AN ABSTRACT OF THE THESIS OF

Amy J. Lindsley for the degree of Master of Science in Fisheries Science presented on June 10, 2016

Title: Juvenile Rockfish (*Sebastes* spp.) Community Composition and Habitat use of Yaquina Bay, Oregon

Abstract approved:

Scott A. Heppell

Estuaries, which provide viable habitat for a plethora of fish and invertebrate species, are being increasingly impacted by anthropogenic and natural forces. Estuaries are important nursery habitat for young-of-the-year (YOY) Pacific rockfish (*Sebastes* spp.). Yaquina Bay, a marine-dominated estuary on the central Oregon Coast, served as a study site for the estuarine use of juvenile rockfishes, and large numbers of juvenile rockfish have been captured in this bay.

Nursery habitats must provide rearing habitat, adequate food resources and refuge. A vital but lacking connection in our understanding of estuaries as nursery habitat is how rockfishes use the different microhabitats within an estuarine ecosystem. As habitats structure biotic communities, determining the ecological requirements for juvenile rockfish habitats that minimize mortality, maximize growth and increase population numbers will assist managers and biologists in managing and protecting critical high-quality nursery areas.

This study provides insight into Oregon rockfish life history, evaluating the spatial and temporal use of estuarine nursery habitat by juvenile rockfishes. The primary objectives were to (1) determine which species of rockfish utilize Yaquina Bay, (2) determine seasonal variations in abundance, and (3) assess the utilization of natural (eelgrass beds, *Zostera marina*) versus anthropogenic (piers) estuarine habitat. I

conducted a mark-recapture study of juvenile rockfishes to begin to elucidate how these species may be using different habitats in the bay.

This study provides evidence for the presence of previously undocumented rockfish species, the overwinter persistence of juvenile rockfish in the estuary, some degree of site fidelity, and apparent minimal movement of juvenile rockfish in the Yaquina Bay estuary during the period of this study, as well as a shift in rockfish community dominance from *S. melanops* to *S. maliger* and *S. caurinus*. The survival and recapture of juveniles in both natural (*Z. marina*) and anthropogenic (piers) habitat demonstrates rockfishes' successful use of multiple Yaquina Bay habitat types as nursery grounds year-round. There is seasonal variability in rockfish use of the anthropogenic and natural habitat, with the anthropogenic habitats having an overall higher capture rate and a higher occurrence of larger rockfish. All eight species *S. melanops*, *S. maliger*, *S. caurinus*, *S. paucispinis*, *S. flavidus*, *S. nebulosus*, *S. pinniger* and *S. auriculatus* are present in the natural, *Z. marina* habitat. *Sebastes pinniger* and *S. auriculatus* are absent from anthropogenic, pier habitat.

The implications of determining habitat parameters, community interactions, seasonal changes of the fish community, and ecosystem mechanisms may be invaluable to support further recreational and commercial fishing and help sustain or increase adult populations. My findings present a significant contribution towards the proper management and conservation of essential habitat for rockfish, a group of species with high commercial value and substantial recreational harvest.

Juvenile Rockfish (*Sebastes* spp.) Community Composition and Habitat use of Yaquina Bay, Oregon

by
Amy J. Lindsley

A THESIS

Submitted to

Oregon State University

In partial fulfillment of
the requirements for the
degree of

Master of Science

Presented June 10, 2016
Commencement June 2017

Master of Science thesis of Amy J. Lindsley presented on June 10, 2016.

APPROVED:

Major Professor, representing Fisheries Science

Head of the Department of Fisheries and Wildlife

Dean of the Graduate School

I understand that my thesis will become part of the permanent collection of Oregon State University libraries. My signature below authorizes release of my thesis to any reader upon request.

Amy J. Lindsley, Author

ACKNOWLEDGEMENTS

This thesis would not have been possible if not for the numerous volunteers who assisted with the field work, including field assistants Christina Bailey, Kat Rector-Gilles, and Josh Etherton. Thank you for your hard work and great attitudes. I would like to acknowledge and thank my advisor, Scott Heppell for his time. A sincere thanks to Jim Power for his guidance, input and involvement. Thank you to my committee Jessica Miller and Ric Brodeur for their guidance, edits, and time. To all those friends I have made who have made this journey quite an adventure, I thank you all. To Loomis, who was there in the field by my side, who supports me in work and in play and kept me sane, I thank you kindly and forever.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

LIST OF TABLES

DEDICATION

This work is dedicated to my mother, for all the support she provides me, as she is always and forever with me. Also to my daughter, Samara Lindsley Loomis, may her escapades in life far exceed the adventures of my own journey.

Juvenile Rockfish (*Sebastes* spp.) Community Composition and Habitat use of Yaquina Bay, Oregon

CHAPTER 1: INTRODUCTION

General Background

As climate change and anthropogenic activities continue to alter ecosystems, the species that inhabit those ecosystems are often negatively impacted. Alterations to habitats are increasing as we encroach further into previously unaltered areas, creating new challenges with which species inhabiting those areas must contend. In many ecosystems, geographic ranges of species are also shifting, causing continuous fluctuations in species assemblages (Gibson-Reinemer and Rahel 2015) and a more fluid biodiversity structure. Estuaries, which provide viable habitat for a plethora of fish, invertebrate and vertebrate species, are particularly vulnerable, being increasingly impacted by anthropogenic and natural forces (Lalli and Parsons 1997; Lellis-Dibble 2008).

The rockfishes of the Pacific Coast

There are more than 70 species of rockfishes (Scorpaenidae: Sebastinae) described for the West Coast of the United States (Love *et al.* 2002), with new species still being discovered (Frable *et al.* 2015). Rockfishes are a diverse group of fishes with varied habitat requirements. They are viviparous, iteroparous fishes with many species being long-lived and deep-dwelling. Like many other marine species, rockfishes undergo ontogenetic shifts in which they utilize different habitats during their larval and juvenile life stages and then migrate to their adult habitat. Parturition (larval extrusion) usually occurs during seasons of highest ocean productivity for most species although the areas of parturition are unknown for both winter and spring spawning species (Love *et al.* 2002). For a variable period of time post-parturition, most rockfishes can be found in the upper mixed zone of the ocean (Larson *et al.* 1994). Pelagic larval duration varies, but likely lasts from 3-6 months (Love *et al.* 2002). Beginning in mid to late spring and early summer, pelagic juveniles recruit to shallower coastal habitats (Lomeli 2009) when they are at least 20 mm in length (Larson *et al.* 1994). The recruitment process of moving towards nearshore habitats may be an active one (Larson *et al*. 1994). Young-of-the-year

(YOY) rockfish are common in nearshore rocky reefs, kelp beds (Love *et al.* 2002) and within estuaries in the benthic environment (Gallagher and Heppell 2010; Dauble *et al.* 2012), then move progressively to deeper habitats as they mature (Love *et al.* 2002).

