoter (BLSC), White-winged Scoter (WWSC), Unidentified Scoter (UNSC), Common Goldeneye (COGO), Barrow's Goldeneye (BOGO), Unidentified Goldeneye (UNGO), Common Merganser (COME), Hooded Merganser (HOME), Red-breasted Merganser (RBME), Unidentified Merganser (UNME), and Bufflehead (BUFF) (Table 1, Appendix A). Final data relevant to GIS and subsequent analysis included: survey year, latitude – longitude coordinates, on/off transect designation, species observed, and count per species observation.

Aquaculture Data

A long-term inclusive database of shellfish aquaculture operations and activities in SPS was non-existent before this research. With multiple agencies exercising permitting and regulatory authority over shellfish aquaculture operations, information exists across State agencies and agency departments. Additionally, these multiple agencies lack a concerted effort in data collaboration and sharing. Consequently, efforts to compile and construct a central database required cross-referencing of multiple resources. All information was acquired from public document sources provided by the State. Initial data was obtained from Washington Department of Fish and Wildlife (WDFW) aquatic farm registration forms, required under WAC 220-76 to be completed by aquaculture farms prior to commencement of culture activities. Ideally, this application would describe aquatic farm information per individual operation including: location - by parcel number, site address and/or section, township and range; size - amount of acres under cultivation; species cultivated; and method of culture. Realistically, information provided by WDFW public records request regarding shellfish aquaculture operations and activity in South Puget Sound over the last 20 years produced a database with substantial gaps (explained in further detail in the Discussion section). Therefore, to fill in data gaps, additional information was obtained from Department of Health (DOH) harvest certificate applications, required under WAC 246-282 by companies or individuals who harvest a commercial quantity of shellfish or any quantity for human consumption. Through DOH harvest certificates, information provided included: location by parcel number, site address, and/or section, township and range; acres harvested; and species harvested. Available information received more often than not remained in raw form, unsuitable for analysis requirements of my research. Consequently, extensive quality assurance/control (QA/QC) was undertaken to convert information to usable data for statistical analysis. Significant gaps existed in WDFW data provided including: lack of parcel ID (as this is optional yet preferred method of location identification); incorrect parcel ID as a result of inaccuracy provided by organization, transferring of data to digital record, or computer formatting errors; and missing acreage information. The final collated database relevant to supplementary analysis consisted of the following: year of operation, parcel ID, total acres cultivated, acres cultivated by species (i.e. clam, geoduck, oyster, mussel). Data was formatted for conversion to a GIS geodatabase for spatial representation and analysis (operations described in detail below).

Spatial Analysis Using Geographic Information Systems

The development and use of spatial databases in studies of both bird populations and aquaculture is increasingly recognized as a valuable method of identifying and analyzing spatial and temporal patterns and trends. As described by Simms (2002), a GIS 1) provides the capability to integrate, scale, organize and manipulate spatial data from many differences sources; 2) can be manipulated, updated, extracted and mapped efficiently; and 3) permits quick and repeated testing of models which could be used to aid in decision-making processes. In particular, use of ArcGIS 10 (ESRI, Inc. 2013) for analysis allowed for the identification and evaluation of the location and extent of shellfish aquaculture activities and its influence on sea duck distribution and abundance over an extended period of time.

Shorezone Sampling Designation

To create a base layer for analysis begin, a sampling framework was created to partition South Puget Sound nearshore areas into manageable units of observation. The entirety of Washington state shorelines has been mapped and made available by the Department of Natural Resources via online GIS data center, as part of an effort to provide a baseline measurement system for any coastal assessments. This shoreline arc was first clipped to our study area, South Puget Sound, comprising sheltered marine waters south of the Tacoma Narrows Bridge. For the purposes of this study, projection and analysis did not require the intricate representation of the many small bays and inlets drawn in the DNR shoreline. As a result, the simplify line tool was used to create a coarser scale map while retaining basic geometry. Using the simplified shoreline, a 500 meter buffer polygon was drawn, as the estimated relevant extent of interaction between our variables, established in past methods of analyzing PSAMP bird count data in response to shoreline attributes (Rice 2007). This buffer was used to identify nearshore parcels for joining of aquaculture sites, discussed in further detail below. In establishing a sampling grid for South Puget Sound, to be uniformly sampled each year, the buffer polygon was first restricted to the 500 m portion extending into the Sound to eliminate irrelevant upland area. This operation was performed using the split polygons tool, where all resulting island and upland polygons were deleted, leaving only the tidal 500 meter polygon. Efforts to further split the shoreline polygon to subsets of roughly equal areas were performed manually. First by generating points every 2 km along the simplified shoreline arc, and second by manually drawing lines extending perpendicular from these points snapping to the edge of the 500 m tidal polygon. Concerted effort was taken within narrow bays and inlets to insure as uniform area as possible. This resulted in the production of 192 shoreline polygons, regarded as our sampling areas where summaries of variable values would be calculated (Figure 2).

Aquaculture Projection

County parcel polygons were obtained from the three counties surrounding South Puget Sound: Mason, Thurston and Pierce. Rather than operating across three separate county assessor offices, a single shapefile representing county 2012 parcel data was provided by the Parcels Working Group at the University of Washington (UWP 2012). This is a collaborative project aimed at promoting the development and coordination of federal, state tribal and local governments to produce a statewide parcel framework accessible to various participating agencies and interested parties (UWP 2012). Still, the parcel shapefile contained many upland parcel entities unnecessary for my work, and parcels were clipped along the 500 m shoreline buffer, to aid in focused and efficient processing. A separate parcel layer clip was created for each year, 1994-2012. Each layer was then joined to its corresponding year of aquaculture activity by county parcel ID, choosing to keep only those records where a join was successful. The function failed to join 152 of the total 888 aquaculture parcels identified in the database. This is an error we accepted as a result of misidentification on the aquatic farm registrations, or changing parcel IDs (eg. splitting, moving, or renaming) over the last 19 years. Representing a minimal proportion of total activity, the data we retained still accurately represented activities. Next, all years were merged, and polygons centroids were converted to points using the feature to point tool. Because parcel polygons often extend perpendicular to shorelines, this feature tool placed some points upland of the shoreline where no aquaculture activity is actually occurring. To remedy this, we used the near tool to generate new coordinates of each point nearest to the simplified shoreline arc. The near distance traveled for each point was checked to ensure location was not altered by more than half of our shoreline polygon size.

Bird Survey Projection

To project bird surveys into a GIS, an x,y feature class was created from geodetic observation coordinates for each year. Data originally represented transects flown throughout the entire Puget Sound Region, so the same 500m shoreline buffer was used to clip points to our study area within South Puget Sound. Complete marine bird observations were further concentrated to our focal nine sea duck species. Like the aquaculture data, all 19 years of bird survey data were then merged to a single point shapefile (unidentified spp. included). For each year, anecdotal observations made while off transect were removed from representation and analysis. Additionally, several small inlet areas identified by WDFW were excluded from representation and analysis as these zones were surveyed only during initial years but later excluded from subsequent aerial transects for safety reasons. Sea duck data existed in stacked columns, with species identified in one and corresponding count adjacent. Therefore, new columns were added to the final merged table to combine our nine species and three unidentified species into four species groups and/or species. These species groups, and included species, are as follows: Scoters – Black, Surf, White-winged and Unidentified Scoter; Mergansers – Common, Hooded, Red-breasted and Unidentified Merganser; Goldeneyes – Common, Barrow's and Unidentified Goldeneye; and Bufflehead. Summed count values were transferred to their appropriate species group row.

Data Overlay Operations

The uniform sampling grid constructed initially from the buffered shoreline polygon was used to integrate our aquaculture and bird survey data for further analysis. Using the framework of the 189 polygons, an identity analysis was performed to append a unique corresponding polyID to each aquaculture point. As bird points did not always align directly with ground point shoreline boundaries (an inherent effect of aerial surveys), the spatial join tool was used to append polyIDs to each bird points using the 'closest' specification, where each observation point joined to the closest shoreline polygon. As a result, each aquaculture and bird point observation over the last 19 years was associated with a specific polygon ID. The two point features, aquaculture and bird, were merged a final time under common year and polyID fields, where each grid cell per year was now correlated with information regarding its use by shellfish aquaculture and by sea duck populations. Using the summary statistics tool, a table was generated to summarize activities per grid cell by year, quantifying the following attributes: 1) frequency and total counts of each four species groups, 2) count and total acreage of shellfish aquaculture, and 3) total acreage of each cultivated species (geoduck, clam, oyster, mussel). Not every grid cell had observations of both aquaculture and bird counts, therefore NULL values were given to those cells and/or years where no sea ducks were observed. However, under the assumption that our data represents the best estimate of shellfish aquaculture activities within South Puget Sound, those grid cells with no observed aquaculture were converted to zero acreage. Summaries identified 3 study site polygons with limited annual observations at 3, 6 and 9 out of the total 19 years of observation, while all other polygons identified 17-19 years of observation. These 3 study sites were consequently removed from any further analysis (Figure 2). This tabular data was then exported from GIS for further statistical analysis.

Statistical Analysis

Research Questions:

1) Do winter sea duck distributions and abundances demonstrate a relationship to the location and extent of shellfish aquaculture in South Puget Sound?

a) If so, what is the direction and magnitude of associations?

b) How do different species groups respond to aquaculture?

c) How do sea duck-aquaculture relationships vary over the last 19 years?

Tabulated data generated in ArcGIS was exported to Excel as an intermediate before further statistical analysis was conducted using JMP Pro 10 (SAS Institute, Inc 2012). Final data was charted in a stacked format, with individual rows representing observations by each unit polyID, further regarded as study site, for each year 1994-2012. Due to the limitations of PSAMP method, data produced from surveys cannot be used to explicitly determine population numbers, but instead can provide index values to characterize and evaluate observed spatial and temporal trends (Nysewander et al. 2005). Indices are often used in studies of animal populations where absolute values are rarely measured. Therefore, relative abundances per year by site for each species group were calculated as a proportion of total abundance. Descriptive analyses were run to explore overall summaries by year, by study site and by species group to uncover overarching trends and identify possible sources of errors. To eliminate unnecessary extreme variation and aid in analysis, aquaculture acreages were defined in four levels, based on frequency of observation: zero, where no aquaculture is present; small, $0 < x \leq 5$ acres; medium, $5 < x \leq 25$ acres , and; large, $x > 25$ acres.

To understand and predict animal-landscape relationships over longer time periods and larger spatial areas, our analytical approaches must incorporate temporal variation in explicit and robust ways (Gutzwiller and Riffell 2007). Analyzing aquaculture-sea duck associations within a single time frame, or summarizing values across a specified time span would not allow for the interpretation of chronic influences and spatial variability of an expanding aquaculture industry on changing sea duck species populations. Several statistical methods to incorporate time measures are available, however the nature and restrictions of our data made a mixed model repeated measures analysis the ideal choice for several reasons. Importantly, mixed models for repeated measures allow opportunity to incorporate simultaneous inferences about time and space in studies of animal-landscape relations (Bissonette and Storch 2007), where our analysis is evaluating the temporal variations within and among our different study sites throughout South Puget Sound. In part, this is because repeated measures controls for non-independence among temporally repeated observations, often where varying levels of data are subsampled within experimental units. Further, mixed model approaches offer greater flexibility in analysis on multiple scales, in particular unbalanced data where some observations may be missing (Gutzwiller and Riffell 2007). This was applicable in our case where some study sites lacked a complete 19 years of observation values.

A mixed model repeated measures analysis was used to determine the effects of year and aquaculture acreage on abundance and distribution of each of our species groups – Bufflehead, Goldeneye, Scoter, Merganser (JMP Pro 10). To set the foundation for our analysis, a description of units, factors, and effects are described below. There are two experimental units that must be accounted for in our analysis, both study site and year. Again, the 189 polygons created in GIS act as our permanent study sites, or subjects. Our analysis aims to identify both within-subject and between-subject factor. In a repeated measures analysis, the effect of year acts as our within-subject factor, with 19 levels. Our between subject factor is acreage size class, with 4 levels. Both acreage and year act as our main fixed effects. Additionally, under a mixed model approach, random effect(s) need to also be identified, under the assumption that this effect represents a sampled estimate of total values. Our experimental unit for acreage size class is our individual study sites. Therefore, acreage size classes cannot be randomized to sites, as they are specific designations of each polygon. Consequently, we assume sites selected are a random sample from the corresponding acreage size classes representative of South Puget Sound. In our analysis, model effects of interest are as follows:

acreage size class
site[acreage size class] & Random
year
year*acreage size class

Where acres, year and the interaction of acres x year (time) are our fixed predictor effects of interest and, to account for spatial variation, where site nested within acres acts as our random effect. This is due to the assumption that sample sites represent our entire South Puget Sound study area, thus providing structure for our estimated effect of aquaculture acreage. The inclusion of a random effect consequently runs our analysis using restricted maximum likelihood (REML), a method of parameter estimation restricted to maximizing the likelihood function over the random effects portion of the model (Gutzwiller and Riffell 2007). This random effect calculates subject effects, accounting for variation in acreage both within and among sites. Our model tests how species abundances respond to aquaculture acres, to temporal variability, and how species respond to aquaculture over time.

Using the above analysis, we tested the following specific hypotheses for each of our species groups:

The test for *interaction* is:

H: there is no interaction between the effects of aquaculture acreage and year on the relative abundance of species groups

A: there is an interaction between the effects of aquaculture acreage and year on the relative abundance of species groups

The test for our main *effect of year* is:

H: the mean relative abundance averaged over aquaculture acreages is equal across all years

A: the mean relative abundance averaged over aquaculture acreages is not equal across as years

The test for the main *effect of acreage* is:

H: the mean relative abundance averaged over years is the same for all acreage values.

A: the mean relative abundance averaged over years differs between the acreage values.

Across our developed model set assessing for the implications of shellfish aquaculture on sea duck population dynamics, support for our null hypotheses would suggest that factors other than those addressed in our valuation might determine the variability of observed sea duck population abundance.

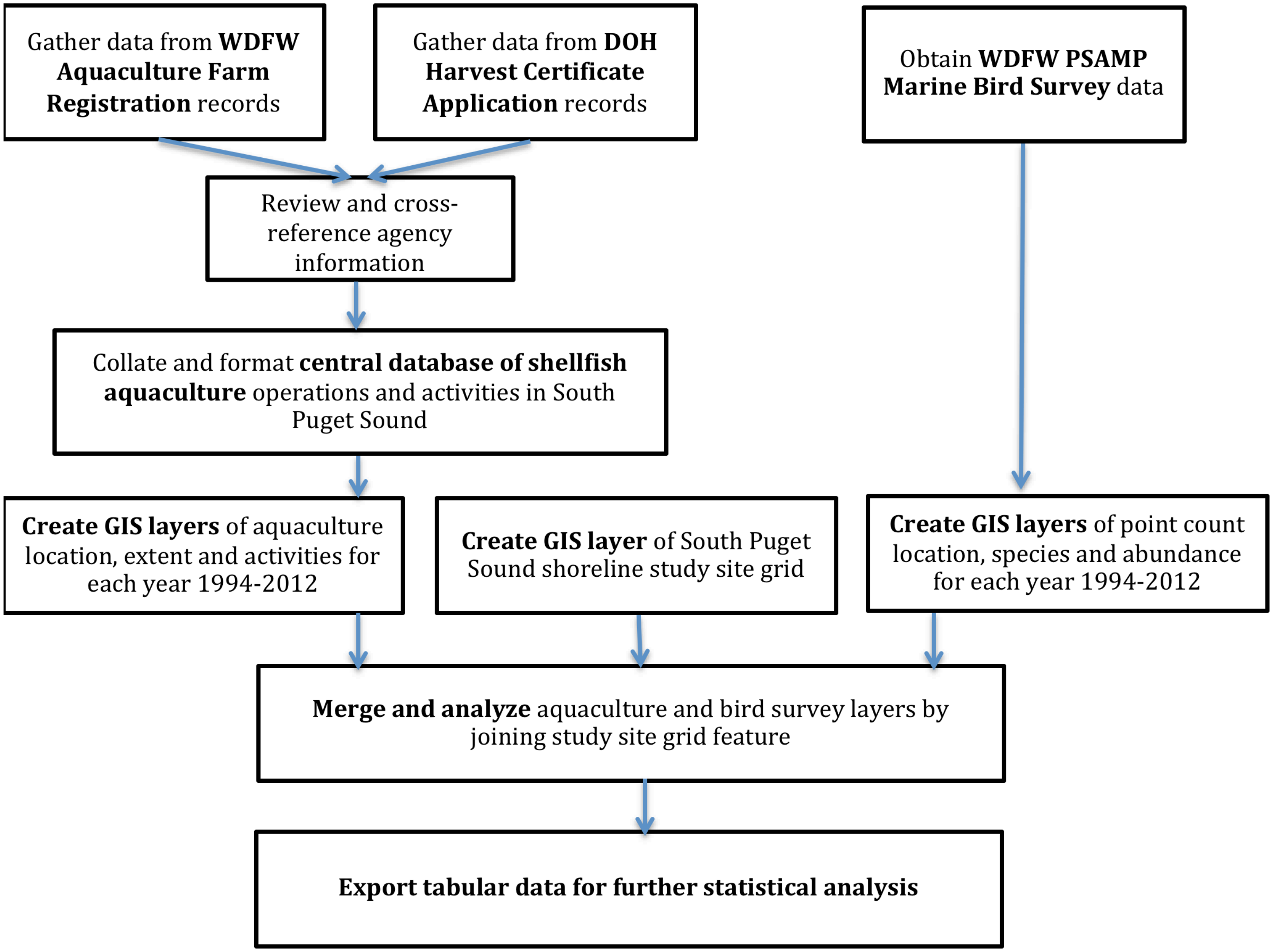

Figure 1. Simplified flow chart depicting method of operations to collate, merge, summarize and export data for statistical analysis.

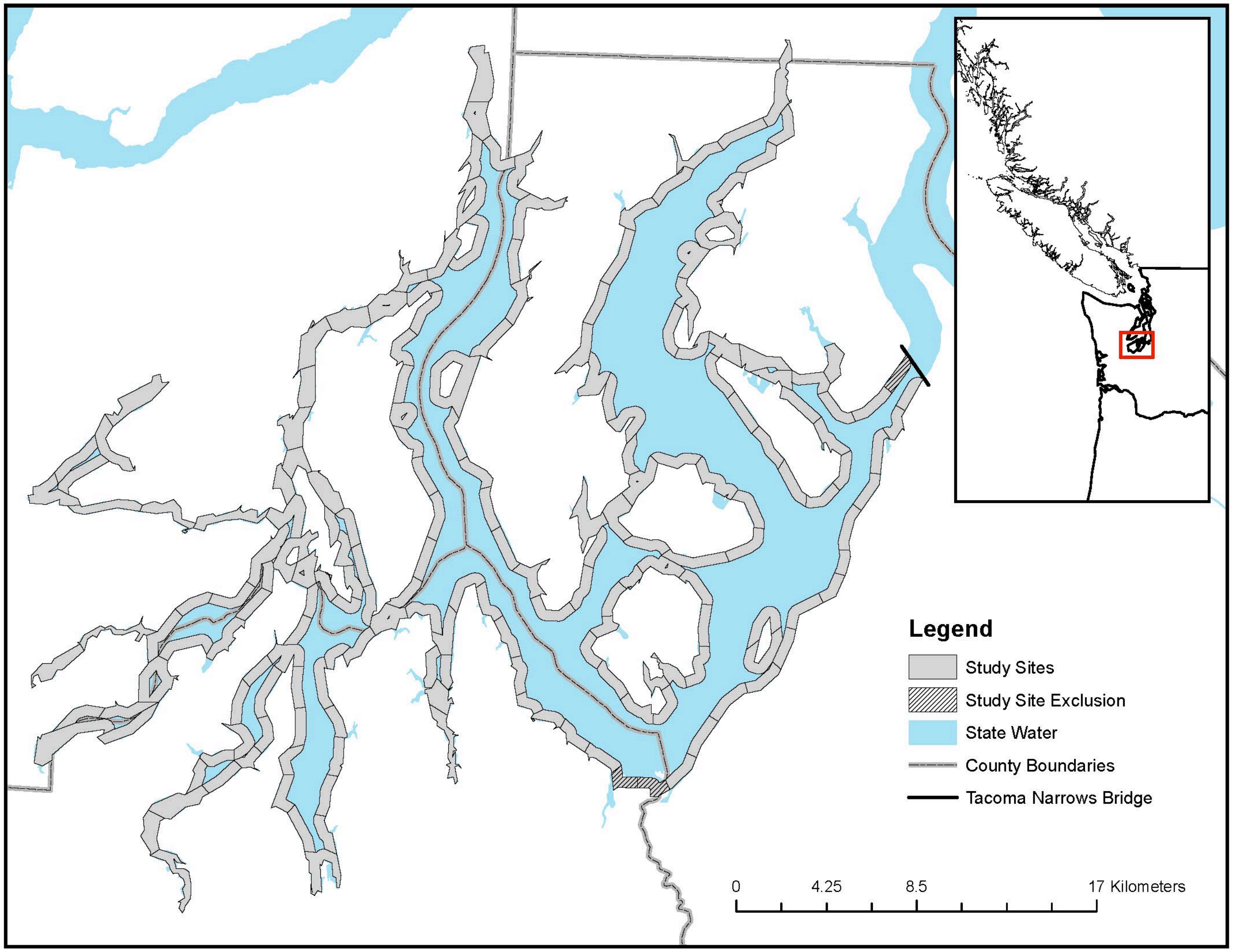

Figure 2. Map depicting study site polygons along South Puget Sound shorelines, generated in a GIS. 192 total sites.189 utilized in analysis. Boundaries follow approx. 2 km of shoreline and extend out 500 meters.