There are numerous variables which may affect recruitment, including abiotic factors, food resources, predation, and interactions among these factors (Miller *et* al. 1991; Baltz and Jones 2003; Ralston 2013). Recruitment can generally be defined as "the number of individuals that reach a specified stage of the life cycle" (Jennings *et al.* 2001); for the purpose of this paper, recruitment refers to the number of juveniles settling into nursery habitats. Rockfish recruitment is highly variable (Dauble *et al.* 2012). However there is an overall lack of biological data on the juvenile life history stages (Love *et al.* 2002) and recruitment of rockfishes (Love *et al.* 1991; Laidig *et al.* 2007).

In the Pacific Northwest rockfish are a focus of increased management efforts due to past fishing pressure and the creation of Rockfish Conservation Areas (RCAs). Rockfishes are a significant portion of the volume and value of regional recreational and commercial fisheries (Ralston *et al.* 2013), but reduced population sizes (Parker *et al.* 2000; Dauble *et al.* 2012) have been cause for concern and led to the declaration of the West Coast groundfish disaster of 2000 (TNC 2008). Commercial rockfish harvest began in the mid-1800s in California (TNC 2008) and by the 1940s commercial harvest occurred along much of the northwest coast (Lenarz 1987). The *Sebastes* complex was the single largest source of revenue in the groundfish fishery during the 1980s and 1990s, with rockfish landings peaking in 1983. Many rockfish stocks were at historically low levels (Laidig *et al.* 2007) and seven species were declared overfished by the National Marine Fisheries Service (USOFR 2013), including canary (*Sebastes pinniger*), yelloweye (*S. ruberrimus*), darkblotched (*S. crameri*), and widow rockfishes (*S. entomelas*), Pacific Ocean perch (*S. alutus*), bocaccio (*S. paucispinis*) and cowcod (*S. levis*) (TNC 2008). In 2002, the Pacific Fisheries Management Council (PFMC) enacted fishing area closures in California, Oregon and Washington in the form of RCAs. These RCAs were implemented as a method to mitigate the effect of fishing on marine ecosystems (Lotterhos *et al.* 2014). In 2010, the Puget Sound/Georgia Basin *S.*

paucispinis were listed as endangered, and *S. pinniger* and *S. ruberrimus* were listed as threatened (USOFR 2010). In 2015, *S. pinniger* was declared rebuilt (PFMC 2015).

Nurseries for fish

The term “nursery” has a variety of definitions, but one feature consistent to all designations is the reference to juvenile habitat. The quality and not just the quantity of nursery habitat, which must provide rearing habitat, adequate food resources and refuge, is critical to a species’ survival (Fuiman and Werner 2002). Estuaries provide nursery habitat for many species, especially marine fish, and therefore the health of the estuaries is important to the health of our fish and fisheries (Lellis-Dibble 2008). As there are few estuaries in Oregon, the majority of which only encompass a small area (160,000 acres (Good 2000)), the threats and encroachment upon them will be intense.

Nursery habitat for fish can be defined as areas where: (a) juvenile fish are present at higher densities, avoid predation more effectively, and grow more rapidly (Beck *et al.* 2001); (b) a greater proportion of individuals contribute to the adult population on a per-unit-basis (Dahlgren *et al.* 2006); or (c) survival and growth rates are higher, with more juveniles reaching the adult stage (Heck *et al.* 2003). In many parts of the world estuaries and seagrass beds are important nursery areas for juvenile and sub-adult stages of recreationally and commercially important fishes (Pollard 1984). In the U.S., commercially and recreationally fished estuarine-dependent species reached historically low levels in the 1990s (Chambers 1992) and even so, from 2000-2004, estuary-dependent species accounted for 46% by weight and 68% by value, of the U.S. commercial fishery landings and approximately 80% of recreational landings (Lellis-Dibble 2008).

Some nursery areas have been designated as essential fish habitat (EFH), because of their substantial positive effects on recruitment and fishery production (Rooper *et al.* 2012). EFH is defined as “those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity” by the 1996 amendments to the Magnuson-Stevens Fishery Conservation and Management Act (USOFR 2006). If we wish to maintain sustainable fisheries and healthy fish populations, then it is imperative that these high-quality nursery habitats be identified, conserved and managed. This study evaluates the spatial and temporal use of estuarine nursery habitat by juvenile rockfishes (*Sebastes* spp.) in order to increase the limited knowledge we have concerning juvenile rockfish, while evaluating the role of estuaries as their nursery habitat. In regards to this study, juvenile rockfish “nursery habitat” refers to the habitat used by post-settlement stage fish in their first year of life.

Estuaries as nursery grounds

The concept of estuaries as nursery habitat was first applied to blue crab over a century ago (Hay 1905). Estuaries provide habitat for numerous resident and transient species and are important in early life history phases of many freshwater, diadromous and marine species (Staples 1980; Boehlert and Mundy 1988; Beck *et al.* 2001; Dahlgren *et al.* 2006). Individuals from at least 28 different families have been found in Oregon estuaries (Table 1.1).

Table 1.1. The twenty-eight families of fish that have been found in Oregon estuaries. Data from Pearcy and Myers 1974; Appy and Collson 2000; Miller and Shanks 2004; Schlosser and Bloeser 2006.

Families in Oregon Estuaries			
Acipenseridae	Clupeidae	Hexagrammidae	Pleuronectidae
Agonidae	Cottidae	Ictaluridae	Salmonidae
Ammodytidae	Embiotocidae	Liparidae	Scorpaenidae
Anarhichadidae	Gadidae	Osmeridae	Sebastidae
Atherinopsidae	Gasterosteidae	Paralichthyidae	Soleidae
Aulorhynchidae	Gobiesocidae	Petromyzontidae	Stichaeidae
Bothidae	Gobiidae	Pholidae	Syngnathidae

These studies indicate that estuaries and bays are viable habitat for a plethora of species, and it has been established that estuaries are viable nursery habitat for YOY Pacific rockfish (Gallagher and Heppell 2010; Dauble *et al.* 2012).

Yaquina Bay

Yaquina Bay is a 15.82 km^2 (Pearcy and Myers 1974) marine-dominated estuary with mixed, semi-diurnal tides. Although there is little natural rocky structure, jetties, docks and riprap are present. In addition to extensive mudflats and established eelgrass (*Zostera* spp.) beds. In Yaquina Bay large numbers of fish are present with a diverse composition of species (Table 1.2) (Appy and Collson 2000), many of which use the bay as nursery habitat (Westrheim 1955; De Ben *et al.* 1990).

Table 1.2. History of studies conducted in Yaquina Bay on estuarine fishes and their use of the estuary as nursery habitat. (Rockfish complexes*: WEVZ (*S. wilsoni/ emphaeus/ variegatus/ zacentrus*) and MFS (*S. melanops/ flavidus serranoides*)).

Year	**Sampling Technique**	**Species**	**Families**	**Identified Nursery Habitat**	**Personnel**
1951-53	Otter trawl	Substantial numbers of English sole, Pacific sanddab & starry flounder		English sole, sanddab & starry flounder	Westrheim 1955
1967-68	Trawl	62 species of fish & epibenthic crustaceans. Most abundant- English sole	31 families of fish & crustaceans. Embiotocidae most represented.		DeBen *et al.* 1990
1970's	Trawl & Seine	Most dominant- English sole, surf smelt & speckled sanddab		Pacific staghorn sculpin, English sole, surf smelt & speckled sanddab	Johnson (*In* Pearcy and Myers 1974)
1975-76	Seine	32 species. Most dominant- shiner perch, English sole, Pacific staghorn sculpin & surf smelt		Black & copper rockfish	Bayer 1981
1998-2000	Trawl	Dungeness crab	Cancridae	Dungeness crab	Armstrong *et al.* 2003
2000	Minnow trap & Seine	38 species. Most dominant- Shiner surfperch		Black & copper rockfish	Appy and Collson 2000
2003-05	Traps	Black, copper and grass rockfish, kelp greenling & cabezon			Schlosser and Bloeser 2006
2003-05	Trawl	30 species. Most dominant- English sole	Percidae & Cottidae most represented		Heppell *et al. In review*
2008-09	Diving & Minnow trap	17 species. Most dominant- rockfish, kelp greenling, unidentified sculpins & saddleback gunnel		Black, copper, WEVZ* & MFS* complex rockfish	Dauble 2010
2004-05	Diving & Minnow trap			Black & yellowtail rockfish	Gallagher and Heppell 2010

Estuaries along the Oregon coast, including Yaquina Bay, should be recognized as EFH for juvenile *S. melanops* and perhaps other *Sebastes* spp. (Gallagher and Heppell 2010). This designation is important as this habitat plays a significant role in rockfishes' life cycles and for conservation of the species that inhabit them. The quality and quantity of available habitat may play a substantial role in population dynamics including predation, growth, and competition (Gallagher and Heppell 2010).

Eelgrass as essential biogenic habitat

Seagrasses are inter- or sub-tidal flowering vascular plants that are established in marine and estuarine waters and grow in large meadows or beds; the majority of species occur in shallow and sheltered coastal waters. Seagrass meadows support highly diverse and productive systems and provide significant ecosystems services, including physical habitat for thousands of bird, invertebrate and fish species, predation refuge, sediment stabilization and nutrient cycling (Valentine and Duffy 2006; Waycott *et al.* 2009). They are used as resident and/or transient habitats by various higher-trophic level consumers (Yamada *et al.* 2010) and have been identified as nursery habitat for fishes (Beck *et al.* 2001; Heck *et al.* 2003). They are among the most threatened ecosystems on earth, with accelerating rates of decline worldwide (Duarte 2002), losing 7% of their identified area per year (IUCN 2014).

Eelgrass, a particular variety of seagrass, is an ecosystem engineer (Ferraro and Cole 2012) that creates physical structure while increasing primary and secondary production, community biomass, and diversity (Beck *et al.* 2001; Duffy 2006). Eelgrass grows on muddy and sandy bottoms in low-current, sheltered water (Matthews 1989) and forms patchy cover throughout many estuaries. *Zostera marina*, a species native to the eastern Pacific, is found in subtidal nearshore and intertidal waters and ranges from the Gulf of California to the northern Bering Sea. Eelgrass systems, like all seagrasses, have high biodiversity (Murphy *et al.* 2000) and support high levels of fish species richness (Pollard 1984). They serve as nurseries for fish (Adams 1976), including YOY and juvenile rockfish (Bayer 1981; Love *et al.* 1991; Matthews 1989; Appy and Collson 2000; Murphy *et al.* 2000). In Oregon’s Yaquina Bay, more species (17-413 mm total length (TL)) and were collected in the eelgrass than in the upper intertidal throughout the year, with peak diversity in July and August (Table 1.2) (Bayer 1981).

Yaquina Bay and juvenile rockfish

Large numbers of juvenile rockfish have been captured in Yaquina Bay, with *S. melanops* reported as the most abundant rockfish (Schlosser and Bloeser 2006) and the sixth most abundant fish overall in the estuary (Appy and Collson 2000). Similarly, Gallagher and Heppell (2010) had catches dominated by *S. melanops*, with the highest densities around anthropogenic structures such as docks and jetties. Dauble and colleagues (2012) investigated the role that natural and anthropogenic influences play in estuarine settlement dynamics, and found Yaquina Bay was a nursery for *S. melanops*, *S. caurinus* and species from the WEVZ (*S. wilsoni/ emphaeus/ variegatus/ zacentrus*) complex, and the MFS complex (*S. melanops/ flavidus serranoides*). In addition, juvenile yellowtail rockfish (*S. flavidus*) specifically identified, grass rockfish (*S. rastrelliger*) and other unidentified rockfishes have been detected (Table 1.2) (Appy and Collson 2000; Schlosser and Bloeser 2006; Gallagher and Heppell 2010; Dauble *et al.* 2012). Juvenile rockfish likely remain in Yaquina Bay through their first winter, as probable age-1 juveniles were captured in early May (Dauble 2010).

In addition to the capture of rockfishes around artificial structures, thirty-two species of fish, including *S. melanops*, were captured from April through September in Yaquina Bay eelgrass beds (Bayer 1981). Other studies had rockfish captures in eelgrass beds beginning in June with numbers peaking in July and then decreasing through August (Appy and Collson 2000). These studies illustrate that eelgrass is suitable habitat for YOY and juvenile rockfish; one of the foci for my study is on *Z. marina* habitat as the reference nursery habitat for juvenile rockfishes, in comparison to how anthropogenic habitats may serve that purpose.