RESULTS

Shellfish Aquaculture

Figure 3. illustrates that total area under cultivation increased steadily since 1994, increasing at a rate of 128 acres annually (Table 2). Further, number of study sites under cultivation increased steadily at a rate of nearly 3 sites per year (Table 2), growing from 37 to 80 total occupied sites (Figure 3). Subsequent comparison of temporal trends in our acreage size classes reveal that medium farms ($5 < x \leq 25$), continued to define that greatest number of our study sites, increasing at a rate of 1.64 sites per year to 34 sites by 2012 (Table 2., Figure 3). Close behind medium-classed study sites, those defined by large operations ($x > 25$), increased by 1.16 sites annually (Table 2), growing from only 5 sites to currently represent 24 in 2012 (Figure 3). Alternatively, small acreages classes ($0 < x \leq 5$) once defining the greatest number of sites with aquaculture, demonstrated a relatively stable trend at an annual growth rate of 0.15 to a current count below historic numbers (Table 2, Figure 3). Further comparisons of species cultivated identify clams as the dominant species cultured over the 19-year study period (Figure 4). Oysters represented the next largest proportion, followed by geoduck and mussels, respectively (Figure 4).

Bufflehead

Testing first for the interaction effects, we reject the stated null hypothesis and conclude that there is a significant interaction between the effects of aquaculture acreage class*year on the relative abundance of Bufflehead, $F(54,3283)=1.59$, $p<0.0043$ (Table 3). Subsequent analyses demonstrated that there were simple effects for year at the zero [$F(18, 3226)=5.40$, $p<0.0001$], small [$F(18,3317)=2.04$, $p=0.0058$] and large

[F(18,3245)=2.75, p<0.0001] levels of the aquaculture acreage size class factor. As Illustrated in Figure 5., across each acreage size class, Bufflehead showed steady increases in relative abundance from 1994 to 2012. Initial divergence of abundance values among acreage size classes spiked in 1997-1998, with subsequent abundances across size classes exhibiting varying degrees of difference in means (Figure 5). Overall, Figure 5. shows that Bufflehead demonstrated higher marginal mean relative abundances at study sites classified by large aquaculture acreage than zero classified sites.

Scoter Species Group

For Scoter species, effects of both year and acreage class individually resulted in significant relationship with Scoter spp. relative abundances. From this, we can first conclude that relative abundance averaged over aquaculture acreage sizes is not equal across all years, F(18,3285)=8.25, p<0.0001 (Table 4). Further analysis show a gradual decline of sample means over time, with significantly lower abundances in later years (2008-2012) compared to initial year (1994-1998) (Figure 6). Secondly, analysis rejected the null hypothesis of acreage and suggests that mean relative abundance averaged over years differs between acreage size classes F(3,314)=4.3, p=0.0095 (Table 4). Tukey HSD comparisons shows that mean relative abundances at medium acreage class sites were significantly greater than at zero class sites (Table 5, Figure 7). However comparisons of small and large acreage class sites suggest no significant difference in Scoter species group relative abundance (Table 5, Figure 7). Analysis of the interaction effect of acreage class*year detected no significance, F(54,3289)=1.18, p=0.2599 (Table 5). The relative conformity of temporal trend lines among varying acreage size classes support evidence of non-significance of interaction (Figure 14, Appendix A).

Goldeneye Species Group

Testing for the effect of aquaculture size class in determining Goldeneye relative abundance values indicate significant differences among levels of acreage, F(3,334)=10.51, p<0.001(Table 6). Supplemental Tukey comparisons of LSMeans reveal that relative abundances at zero acreage sites are significantly greater than those at small, medium and large acreage sites at 0.3050 compared to 0.2396, 0.1870, and 0.1868, respectively (Table 6, Figure 7). However, comparisons between varying levels of aquaculture acreage revealed no significant difference in determining abundance values (Table 6, Figure 7). Testing for the effect of time revealed no significant influence on Goldeneye relative abundances, F(18, 3302)=1.34, p=0.1521. Further, testing for the interaction effect of acreage*year provided no significant results, F(54, 3306)=0.93, p=0.6210 (Table 6).

Merganser Species Group

First examining for our interaction effect, acreage*year, analysis failed to reject the null hypothesis that there is no interaction between the effects of aquaculture acreage and year on the relative abundance of Merganser Spp, F(54,3327)=0.82, p=0.8214 (Table 8). However, individual main effects of year and acreage both exhibited a significant interaction with Merganser population abundances. Analysis determines that the mean relative abundance averaged over aquaculture acreage size classes is not equal across all years, F(18,3322)=1.66, p=0.0398 (Table 8). Figure 8. demonstrates that while relatively stable, Merganser relative abundances are showing a slight increase over time. Testing for the effect of acreage concludes that mean relative abundance averaged over years differed significantly between acreage size classes, F(3, 359)=3.32, p=0.0201 (Table 8).

Additional Tukey HSD of sample mean differences show that relative abundance at sites classified by zero aquaculture acreage, 0.086, are significantly different than abundance values at large acreage classes, at 0.033 (Table 9, Figure 8).

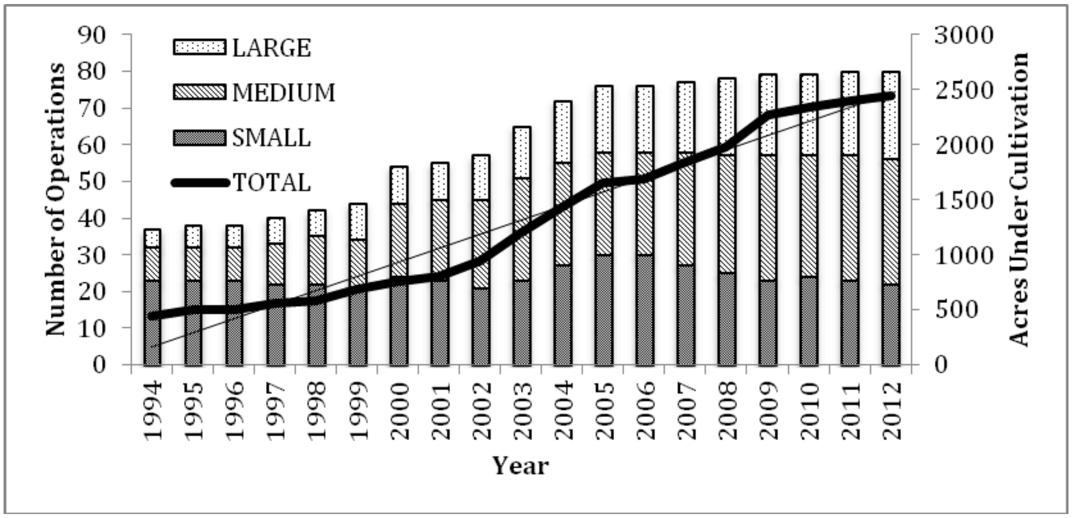

Figure 3. Growth in shellfish aquaculture in South Puget Sound by total acres under cultivation (black line)($p<0.001$, $R^2=0.96$) and number of study sites under cultivation (shaded bars) by acreage size class - small (0>x≥5), medium (5>x≥25) and large (x>25).

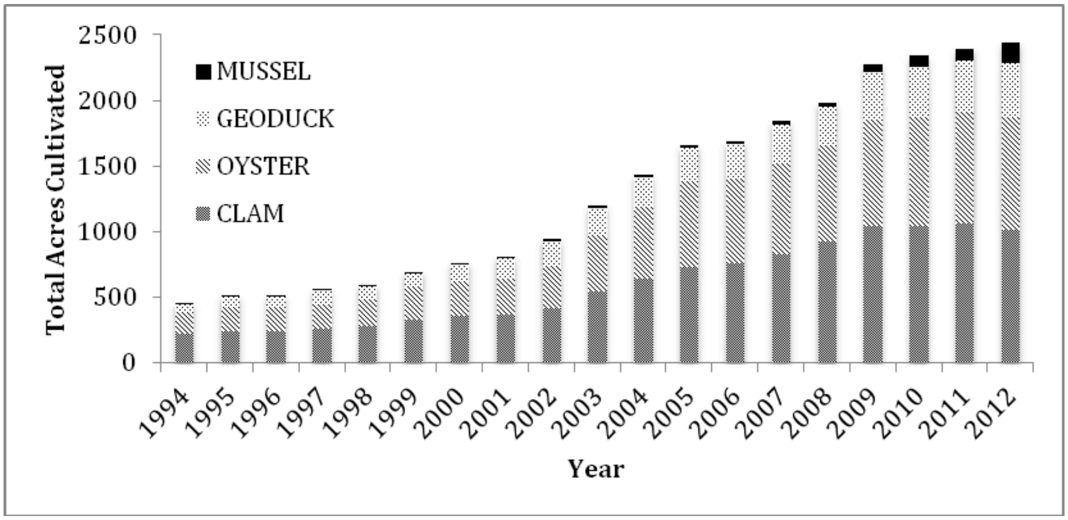

Figure 4. Growth in total acres cultivated across South Puget Sound aquaculture study sites delineated by shellfish species cultured – mussel, geoduck, oyster and clam.

Table 2. Rate of change in acres and count of study sites under cultivation in South Puget Sound from 1994 to 2012 by aquaculture size class – zero, (0) small (0>x≥5), medium (5>x≥25) and large (x>25).