Ontogenetic shifts

Juvenile fish have a greater need for shelter and therefore have more specialized habitat requirements than older fish (Anderson *et al.* 1989). As such, many species utilize nursery areas and subsequently migrate to other habitats as their needs change; these movements are termed ontogenetic shifts (Anderson *et al.* 1989; Love *et al*. 1991; Dahlgren and Eggleston 2000). Many species present in seagrass nursery areas as juveniles relocate to other habitats at a certain length, as the seagrass may no longer provide adequate shelter (Pollard 1984) or foraging opportunities. As the transition between habitats occurs, different elements may affect the cohort: new predators, competitors, and alterations in available resources (Love *et al.* 1991). How juveniles select a habitat and how they use existing habitats, which affects the distribution of the recruits, has not been determined (Nelson 2001) but descriptions characterizing the types of habitats used during each life-history stage are necessary in order to evaluate the importance of habitat features to population success (Matthews 1989), demography and connectivity to adult habitats (Gillanders *et al.* 2003).

Movement of rockfishes in estuaries

A vital but lacking connection in our understanding of estuaries as nursery habitat is the movement patterns of fishes (Beck *et al.* 2001), and in particular how fish may use different habitats for different purposes. Migration from one habitat to another occurs in many species, due to changes of season, growth and development (Kamimura and Shoji 2013). For my research I investigated three primary types of movement in the rockfishes of Yaquina Bay: ontogenetic, relocation, and seasonal (Love *et al.* 1991). Ontogenetic movement is size or age-related and relocation is movement of similar-sized individuals amongst habitats. Size-related movement is common across depths as most juvenile *Sebastes* spp. recruit to shallower habitat than the typical adult habitat. Seasonal movement has been related to changes in water turbulence and temperature, as with the arrival of fall and winter storms, juveniles appear to move to deeper reefs for more protected waters (Love *et al.* 1991). As part of this project I conducted a mark-recapture study of juvenile rockfishes to begin to elucidate how those species may be using different habitats in the bay.

Species assemblages

The Yaquina Bay ecosystem is composed of a diverse, dynamic community of juvenile and small-bodied fish species fish. There are resident fishes as well as seasonal resident (or life history stage users), transient (occur in the course of foraging over a variety of habitats) and casual (fish that appear only occasionally) users of the estuary (Bell and Pollard 1989). The amount and type of habitat/structure in Yaquina Bay influences species assemblages, distribution and abundance. Alterations in habitat may change the distribution of species, and a change in single species' distribution may result in significant community shifts. The implications of determining habitat parameters, community interactions, seasonal changes of the fish community, and ecosystem mechanisms may be invaluable to support further recreational and commercial fishing and help sustain or increase adult populations.

Summary

Previous research has demonstrated that (1) Yaquina Bay is nursery habitat for juvenile rockfishes (Appy and Collson 2000; Schlosser and Bloeser 2006; Gallagher and Heppell 2010; Dauble *et al.* 2012); (2) anthropogenic structures are associated with higher rockfish density (Gallagher and Heppell 2010; Dauble *et al.* 2012); and (3) rockfishes in Yaquina Bay use eelgrass as habitat in the first year of their life (Bayer 1981; Appy and Collson 2000) and (4) Yaquina Bay estuary may provide habitat through the first year of life and perhaps longer (Dauble 2010). However, the detailed habitat use patterns by YOY and juvenile rockfishes among habitats within Yaquina Bay remain uncharacterized, as does the long-term residence time of these fish in the estuary.

The overarching goal of this study was to investigate the use of Yaquina Bay as a nursery by YOY and juvenile rockfishes. The primary objectives were to (1) determine which species of rockfish utilize Yaquina Bay as nursery habitat; (2) determine seasonal variations in juvenile rockfish abundance; (3) assess the use of natural versus anthropogenic estuarine habitat by juvenile rockfishes; and (4) elucidate juvenile rockfish spatio-temporal distribution in Yaquina Bay nursery habitat. The implications of determining habitat parameters, community interactions, seasonal changes of the fish community, and ecosystem mechanisms may be invaluable to support further recreational and commercial fishing and help sustain or increase adult populations. My findings present a significant contribution towards the proper management and conservation of essential habitat for rockfish, a group of species with high commercial value and substantial recreational harvest. This information will assist in the recognition of critical fish habitat and has the potential to protect and restore this habitat.

Literature Cited

Adams, S.M. 1976. Feeding ecology of eelgrass fish communities. Transactions of American Fisheries Society 4:514-519.

Anderson, T.W., E.E. DeMartini and D.A. Roberts. 1989. The relationship between habitat structure, body size, and distribution of fishes at a temperate artificial reef. Bulletin of Marine Science 44:681-697.

Appy, M. and P.J. Collson. 2000. Oregon coastal juvenile rockfish study (Draft). Estuarine Habitat, Marine Resources Division. Oregon Department of Fish and Wildlife.

Baltz, D.M. and R.F. Jones. 2003. Temporal and spatial patterns of microhabitat use by fishes and decapod crustaceans in a Louisiana estuary. Transactions of the American Fisheries Society 132(4):662-678.

Bayer, R.D. 1981. Shallow-water intertidal ichthyofauna of the Yaquina Estuary, Oregon. Northwest Science Vol. 55(3):182-193.

Beck, M.W., K.L. Heck Jr., K.W. Able, D.L. Childers, K. Hoshine, D.B. Eggleston, B.M. Gillanders, B. Halpern, C.G. Hays, K. Hoshine, T.J. Minello, R.J. Orth, P.F. Sheridan, and M.P. Weinstein. 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. BioScience 51(8):633-641.

Bell, J.D. and D.A. Pollard. 1989. Ecology of fish assemblages and fisheries associated with seagrassess. *In:* A.W.D. Larkum, A.J. MacComb and S.A. Shepard (eds.) Biology of Seagrasses: A Treatise on the biology of seagrasses with special reference to the Australian region. Elsevier Science Limited, California. 565-609 pp.

Boehlert, G.W. and B.C. Mundy. 1988. Roles of behavioral and physical factors in larval and juvenile fish recruitment to estuarine nursery area. American Fisheries Society Symposium 3:51-67.

Chambers, J.R. 1992. Coastal degradation and fish population losses. *In* Stroud, R.H. (Ed.), Stemming the ride of coastal fish habitat loss. Marine Recreational Fish Symposium. Proceedings of the National Symposium on Fish Habitat Conservation. Baltimore, MD. pp. 45-51.

Dauble, A.D. 2010. Young-of-the-year rockfish (*Sebastes* spp.) settlement dynamics in Oregon estuaries. MS thesis. Oregon State University, Corvallis, Oregon.

Dauble, A.D., S.A. Heppell, and M.L. Johansson. 2012. Settlement patterns of young-of-the-year rockfish among six Oregon estuaries experiencing different levels of human development. Marine and Ecology Progress Series Vol. 448:143-154.

Dahlgren, C.P. and D.B. Eggleston. 2000. Ecological processes underlying ontogenetic habitat shifts in a coral reef fish. Ecology 81(8):2227-2240.

Dahlgren, C.P., G.T. Kellison, A.J. Adams, B.M. Gillanders, M.S. Kendall, C.A. Layman, J.A. Ley, I. Nagelkerken, and J.E. Serafy. 2006. Marine nurseries and effective juvenile habitats: concepts and applications. Marine Ecology Progress Series 321:291-295.

De Ben, W.A., W.D. Clothier, G.R. Ditsworth, and D.J. Baumgartner. 1990. Spatio-temporal fluctuations in the distribution and abundance of demersal fish and epibenthic crustaceans in Yaquina Bay, Oregon. Estuaries 13(4):469-478.

Duarte, C.M. 2002. The future of seagrass meadows. Environmental Conservation 29(2):192-206.

Duffy, J.E. 2006. Biodiversity and the functioning of seagrass ecosystems. Marine Ecology Progress Series 311:233-250.

Ferraro, S.P. and F.A. Cole. 2012. Ecological periodic tables for benthic macrofaunal usage of estuarine habitats: Insights from a cast study in Tillamook Bay, Oregon, USA. Estuarine, Coastal and Shelf Science 102-103:70-83.

Frable, B.W., D.W. Wagman, T.N. Frierson, A. Aguilar, and B.L. Sidlauskas. 2015. A new species of *Sebastes* (Scorpaeniformes: Sebastidae) from the northeastern Pacific, with a redescription of the blue rockfish, *S. mystinus* (Jordan and Gilbert, 1881). Fishery Bulletin 113(4): 355-378.

Fuiman, L.A. and R.G. Werner (eds.). 2002. Fishery Science: The unique contributions of early life stages. Blackwell Science, Oxford. 326 pp.

Gallagher, M.B. and S.S. Heppell. 2010. Essential habitat identification for age-0 rockfish along the central Oregon Coast. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 2:60-72.

Gibson-Reinemer, D.K. and F.J. Rahel. 2015. Inconsistent range shifts within species highlight idiosyncratic responses to climate warming. PLOS ONE 10(7). DOI:10.1371/journal.pone.0132103.

Gillanders, B.M., K.W. Able, J.A. Brown, D.B. Eggleston and P.F. Sheridan. 2003. Evidence of connectivity between juvenile and adult mobile marine fauna: an important component of nurseries. Marine Ecology Progress Series 247:281-295.

Good, J.W. 2000. Summary and current status of Oregon's estuarine ecosystems. *In* The Oregon State of the Environment Report 2000. Oregon Progress Board, Salem, Oregon.

Hay, W.P. 1905. The Life History of the Blue Crab, *Callinectes sapidus*. U.S. Bureau of Fisheries. Washington, DC.

Heck, K.L., G. Hays, and R.J. Orth. 2003. Critical evaluation of the nursery role hypothesis for seagrass meadows. Marine Ecology Progress Series 253:123-136.

IUCN (International Union for Conservation of Nature). 2014. Seagrass habitat declining globally. The IUCN Red List of Threatened Species. Available: http://www.iucnredlist.org/news/seagrass-habitat-declining-globally. (June 23, 2015).

Jennings, S., M.J. Kaiser, and J.D. Reynolds. 20001. Marine Fisheries Ecology. Blackwell Publishing. Malden, MA. 417 pp.

Kamimura, Y. and J. Shoji. 2013. Does macroalgal vegetation cover influence post-settlement survival and recruitment potential of juvenile black rockfish *Sebastes chenii*? Estuarine, Coastal and Shelf Science 129:86-93.

Laidig, T.E., J.R. Chess, and D.F. Howard. 2007. Relationship between abundance of juvenile rockfishes (*Sebastes* spp.) and environmental variables documented off northern California and potential mechanisms for the covariation. Fisheries Bulletin 105:39-48.

Lalli, C.M. and T.R. Parsons. 1997. Biological Oceanography: An Introduction. Butterworth-Heinemann, Oxford. 314 pp.

Larson, R.J., W.H. Lenarz, and S. Ralston. 1994. The distribution of pelagic juvenile rockfish of the genus *Sebastes* in the upwelling region off central California. California Cooperative Oceanic Fisheries Investigations Report 35:175-221.

Lenarz, W.H. 1987. A history of California rockfish fisheries. Pages 35-42 *in* Proceedings of the International Rockfish Symposium. Alaska Sea Grant Report 87-2, Anchorage.

Lellis-Dibble, K.A., K.E. McGlynn and T.E. Bigford. 2008. Estuarine fish and shellfish species in U.S. commercial and recreational fisheries: economic value as an incentive to protect and restore estuarine habitat. National Marine Fisheries Service. National Oceanic and Atmospheric Administration Technical Memorandum NMFS-F/SPO-90.

Lomeli, M.J.M. 2009. The movement and growth patterns of young-of-the-year black rockfish, (*Sebastes melanops*) inhabiting two rocky intertidal areas off Northern California. MS thesis. Humboldt State University, Arcata, California.

Lotterhos, K.E., S.J. Dick and D.R. Haggarty. 2014. Evaluation of rockfish conservation area networks in the United States and Canada relative to the dispersal distance for black rockfish (*Sebastes melanops*). Evolutionary Applications 7:238-259.

Love, M.S., M.H. Carr, and L.J. Haldorson. 1991. The ecology of substrate-associated juveniles of the genus *Sebastes.* Environmental Biology of Fishes 30:225-243.

Love, M.S., M. Yoklavich, and L. Thorsteinson. 2002. The rockfishes of the northeast Pacific. University of California Press, Berkeley and Los Angeles, California. 405 pp.

Matthews, K.R. 1989. A comparative study of habitat use by young-of-the-year, subadult, and adult rockfishes on four habitat types in central Puget Sound. Fishery Bulletin 88(2):223-239.