	Rate of Change	
Size Class	Acres	Count
Large	105.51	1.16
Medium	21.56	1.64
Small	0.71	0.15
Zero		-2.92
Total	127.79	2.95

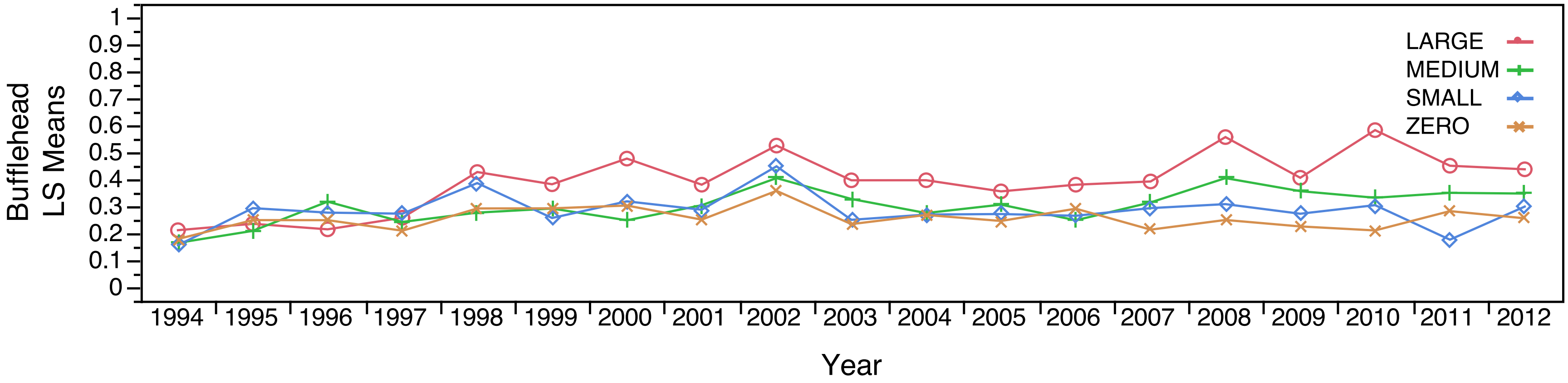

Figure 5. Sample means plot depicting significant interaction effect of aquaculture by year on Bufflehead relative abundance of winter populations in South Puget Sound. Levels of aquaculture acreage defined as large (open red circle), medium (green plus), small (open blue diamond) and zero (brown x) aquaculture acreage size classes. F(54,3283)=1.59, p=0.0043.

Table 3. Results of test slices report for significant interaction effect of acreage x year on Bufflehead relative abundances. Shows the effect of time on each acreage size class

	NumDF	DenDF	F Ratio	Prob > F
Large	18	3245	2.75	<.0001
Medium	18	3295	1.46	0.0958
Small	18	3317	2.04	0.0058
Zero	18	3226	5.4	<.0001

Table 4. Standard least squares REML results of fixed effects analyzing Scoter species (BLSC, SUSC, WWSC, UNSC) winter relative abundances in South Puget Sound from 1994 to 2012.

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Acreage Class	3	3	314.8235123	3.394	0.0183
Year	18	18	3285.446328	8.2477	<.0001
Acreage Class*Year	54	54	3289.479811	1.1172	0.2599

Table 5. Tukey HSD crosstab report for interaction effect of aquaculture acreage size on Scoter species group (BLSC, SUSC, WWSC, UNSC) winter relative abundance in South Puget Sound averaged over 1994-2012. Levels not connected by the same letter are significantly difference (p<0.05).

Level			Least Sq Mean	Std Error
MEDIUM	A		0.43680579	0.02725981
SMALL	A	B	0.41841467	0.02493732
LARGE	A	B	0.39141436	0.03743206
ZERO		B	0.35492628	0.01362282

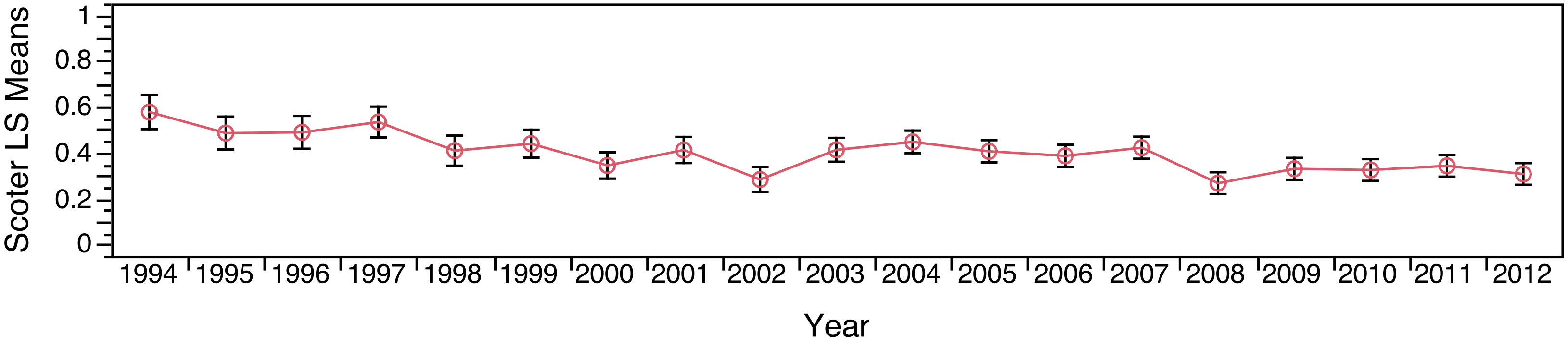

Figure 6. Sample means of Scoter species (SUSC, BLSC, WWSC, UNSC) winter relative abundance in South Puget Sound from 1994-2012. Standard error bars included. Results from standard least squares REML, F(18, 3285), p<0.0001.

Table 6. Standard least squares REML results of fixed effects analyzing Goldeneye species (COGO, BAGO, UNGO) winter relative abundances in South Puget Sound from 1994 to 2012.

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Acreage Class	3	3	334.8209456	10.5101	<.0001
Year	18	18	3301.93743	1.3399	0.1521
Acreage Class*Year	54	54	3306.296044	0.9297	0.621

Table 7. Tukey HSD crosstab report for interaction effect of aquaculture acreage size on Goldeneye species group (COGO, BOGO, UNGO) winter relative abundance in South Puget Sound averaged over 1994-2012. Levels not connected by the same letter are significantly difference (p<0.05).

Level			Least Sq Mean	Std Error
ZERO	A		0.30502524	0.01130776
SMALL		B	0.23962439	0.02097505
MEDIUM		B	0.18704016	0.02302209
LARGE		B	0.18682118	0.03155346

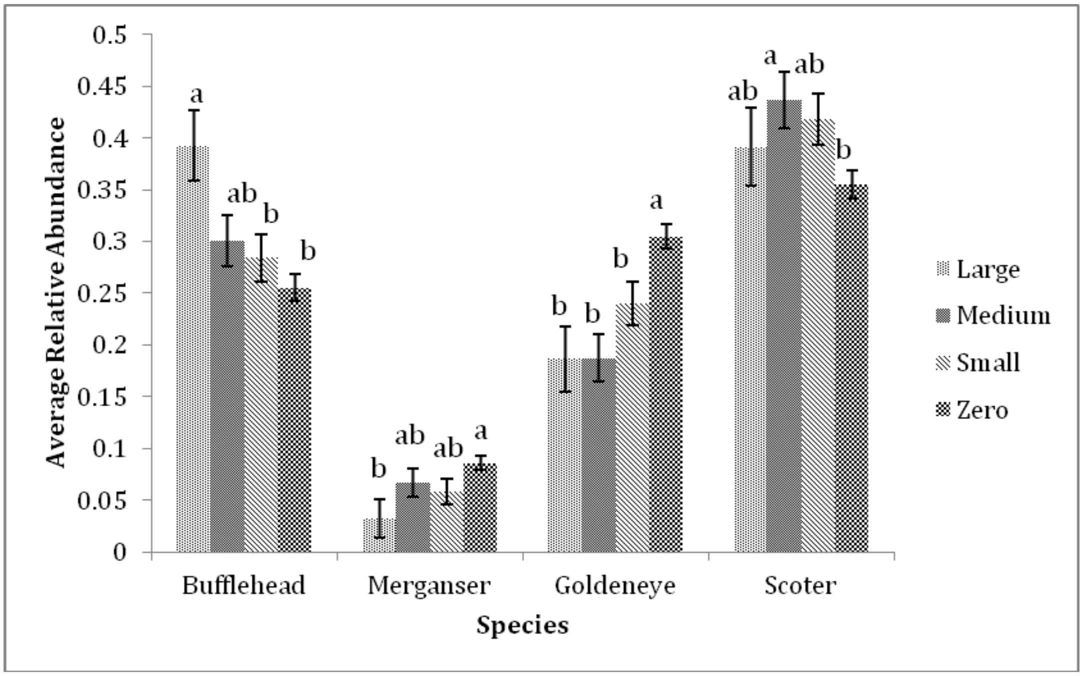

Figure 7. A comparison of Tukey HSD results by species group. Relative abundances by acreage size class averaged over time. In each species group, results not connected by the same letter are significantly different (p<0.05).

Table 8. Standard least squares REML results of fixed effects analyzing Merganser species (COME, HOME, RBME, UNME) winter relative abundances in South Puget Sound from 1994 to 2012.

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Acreage Class	3	3	359	3.3173	0.0201
Year	18	18	3322	1.6572	0.0398
Acreage Class*Year	54	54	3327	0.8211	0.8214

Table 9. Tukey HSD crosstab report for interaction effect of aquaculture acreage size on Merganser species group (COME, HOME, RBME, UNME) winter relative abundance in South Puget Sound averaged over 1994-2012. Levels not connected by the same letter are significantly difference ($p<0.05$).