Miller, J.A., J.S. Burke, and G.R. Fitzhugh. 1991. Early life history Patterns of Atlantic North American flatfish: likely (and unlikely) factors controlling recruitment. Netherlands Journal of Sea Research 27(3/4):261-275.

Miller, J.A. and A.L. Shanks. 2004. Ocean-estuary coupling in the Oregon upwelling region: abundance and transport of juvenile fish and of crab megalopae. Marine Ecology Progress Series 271:267-279.

Murphy, M.L., S.W. Johnson, and D.J. Csepp. 2000. A comparison of fish assemblages in eelgrass and adjacent subtidal habitats near Craig, Alaska. Alaska Fishery Research Bulletin 7:11-21.

Nelson, P.A. 2001. Behavioral ecology of young-of-the-year kelp rockfish, *Sebastes atrovirens* Jordan and Gilbert (Pices: Scorpaenidae). Journal of Experimental Marine Biology and Ecology 256:33-50.

PFMC (Pacific Fishery Management Council). 2015. Petrale sole and canary rockfish, important West Coast groundfish stocks, rebuilt to sustainable level. Groundfish. Available: http://www.pcouncil.org/2015/06/37408/petrale-sole-and-canary-rockfish-important-west-coast-groundfish-stocks-rebuild-to-sustainable-level/. (April 9, 2016.)

Parker, S.J., S.A. Berkeley, J.T. Golden, D.R. Gunderson, J. Heifetz, M.A. Hixon, R. Larson, B.M. Leaman, M.S. Love, J.A. Musick, V.M. O’Connell, S. Ralston, H.J. Weeks, and M.M. Yoklavich. 2000. Management of Pacific rockfish. Fisheries 25(3):22-30.

Pearcy, W.G. and S.S. Myers. 1974. Larval fishes of Yaquina Bay, Oregon: a nursery ground for marine fishes? Fishery Bulletin 72(1):201-213.

Pollard, D.A. 1984. A review of ecological studies on seagrass-fish communities, with particular reference to recent studies in Australia. Aquatic Botany 18:3-42.

Ralston, S., K.M. Sakuma, and J.C. Field. 2013. Interannual variation in pelagic juvenile rockfish (*Sebastes* spp.) abundance - going with the flow. Fisheries Oceanography 22(4):288-308.

Rooper, C.N., J.L. Boldt, S. Batten, and C. Gburski. 2012. Growth and production of Pacific ocean perch (*Sebastes alutus*) in nursery habitats of the Gulf of Alaska. Fisheries Oceanography 21(6):415-429.

Schlosser, S. and J. Bloeser. 2006. The collaborative study of juvenile rockfish, cabezon, and kelp greenling habitat associations between Morro Bay, California and Newport, Oregon. California Sea Grant and Pacific Marine Conservation Council Cooperative Research Project.

Staples, D.J. 1980. Ecology of juvenile and adolescent banana prawns, *Peraeus merguiensis*, in a mangrove estuary and adjacent off-shore area so the Gulf of Carpenteria. Australian Journal of Marine Freshwater Research 31:635-652.

TNC (The Nature Conservancy). 2008. History of the U.S. West Coast groundfish fishery. Available: http://www.morrobaycommunityquotafund.org/wpcontent/uploads/2012/10/CCGP_GroundfishFisheryHistory_080515-1.pdf. (June 29, 2014).

USOFR (U.S. Office of the Federal Register). 2006. Magnuson-Stevens Act Provisions, Fisheries off West Coast States, Pacific Coast Groundfish Fishery. National Oceanic and Atmospheric Administration. Federal Register 50 CFR Part 660. (docket number 051213334-6119-02; I.D. 112905C). RIN 0648-AT98.

USOFR (U.S. Office of the Federal Register). 2010. Endangered and Threatened Wildlife and Plants: Threatened Status for the Puget Sound/Georgia Basin Distinct Population Segments of Yelloweye and Canary Rockfish and Endangered Status for the Puget Sound/Georgia Basin Distinct Population Segment of Bocaccio Rockfish Code of Federal Regulations, 50 CFR Parts 223 and 224. National Marine Fisheries and National Oceanic and Atmospheric Administration, United States Department of Commerce. Vol. 75(81):22276-22290.

USOFR (U.S. Office of the Federal Register). 2013. Title 50- Wildlife and Fisheries. Chapter VI: Fishery conservation and management, Sub-part C: West coast groundfish fisheries. Code of Federal Regulations, 660.40. National Oceanic and Atmospheric Administration, United States Department of Commerce. Available: http://cfr.vlex.com/vid/overfished-species-rebuilding-plans-300048238. (accessed May 15, 2014).

Valentine, J.F. and J.E. Duffy. 2006. The central role of grazing is seagrass ecology. *In*: Larkum A.W.D, R.J. Orth, and C.M. Duarte (eds.) Seagrasses: biology, ecology and conservation. Springer, Dordrecht. p.463-501.

Waycott, M., C.M. Duarte, T.J.B. Carruthers, R.J. Orth, W.C. Dennison, S. Olyarnik, A. Calladine, J.W. Fourqurean, K.L. Heck Jr., A.R. Hughes, G.A. Kendrink, W.J. Kenworthy, F.T. Short, and S.L. Williams. 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proceeding of the National Academy of Sciences 106(30):12377-12381.

Westrheim, S.J. 1955. Size composition, growth, and seasonal abundance of juvenile English sole (*Parophrys vetulus*) in Yaquina Bay. Fish Commission of Oregon, Research Briefs 6(2):4-9.

Yamada, K., M. Hori, Y. Tanaka, N. Hasegawa, and M. Nakaoka. 2010. Contribution of different functional groups to diet of major predatory fishes at a seagrass meadow in northeastern Japan. Estuarine, Coastal and Shelf Science 86:71-82.

CHAPTER 2: JUVENILE ROCKFISH (*SEBASTES* SPP.) COMMUNITY COMPOSITION AND HABTIAT USE OF YAQUINA BAY

Introduction

Habitat quality, along with the quantity and diversity of habitat, plays a substantial role in population dynamics through effects on fish growth, competition and survival (Able 1999; Gallagher and Heppell 2010; MacNeill 2010). Determining habitat requirements of fish species is imperative for the proper management and conservation of these essential environments and to guide future ecosystem studies. Productive habitat is vital for fish to thrive and survive, and is important for overall ecosystem diversity. Alteration and loss of habitat is of particular concern because of ever increasing human impacts.