Level			Least Sq Mean	Std Error
ZERO	A		0.08573273	0.00654795
MEDIUM	A	B	0.06654402	0.01377676
SMALL	A	B	0.05824106	0.01246492
LARGE		B	0.03256016	0.01880374

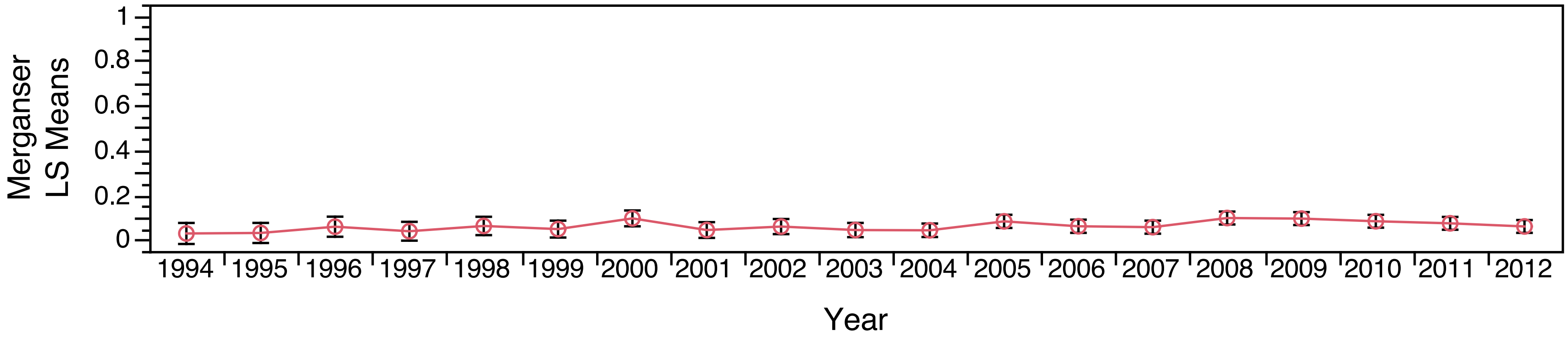

Figure 8. Sample means of Merganser species (COME, HOME, RBME, UNME) winter relative abundance in South Puget Sound from 1994-2012. Standard error bars included. Results from standard least squares REML, F(18,3322)=1.66, p=0.0398.

Discussion

Sea Duck – Aquaculture Relations

This study is one of the first to examine sea duck population dynamics in response to changing nearshore aquaculture landscapes across two decades in South Puget Sound. While many studies of animal-habitat relations incorporate measures of either time or space (Biossonette and Storch 2007), our mixed model approach to analyzing repeated measures data permitted simultaneous inference of both spatial and temporal factors. In studying the interface of condition and time-based effects we expand our frame of inference to better address how winter sea duck populations are responding to changing aquaculture landscapes. This research directly addressed recommendations to include broader spatial and temporal scales of analysis to monitor and evaluate possible factors contributing to the decline of Pacific coast sea duck populations (SDJV 2012, WDFW 2010). Furthermore, we evaluate the ecological role of shellfish aquaculture on sea duck populations and on coastal marine habitats by explicitly incorporating the influence of time, space and intensity of aquaculture (Simenstad and Fresh 1995). Our study concluded significant responses to aquaculture by all four species groups – Bufflehead, Goldeneye, Scoter and Merganser; however, in concordance with past studies of sea duck-aquaculture relations, our results depict a range of direction and degree of responses among species. Our results show varied responses in regards to the interaction effect of acreage by time, and individual effects of acreage and year.

Contrary to a negative disturbance definition of aquaculture, both Bufflehead species and the Scoter species group (BLSC, SUSC, WWSC, UNSC) exhibited a positive association with shellfish cultivation operations in the South Puget Sound. However, variation in degree and significance of response to different model parameters was observed between species groups. In testing for our interaction of acreage and year, only the Bufflehead demonstrated a statistically significant relationship of relative abundance responses to a changing aquaculture environment. Results specified greater abundances values within study sites under large levels of cultivation as opposed to those under small or no levels of cultivation. While Scoter species failed to exhibit a significant response to interaction effects, averaging mean relative abundance over time showed Scoter species abundance values were clearly greater at medium level compared to zero level aquaculture sites. Several indications, which could explain these trends, have been identified in past studies. Because food quality and quantity strongly influence habitat use in birds (Palm et al. 2012), observed population dynamics may reflect spatial and temporal patterns in food resources. One commonly identified driver of positive associations between sea ducks and aquaculture can be attributed to the addition of food resources provided by aquaculture operations. Bufflehead and Scoter species are both characterized as omnivorous diving ducks, predating largely on bottom-dwelling marine invertebrates in coastal bays and inlets, consisting predominantly of bivalve mollusks and crustaceans (SDJV 2003b,c,j,k). In a study by Kirk et al. (2007) comparing mussels on natural and aquaculture-structured habitats found that mussel density and morphology differed dramatically between artificial structures and intertidal habitats. Specifically, that mussel densities were considerably higher within aquaculture facilities by providing new substrate on which to attach. Further, that mussels grown on structures tended to be larger, thinner shelled and attached more weakly than comparative intertidal specimens

(Kirk et al. 2007), thus providing a more profitable resource to local sea duck predators (Zydelis et al. 2009).

Foraging theory suggests that animals respond to changes in food abundance and quality, encouraging species to optimize net energy intake when faced with variation in prey attributes or abundance (Kirk et al. 2008, Lewis et al. 2008). Therefore, changes in sea duck distributions and abundances can reflect underlying prey resource availability. This may be particularly true for Bufflehead and Scoter species as dominantly molluscivorous sea ducks feeding largely on wild mussels, and further documented to severely deplete structure-grown mussels in the presence of off-bottom aquaculture (Kirk et al. 2007). It is of interest to mention that some shellfish farmers actually welcome predatory sea ducks - by which the predation of mussels fouling aquaculture structures is alleviated without the costly efforts of doing so manually (Kirk et al. 2008). The possibility of a mutually sustainable or even positive wildlife-industry interaction is all too rare (Zydelis et al. 2009), and consequently should inspire further collaborative research. Although we did not directly observe mechanisms driving population dynamics, these positive associations support use theories that sea duck species may exploit novel and advantageous prey populations provided by aquaculture operations.

Although these two species groups documented similar responses to our model effect of aquaculture, their observed overall population trends diverge considerably. Bufflehead species were one of two groups (the other, Merganser) to exhibit overall increases in relative abundance values over time, regardless of acreage class specifications. Past studies of WDFW PSAMP marine bird data have also found that Bufflehead, representing the second most numerous diving duck in Puget Sound, demonstrated more stable populations patterns among wintering sea duck species (Nysewander et al. 2005). This may suggest the overall stability of Bufflehead populations to adjust to changing nearshore landscapes and advancing aquaculture operations. In contrast, Scoter species, although comprising the greatest proportion of sea duck populations also represent one of the most extreme declines, at an estimated Sound-wide decline of 53% (WDFW 2010). This significant declining trend was similarly identified in my analysis (Figure 6, 10). However, lack of negative relations with shellfish aquaculture, may suggest that alternative sources may be at play leading to long-term declines, such as: natural environmental attributes (Zydelis et al. 2006), availability of herring spawn (Anderson et al. 2009), cumulative levels of nearshore urbanization (Rice 2007), or predation of scoters (Anderson et al. 2012),

Our Goldeneye species group (BAGO, COGO, UNGO) exhibited a unique response to aquaculture compared to other species groups of interest. Despite the relative temporal stability of species group abundances, with no significant influence recognized by the effect of year, Goldeneye showed a significant negative response to any level of aquaculture. Figure 16. illustrates the relatively constant temporal trend of greater population abundance in zero-classed study sites compared to small, medium and large. Results suggest that presence of shellfish aquaculture may be displacing wintering Goldeneye species populations throughout South Puget Sound. However, the lack of significance between small medium and large operations could indicate that greater intensity of aquaculture do not invoke significantly increased responses by Goldeneye. Comparable negative associations to shellfish aquaculture were reflected in analysis of the Merganser species group (COME, HOME, RBME, UNME). Although Mergansers comprised the smallest proportion of sea duck abundances over all, this species group demonstrated a significant increase in abundance values over time. This increasing trend is representative of Sound-wide trends in Merganser populations, as one of few sea duck species with some degree of increase (Nysewander et al 2005). Added analysis of abundance values associated with varying aquaculture acreage levels indicate that populations occurred in significantly lower numbers in large-class sites compared to those of zero-class delineations. This illustrates that even under increasing population trends, species are adversely responding to extensive shellfish aquaculture operations.

Similar deleterious impacts of shellfish aquaculture have been identified in past studies to both directly and indirectly drive observed marine bird habitat use and patterns. Similar to mechanisms lending to utilization of choice resources, observed absence in certain areas may suggest lack of availability to vital habitat. In regards to sea ducks, the most recognized source of negative implications of aquaculture is the degradation or alteration of critical foraging habitat. This is most likely a response to change of prey landscapes due to nearshore fauna alterations (Caldow et al. 2003), declines to seagrass communities (Tallis et al. 2009) and sediment modifications (Connolly and Colwell 2005). One study by Caldow et al. (2003), found that the effects of intertidal mussel cultivation were associated with decreases in over-wintering nearshore bird overall abundance and species richness. A similar study on the effects of oyster cultivation in three major estuaries in Washington found that aquaculture harvest practices had identifiable and distinct impacts on eelgrass density and growth, with lower densities observed in all oyster culture areas (Tallis et al. 2009). Negative disturbance of seagrass communities could have further implications to dependent infaunal benthic and epibenthic prey species on which predatory sea ducks rely (Dumbauld et al. 2009). These influences to seagrass communities could be especially suggestive of our observed negative response in Merganser species, as the only piscivorous diving duck of focus feeding largely on small fish, crustaceans and aquatic insects (SDJV 2003e,g.i), which rely on functional seagrass habitats.

Despite varying results documented to nearshore ecosystems under shellfish aquaculture activity, the overall conclusion of shift in community structure and ecosystem processes demonstrate varying directions and degrees of disturbance (Simenstad and Fresh 1995). The concern then becomes, how to quantify changes that provide for some species while displacing other. Caldow et al. (2003) suggests then, that evaluations of aquaculture may require assessments on a case-by-case basis. This issue is evident in our study, where different species groups are documented relating to aquaculture in varying ways, coinciding with past results suggesting that responses to aquaculture may be species-specific (Connolly and Colwell 2005). Further, one might ask how different sea duck species themselves relate, whereby past studies have suggested the sheer mass of feeding scoter populations in certain coastal estuaries, as a top predator, may influence community dynamics of competing predators (Lewis et al. 2007).

Future Considerations

The dynamics of evaluating wildlife-landscape relations coupled with the inherent difficulty involved in marine bird population studies highlight the complexity of quantifying sea duck responses to shellfish aquaculture. As a result, many additional questions have developed out of this study, further identifying several key areas of expansion for future studies. Our efforts focused only on identifying sea duck relations to one key anthropogenic habitat feature - shellfish aquaculture. By expanding future studies to incorporate for additional natural habitat features, this may provide identification of alternative sources of variation in sea duck population observations. We recommend using two key natural habitat features in future analysis: nearshore substrate type and intertidal width. In a study addressing movements of foraging winter scoter populations, Kirk et al. (2008) found that populations demonstrated significantly different feeding behaviors between soft-bottom intertidal flats and rocky intertidal shores. Supported in additional studies as a response to differing prey landscapes, such as species composition (Kirk et al. 2008) and density (Lewis et al. 2008). Furthermore, past studies by Zydelis et al. (2006, 2009) have identified intertidal width as an important predictor in scoter population distributions, even under varying substrate type. This is not surprising, as the intertidal zone constitutes the majority of habitat utilized by sea ducks.