Estuaries are one of the most dynamic ecosystems in the world (Heady *et al.* 2014), providing habitat for numerous species and serving as important nursery grounds for many marine organisms (Staples 1980; Pollard 1984; Boehlert and Mundy 1988; Beck *et al.* 2001; Dahlgren *et al.* 2006). Estuaries are ecotones, a transition zone where the fresh water mixes with seawater creating some of the most biologically productive areas on Earth (Kennish 2002). Worldwide, however, estuarine habitats are in peril, with millions of acres having been lost in the last century due to both direct (development) and indirect (pollution, altered ecosystem) anthropogenic impacts (Hughes *et al.* 2014). In addition to outright loss of estuary area, many estuaries are in poor health and have degraded water quality (NOAA 2008); this can result in the loss of certain ecosystem functions (Hughes *et al.* 2014). Trends suggest that by 2025 most if not all estuaries will be significantly impacted due to increased habitat loss from anthropogenic forces as coastal human populations continue to grow (Kennish 2002). Increased habitat loss and degradation can negatively impact species vitality, therefore it is critical to identify and protect productive habitats to allow species to survive and thrive.

“Nursery areas” serve as a critical habitat component for many species (Fuiman and Werner 2002) providing vital rearing habitat, important resources, and refugee for the initial stages of life. The term “nursery” has a variety of definitions, but one feature consistent to all designations is the reference to juvenile habitat. Juvenile habitat for fish can be defined as areas where: (a) juvenile fish are present at higher densities, avoid predation more effectively, and grow more rapidly (Beck *et al.* 2001); (b) a greater proportion of individuals contribute to the adult population on a per-capita-basis (Dahlgren *et al.* 2006); or (c) survival and growth rates are higher, with more juveniles reaching the adult stage (Heck *et al.* 2003). In many parts of the world estuaries and seagrass beds are important nursery areas for juvenile and sub-adult stages for both recreationally and commercially important fishes (Pollard 1984).

Some nursery areas have been deemed essential fish habitat (EFH) ("those waters and substrate necessary to fish for spawning, breeding, feeding or growth to maturity", NOAA 2006), because of their substantial positive effects on recruitment and fishery production (Rooper *et al.* 2012). If we wish to maintain sustainable fisheries and healthy fish populations then it is imperative that these high-quality nursery habitats are identified, conserved and managed. This study evaluates the spatial and temporal use of temperate estuarine nursery habitat by juvenile rockfishes (*Sebastes* spp.) in order to increase the limited knowledge we have of the early life stages of the rockfishes, while evaluating the role of estuaries as nursery habitat. In this context juvenile rockfish "nursery habitat" refers to the habitat used by post-settlement stage rockfish in their first year of life.

Rockfish

There are more than 70 species of rockfishes (Scorpaenidae: Sebastinae) described for the West Coast of the United States (Love *et al.* 2002), with new species still being discovered (Frable *et al.* 2015). Rockfishes are a diverse group of fishes with varied habitat requirements. They are viviparous, iteroparous fishes with many species being long-lived and deep-dwelling. Like many other marine species, rockfishes undergo ontogenetic shifts in which they utilize different habitats during their larval and juvenile life stages and then migrate to their adult habitat. Parturition (larval extrusion) usually occurs during seasons of highest ocean productivity for most species although the areas of parturition are unknown for both winter and spring spawning species (Love *et al.*

2002). For a variable period of time post-parturition most rockfishes can be found in the upper mixed zone of the ocean (Larson *et al.* 1994). Pelagic larval duration varies, but likely lasts from 3-6 months (Love *et al.* 2002). Beginning in mid to late spring and early summer, pelagic juveniles recruit to shallower coastal habitats (Lomeli 2009) when they are at least 20 mm in length (Larson *et al.* 1994). The recruitment process of moving towards nearshore habitats may be an active one (Larson *et al*. 1994). Young-of-the-year (YOY) rockfish are common in nearshore rocky reefs, kelp beds (Love *et al.* 2002) and the benthos of estuaries (Gallagher and Heppell 2010; Dauble *et al.* 2012), then move progressively to deeper habitats as they mature (Love *et al.* 2002).

Many rockfishes undergo dramatic alterations in both ecology and habitat through each life stage. With each new habitat occupied the fish must orient to changing conditions, throughout their ontogenetic development (Boehlert and Mundy 1988). The distribution of mobile animals may be determined by behavioral responses to ecological processes, including changing challenges (i.e. changes in predation risk) that change with body size, which ultimately will influence population dynamics of species and the ontogenetic shifts across habitat (Dahlgren and Eggleston 2000). Many juvenile species of *Sebastes* go through coincident changes in physical conditions and trophic relationships associated with changing habitat at around 50 mm standard length (Boehlert and Yoklavich 1983).

Adult habitat requirements are largely understood for most species (McCain *et al.* 2005) but critical habitats for other life stages are largely unknown. There is a lack of biological data on the juvenile life history stages (Love *et al.* 2002) and recruitment of rockfishes (Love *et al.* 1991; Laidig *et al.* 2007). Recruitment can be defined as "the number of individuals that reach a specified stage of the life cycle" (Jennings *et al.* 2001). For this paper, recruitment refers to the number of juveniles settling into nursery habitats and, for rockfish, recruitment is highly variable (Dauble *et al.* 2012). There are numerous variables which may affect recruitment, including abiotic factors, food resources, predation, and interactions among these factors (Miller *et al.* 1991; Baltz and Jones 2003; Ralston 2013). Previous work has demonstrated that YOY rockfish utilize both nearshore/intertidal habitats and estuaries during the first summer of life (Gallagher and

Heppell 2010; Dauble *et al.* 2012). However, the broader role that estuaries play in their life history, including the importance as nursery habitat, and the influence of both anthropogenic and natural structure, have not been intensively investigated.