Second, it would be valuable to further explore varying levels of spatial and temporal scales of inference. For example, supplementary integration of efforts directed at specific bays and inlets of South Puget Sound with documented heavy uses by both sea duck species and aquaculture industry. Because temporally repeating focused observations within nearly 200 study sites is unreasonable, these additional direct inferences on specific interactions of sea ducks and aquaculture could uncover underlying mechanisms of observed broad-scale relations. Likewise, because many sea ducks that utilize South Puget Sound during non-breeding periods do so for a large portion of their annual cycle (Gaydos and Pearson 2011) further addressing seasonal variations may help clarify site-specific directions and degrees of disturbance. This may be especially true for sea ducks, such as scoters, where within-season variation of foraging behaviors have been observed (Palm et al. 2012). Specific to aquaculture, while artificial farm structures may provide novel foraging habitat, the pulse of prey that draw opportunistic sea duck species, may lack the stability to provide a lasting resource and this variability may have further ecological implications to wintering sea ducks (Kirk et al. 2008).

Finally, future studies of this nature would benefit from additional information regarding specific aquaculture method and activity. In this analysis, by characterizing each of the study sites by total acres cultivated, inferences could be drawn on the intensity of operation - whereby larger operations using greater portions of tidal area would require greater degree of cultivation effort, thus industry activity. However, bivalve species are not all cultivated in the same manner, and still within each species, method of cultivation varies by tidal and industry resources. Therefore, it would be beneficial to address specific responses of sea duck populations to differing cultivation operations. Effect of aquaculture method has been employed in past studies, demonstrating greater degree of negative implications due to on-bottom methods (eg. Dumbauld et al. 2009) versus neutral or beneficial implications of off-bottom methods (e.g. Zydelis et al. 2009). Method-specific evaluations in South Puget Sound would allow greater ability to tease out certain deleterious implications associated with certain culture operations, while also identifying those where mutual sea duck – industry inhabitance is occurring.

Conclusions

Long-term population declines in many sea duck species wintering in Puget Sound have sparked concerns of local wildlife conservation and management agencies. Given the limited understanding of sea duck basic biology and the inherent challenges of studying species with such broad and remote distributions, current knowledge is lacking in its ability to identify sources of decline. In Puget Sound in particular, an understanding of habitat requirements, and identification and evaluation of possible limiting factors, remains insufficient to best understand and mitigate these declines. From this need, our research contributes to this limited body of knowledge by providing an assessment of sea duck habitat use and availability in response to a variable aquaculture landscape.

This study is the first of its scale to address the influence of shellfish aquaculture on winter sea duck populations. As my study supports, by explicitly incorporating for both spatial and temporal variability in assessments of sea duck-aquaculture relations, efforts may provide a better understanding of the direction and degree of suggested associations. However, this is only one aspect of defining sea duck interactions with aquaculture, where further efforts could benefit from integrating scales of inference across different life stages, to better understand underlying mechanisms.

Findings suggest that the location and extent of shellfish aquaculture plays a significant role in defining winter sea duck population distribution and abundance in South Puget Sound. However, that sea duck responses to aquaculture differ in the nature and degree according to species or species group. Whereby Bufflehead and Scoter species (Black Scoter, Surf Scoter, White-winged Scoter) exhibited varying levels of positive associations with aquaculture; however, Goldeneye species (Common

Goldeneye, Barrow's Goldeneye) and Merganser species (Common Merganser, Hooded Merganser, Red-breasted Merganser) demonstrated differing degrees of negative responses to aquaculture. This study highlights the complexity of analyzing sea duck populations in an anthropogenically charged landscape - that aquaculture induced disturbances are divergent at times, that sea duck habitat use patterns are dynamic, and that consistent future monitoring and assessment efforts are needed to clearly evaluate changing ecosystems.

CHAPTER THREE

GENERAL CONCLUSIONS

Observed long-term declines in many Puget Sound winter sea duck populations have driven the scientific community to address the significant lack of knowledge defining basic sea duck biology and ecology. Conservation and management agencies have recognized that without sustained and expanded effort to identify sea duck habitat use, needs and availability of Puget Sound winter grounds, effective measures to mitigate or reverse observed declines remains unlikely. By investigating the implications of shellfish aquaculture on winter sea duck populations in South Puget Sound, our findings suggest:

- Aquaculture location and extent plays a significant role in determining sea duck distribution and abundance.
- Sea duck responses to aquaculture vary in nature and degree by species or species group
  - Bufflehead respond positively over time to a changing aquaculture landscape, with greatest abundances at study sites with greater than 25 acres of cultivation.
  - Scoter species (BLSC, SUSC, WWSC) respond positively overall to study sites subject to between 5 and 25 acres of cultivation compared to those with no cultivation. Though, species trends also show overall declines in relative abundances over time within our study area.
  - Goldeneye species (BAGO, COGO) remained stable in their overall abundance trends; however, these species were negatively associated with

  aquaculture. Relative abundances were significantly greater at study sites under zero cultivation activity compared to any level of cultivation.

  - Merganser species group (COME, HOME, RBME), while showing significant increases in abundance over time, demonstrated negative association with aquaculture. Relative abundances were clearly greater at sites under zero cultivation compared to those with greater than 25 acres of cultivation.

The presence of sea duck-aquaculture associations may be clear, however the variability in direction and degree of relations suggest that industry in South Puget Sound, while proving deleterious for some species, may provide for others. These findings highlight the dynamic nature of sea duck-aquaculture relationships and the need for continued investigations to inform industry practices and resource management agency options to minimize the impacts of aquaculture on nearshore ecosystems and sea duck populations. To provide a comprehensive understanding of this animal-landscape relationship, monitoring and assessment efforts should strive to:

- Maintain broad spatial and temporal scales of inference to account for the heterogeneity of habitat and resources
- Further integrate local scale research to link underlying mechanisms defining regional populations trends
  - Thereby better understanding species-specific responses
- Connect efforts across different stages throughout their annual cycles – among molting, breeding and wintering habitats

Our determinations to collate a database of activities in South Puget Sound have identified the abundance of information available in characterizing aquaculture in the State. However, the exhaustive efforts required to provide a representative and analytical resource should prompt regulatory agencies to readdress their permitting requirements, documentation methods and collaborative capacities. To succeed at understanding sea duck-aquaculture relationships, it is important those agencies develop and maintain a complete representation of shellfish aquaculture operations and activities in the state. Promoting this will require:

- Redevelopment of permitting requirements, regulation and documentation to improve analytical capacities
    - To include detailed spatial location
    - To include specific harvest methods
- Communication and collaboration among regulatory agencies (WDFW, DOH, DNR) to make productive and efficient use of shellfish aquaculture information
    - Integrated application process and central database
- Communication and collaboration within agencies (WDFW licensing, records, wildlife) to effectively allocate resources and advance research capacities
- Communication and collaboration with independent research organizations (SDJV, PCSGA, PSI) and shellfish industry to build productive and cooperative relationships to address sea duck-industry conflict

This study was the first in Puget Sound to build a comprehensive database of shellfish aquaculture at this temporal and spatial capacity, and integrate this into winter sea duck habitat assessments. Our efforts have provided novel findings elucidating sea duck-aquaculture relationships in Puget Sound, a foundation for growth and management of a functional aquaculture database, and suggestions to advance effective agency and industry cooperative research efforts. To effectively address complex issues pertaining to both declining sea duck populations and advancing aquaculture industry, it is necessary to develop dynamic methods to meet the challenges of a dynamic system. Ultimately, the objective of conservation, management and industry is to meet the pressures of balancing the functional requirements of sea duck habitats with the economic values of a shellfish aquaculture in Puget Sound.

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APPENDIX A.

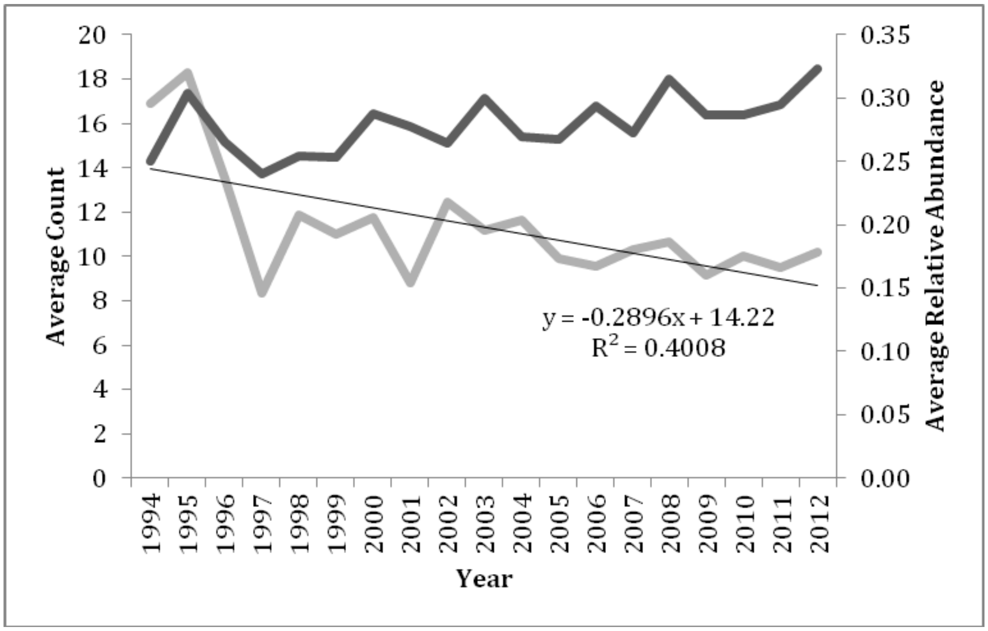

Figure 9. Raw means analysis of average count (light grey) and average relative abundance (dark grey) of Goldeneye species (BAGO, COGO, UNGO) across South Puget Sound study sites (n=189) from 1994 to 2012.

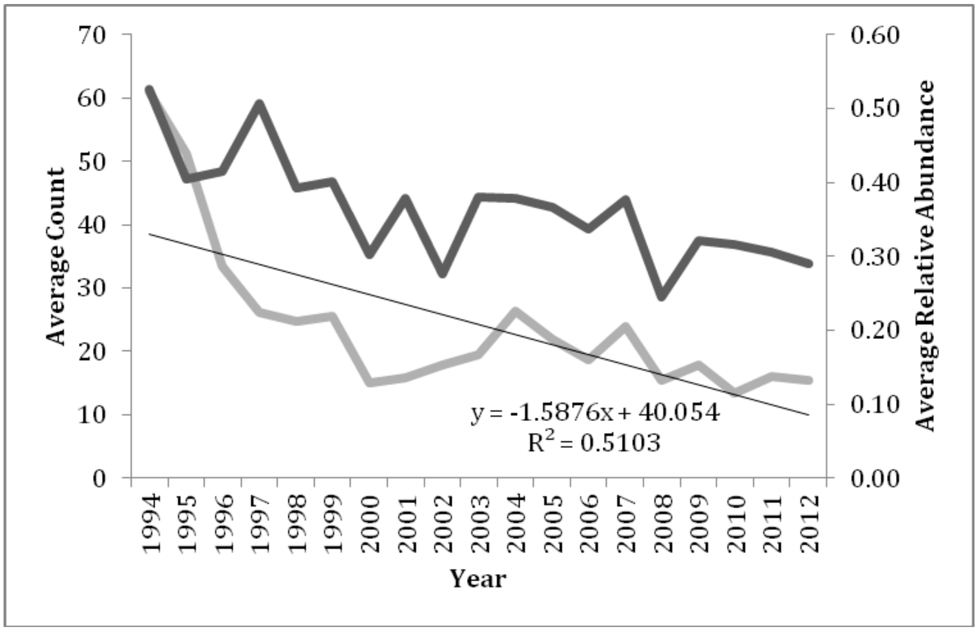

Figure 10. Raw means analysis of average count (light grey) and average relative abundance (dark grey) of Scoter species (BLSC, SUSC, WWSC, UNSC) across South Puget Sound study sites (n=189) from 1994 to 2012.

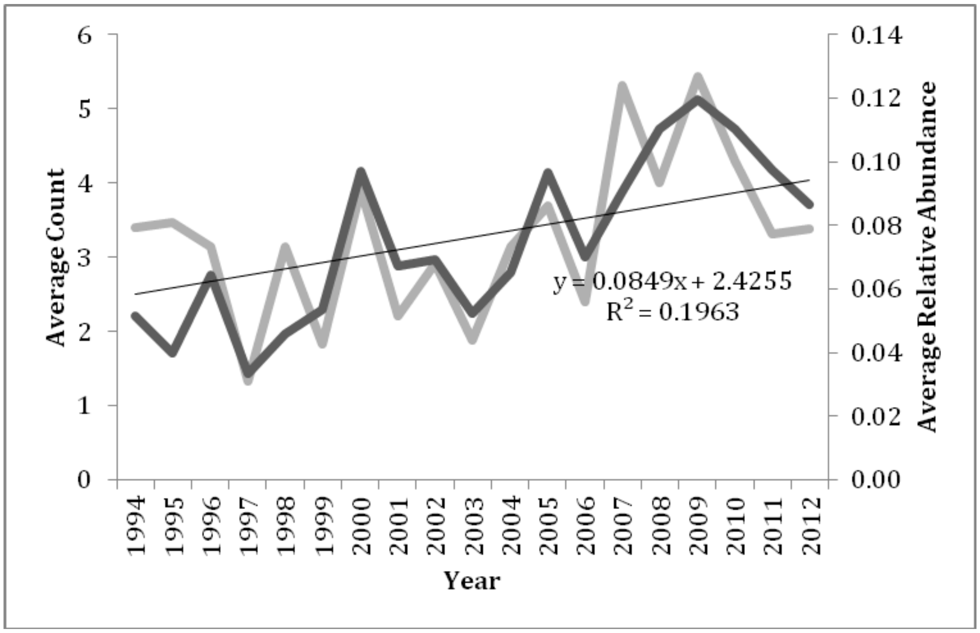

Figure 11. Raw means analysis of average count (light grey) and average relative abundance (dark grey) of Merganser species (COME, HOME, RBME, UNME) across South Puget Sound study sites (n=189) from 1994 to 2012.

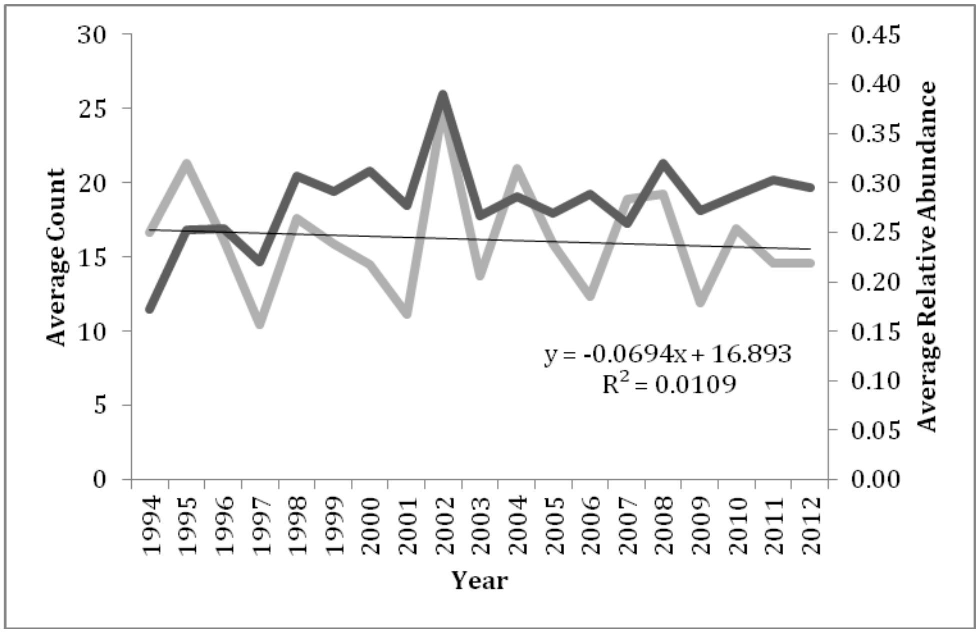

Figure 12. Raw means analysis of average count (light grey) and average relative abundance (dark grey) of Bufflehead species across South Puget Sound study sites (n=189) from 1994 to 2012.

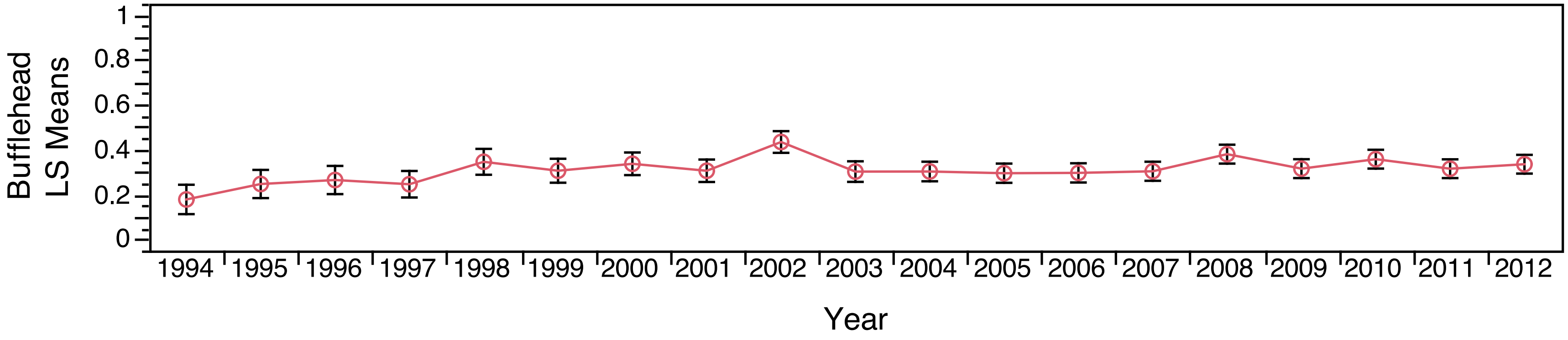

Figure 13. Sample means of Bufflehead winter relative abundance in South Puget Sound from 1994-2012. Calculated using standard least squares REML. F(18, 3280), p<0.0001.

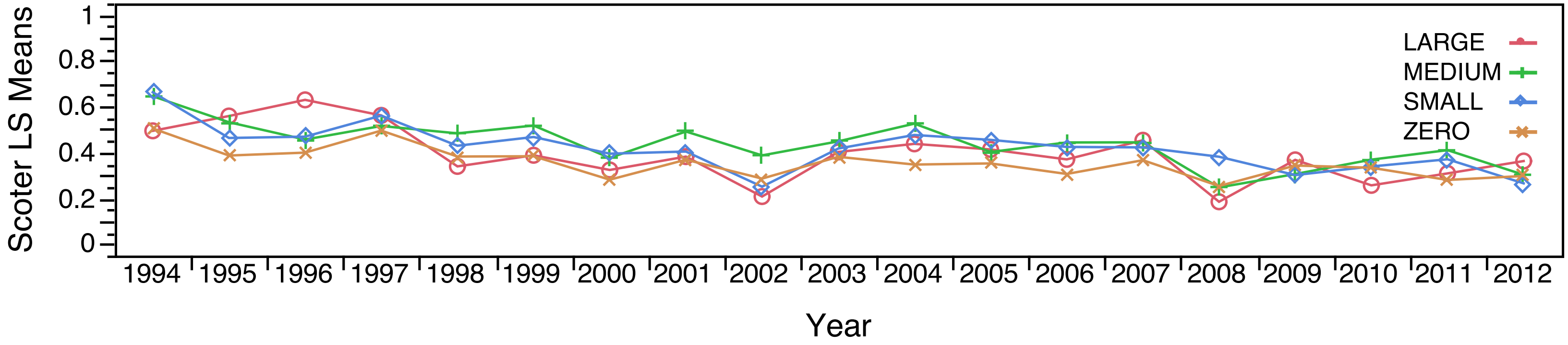

Figure 14. Sample means of Scoter species (SUSC, BLSC, WWSC, UNSC) winter relative abundance in South Puget Sound by study sites defined as large (open red circle), medium (green plus), small (blue diamond) and zero (brown x) aquaculture acreage size classes Non-significant interaction calculated using REML based repeated measured analysis testing for acreage class*year (p=0.2599).

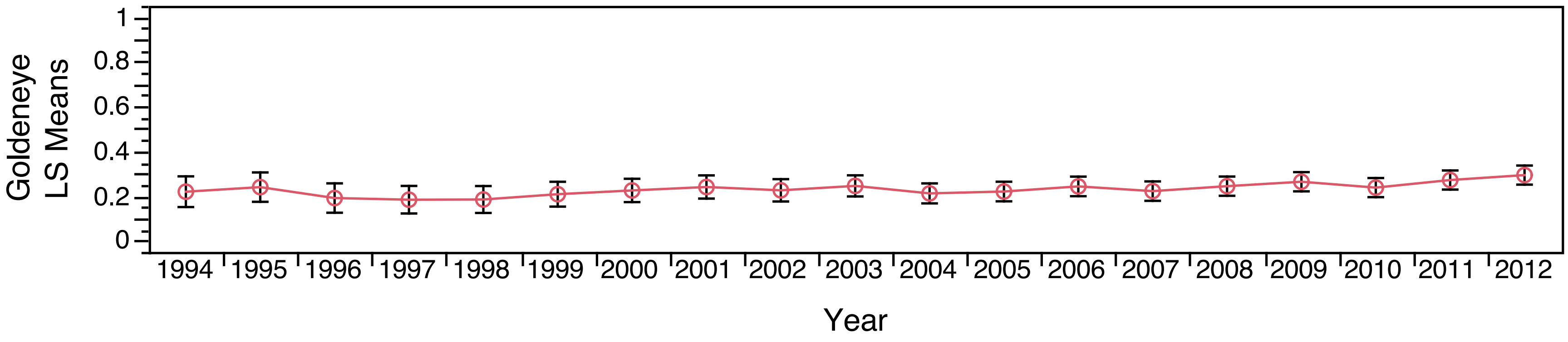

Figure 15. Sample means of Goldeneye species (COGO, BAGO, UNGO) winter relative abundance in South Puget Sound from 1994-2012. Calculated using standard least squares REML. (p=0.1521).

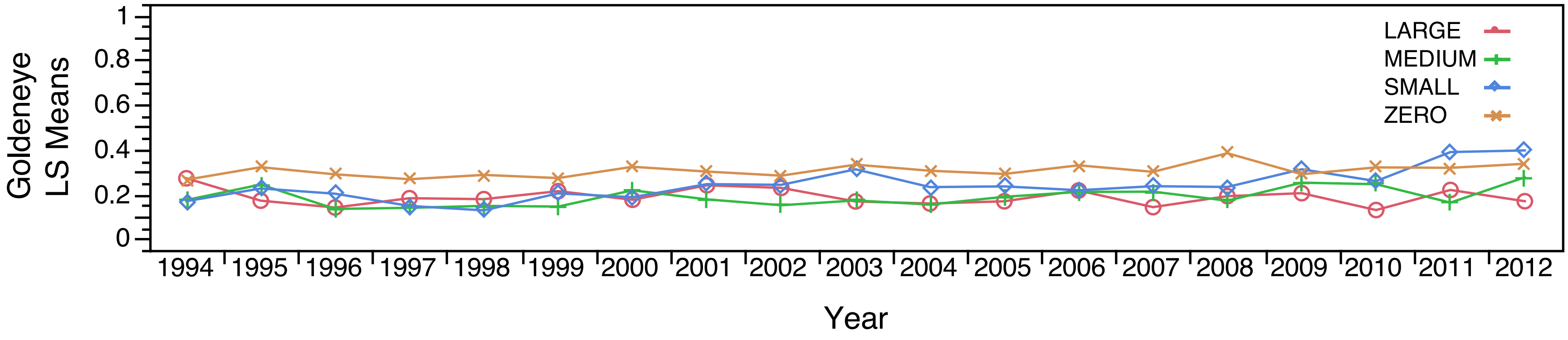

Figure 16. Sample means of Goldeneye species (COGO, BAGO, UNGO) winter relative abundance in South Puget Sound by study sites defined as large (open red circle), medium (green plus), small (blue diamond) and zero (brown x) aquaculture acreage size classes Non-significant interaction calculated using REML based repeated measured analysis testing for acreage class*year (p=0.6210).

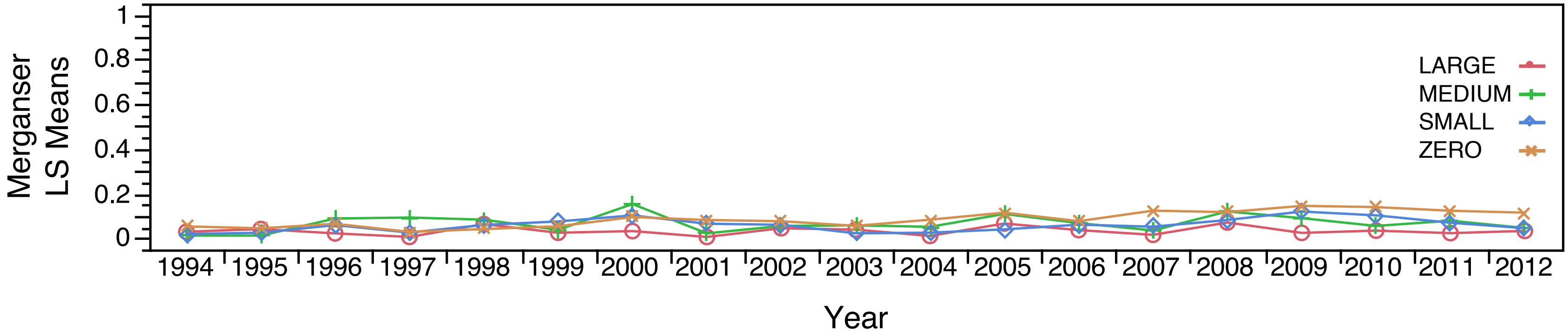

Figure 17. Sample means plot depicting non-significant interaction effect of aquaculture by year on Merganser species group (COME, HOME, RBME, UNME) relative abundance of winter populations in South Puget Sound. Levels of aquaculture acreage defined as large (open red circle), medium (green plus), small (blue diamond) and zero (brown x) aquaculture acreage size classes. F(54,3327)=0.82, p=0.8214.

Table 10. Standard least squares REML results of fixed effects analyzing Buffhead winter relative abundances in South Puget Sound from 1994 to 2012.

Source	Nparm	DF	DFDen	F Ratio	Prob > F
Acreage Class	3	3	309	5.1104	0.0018
Year	18	18	3279	4.6693	<.0001
Acreage Class*Year	54	54	3283	1.5853	0.0043

Table 11. Tukey HSD crosstab report for interaction effect of aquaculture acreage size on Bufflehead winter relative abundance in South Puget Sound averaged over 1994-2012. Levels not connected by the same letter are significantly difference (p<0.05).

Level			Least Sq Mean	Std Error
LARGE	A		0.39263543	0.03425058
MEDIUM	A	B	0.30085448	0.02492296
SMALL		B	0.28431502	0.02284394
ZERO		B	0.25549815	0.01255311

Table 12. Standard least squares REML variance component estimates measuring Bufflehead winter relative abundance across 189 study sites in South Puget Sound.

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
Site[Acreage Class]	0.5028	0.02065	0.00212	0.01650	0.02481	33.46
Residual		0.04107	0.00102	0.03914	0.04316	66.54
Total		0.06173	0.00231	0.05743	0.06654	100

Table 13. Standard least squares REML variance component estimates measuring Scoter species (BLSC, SUSC, WWSC, UNSC) winter relative abundance across 189 study sites in South Puget Sound.

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
Site[Acreage Class]	0.4399	0.02388	0.00249	0.01900	0.02877	30.553
Residual		0.05429	0.00135	0.05173	0.05705	69.447
Total		0.07818	0.00278	0.07300	0.08394	100

Table 14. Standard least squares REML variance component estimates measuring Goldeneye species (COGO, BAGO, UNGO) winter relative abundance across 189 study sites in South Puget Sound.

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
Site[Acreage Class]	0.33448	0.01575	0.00168	0.01244	0.01905	25.065
Residual		0.04709	0.00117	0.04487	0.04947	74.935
Total		0.06284	0.00201	0.05907	0.06698	100

Table 15. Standard least squares REML variance component estimates measuring Merganser species (COME, HOME, RBME, UNME) winter relative abundance across 189 study sites in South Puget Sound.

Random Effect	Var Ratio	Var Component	Std Error	95% Lower	95% Upper	Pct of Total
Site[Acreage Class]	0.2091	0.00478	0.00055	0.00363	0.00587	17.299
Residual		0.02286	0.00056	0.02179	0.02402	82.701
Total		0.02764	0.00077	0.02619	0.02923	100

Table. 1. Nine species common in Puget Sound, including WDFW species code, feeding characteristics (Rice 2007) and abundance in and dependence on marine environment (Gaydos and Pearson 2011). O = omnivore; C = carnivore, R = rare, M = medium, H = high.

Scientific Name	Common Name	Species Code	Diet	Primary Food	Feeding Behavior	Winter	Spring	Summer	Fall	Marine habitat	Marine derived food
Bucephala albeola	Bufflehead	BUFF	O	Invertebrate	Surface Dive	H	H	R	H	H	H
Bucephala clangula	Common Goldneye	COGO	O	Invertebrate	Surface Dive	H	H	R	H	H	H
Bucephala islandica	Barrows Goldeneye	BAGO	O	Invertebrate	Surface Dive	H	H	R	H	H	H
Lophodytes cucullatus	Hooded Merganser	HOME	C	Fish	Surface Dive	M	M	R	M	M	M
Melanitta fusca	White-winged scoter	WWSC	C	Invertebrate	Dive	H	H	H	H	H	H
Melanitta nigra	Black Scoter	BLSC	O	Invertebrate	Surface Dive	M	M	R	M	M	M
Melanitta perspicillata	Surf Scoter	SUSC	C	Invertebrate	Surface Dive	H	H	H	H	H	H
Mergus merganser	Common Merganser	COME	C	Fish	Surface Dive	M	M	R	M	M	M
Mergus serrator	Red-breasted Merganser	RBME	C	Fish	Surface Dive	H	H	R	H	M	H
	Unidentified Goldeneye	UNDD	O	Invertebrate	Surface Dive						
	Unidentified Merganser	UNME	O	Fish	Surface Dive						
	Unidentified Scoter	UNSC	O	Invertebrate	Dive						