Rockfishes in the Pacific Northwest are a focus of increased management efforts due to past excessive fishing pressure and the creation of rockfish conservation areas (RCAs). Rockfishes are a significant portion of the volume and value of regional recreational and commercial fisheries (Ralston *et al.* 2013), but reduced population sizes (Parker *et al.* 2007; Dauble *et al.* 2012) have been cause for concern and led to the declaration of the West Coast groundfish disaster of 2000 (TNC 2008). Commercial rockfish harvest began in the mid-1800s in California (TNC 2008) and by the 1940s commercial harvest occurred along much of the northwest coast (Lenarz 1987). The *Sebastes* complex was the single largest source of revenue in the groundfish fishery during the 1980s and 1990s, with rockfish landings peaking in 1983. Several rockfish stocks are now at historically low levels (Laidig *et al.* 2007) and in the last decade seven species have been declared overfished by the National Marine Fisheries Service (USOFR 2013), including canary (*S. pinniger*), yelloweye (*S. ruberrimus*), darkblotched (*S. crameri*), and widow rockfish (*S. entomelas*), Pacific Ocean perch (*S. alutus*), bocaccio (*S. paucispinis*) and cowcod (*S. levis*) (TNC 2008). In 2002, the Pacific Fisheries Management Council (PFMC) enacted fishing area closures in California, Oregon and Washington in the form of RCAs. These RCAs were implemented as a method to mitigate the effect of fishing on marine ecosystems (Lotterhos *et al.* 2014). In 2010, the Puget Sound/Georgia Basin *S. paucispinis* were listed as endangered, and *S. pinniger* and *S. ruberrimus* were listed as threatened (USOFR 2010). In 2015, *S. pinniger* was declared rebuilt (PFMC 2015).

Estuaries as rockfish nurseries

Estuaries along the Oregon coast, including Yaquina Bay, should be recognized as EFH for juvenile black rockfish (*S. melanops*) and perhaps other *Sebastes* spp. (Gallagher and Heppell 2010). This designation is important as this habitat plays a significant role in rockfishes' life cycles and for conservation of the species that inhabit them. The quality and quantity of available habitat may play a substantial role in population dynamics including predation, growth, and competition (Gallagher and Heppell 2010).

Yaquina Bay has an abundant and diverse ichthyofauna (Appy and Collson 2000), many species of which use the bay as nursery habitat (De Ben *et al.* 1990). Studies in Yaquina Bay have captured large numbers of juvenile rockfish, with *S. melanops* traditionally being the most abundant rockfish (Appy and Collson 2000; Schlosser and Bloeser 2006; Gallagher and Heppell 2010). Schlosser and Bloeser (2006) found *S. melanops* to be the most dominant species and Appy and Collson (2000) determined it to be the sixth most abundant fish overall. Yaquina Bay was determined to be a nursery for *S. melanops*, copper rockfish (*S. caurinus*) and species from the WEVZ complex (*S. wilsoni/ emphaeus/ variegatus/ zacentrus*) and the MFS complex (*S. melanops/ flavidus/ serranoides*) (Dauble *et al.* 2012). In addition, juvenile yellowtail rockfish (*S. flavidus*) specifically identified, grass rockfish (*S. rastrelliger*) and other unidentified rockfishes have been detected (Appy and Collson 2000; Schlosser and Bloeser 2006; Gallagher and Heppell 2010; Dauble *et al.* 2012).

Seagrasses are inter- or sub-tidal flowering vascular plants in marine and estuarine waters that form large meadows or beds and provide viable habitat for many estuarine species. Seagrass meadows support highly diverse and productive systems (Waycott *et al.* 2009; Valentine and Duffy 2006) and have been identified as providing nursery habitat for a variety of species (Bayer 1981; Matthews 1989; Appy and Collson 2000; Beck *et al.* 2001). *Zostera marina*, a native species of eelgrass on the Pacific Coast, is found in subtidal nearshore and intertidal waters and ranges from the Gulf of California to the northern Bering Sea. Eelgrass systems have specifically been identified as nursery habitat for YOY and juvenile rockfish (Bayer 1981; Matthews 1989; Love *et al.* 1991; Appy and Collson 2000; Murphy *et al.* 2000).

Movement and survival

A vital but lacking connection in our understanding of estuaries as nursery habitat is the investigation of movement patterns (Beck *et al.* 2001), and in particular how fish may use different habitats for different purposes and at different times. Many species of fish utilize nursery areas and subsequently migrate to other habitats as their needs change (Anderson *et al.* 1989; Love *et al*. 1991; Dahlgren and Eggleston 2000). In the rockfishes, size-related movement is common across depths as most juvenile *Sebastes* spp. recruit to shallower habitat than the typical adult habitat (Love *et al.* 1991). A survey of habitat type, species composition and growth of juvenile rockfish in estuaries and on nearshore reefs indicated that habitat partitioning among species may occur at a very early stage of life (Gallagher and Heppell 2010). Descriptions characterizing the types of habitats used during each life-history stage are necessary in order to evaluate the importance of these habitat features to population success (Matthews 1989), as well as demography and connectivity between nursery and adult habitats (Gillanders *et al.* 2003).

The mechanisms by which YOY rockfish move to deeper, rocky habitats from shallow ones have not been identified (West *et al.* 1994). Biological or physical factors could trigger movement to deeper waters or new habitats. These factors might include changes in photoperiod, temperature, salinity, size, age, and food availability or body conditions (Boehlert 1981; Boehlert and Yoklavich 1983). Seasonal movement appears to be related to changes in turbidity and temperature (Love *et al.* 1991), and a decrease in density of rockfishes relating to increased storms in November and early December has been observed (Johnson *et al.* 2001). Substantial distances may be traveled during the ontogenetic movement to adult habitat (Love *et al.* 1991). The duration and timing of these migrations varies widely among species, some species make a series of progressive movements to deeper reefs, over a duration as long as several years (Love *et al.* 1991), while others may remain in the inshore habitat for up to 4 years (Leaman 1976). Black rockfish may take months to move from inshore juvenile habitat to adult habitat (Boehlert 1982).

I used visible implant elastomer (VIE) mark and recapture tagging techniques to characterize rockfish nursery habitat types and investigate home ranges, site fidelity, persistence and survival of rockfishes in these different habitat types. Studying movement and survival of early post-settlement stages of fishes is challenging. Fish need to be tagged and the majority of tag types available are either unsuitable for such small body sizes (e.g., passive integrated transponder (PIT) tags, external tags), or are cost prohibitive (e.g., active telemetry tags). VIE tagging, however, has been successfully used for marking small fishes in both marine and freshwater environments (Dewey and Zigler 1996; Byerly 1999; Johnson 2000; Griffiths 2002; Lomeli 2004). VIE tagging, which involves injecting a fluorescent colored liquid elastomer into the transparent tissue of the fish, thereby forming a permanent, easily read mark, is an ideal method for marking small fish to investigate growth, movement, survival, site fidelity, predation, habitat and other factors. VIE has been successfully used in tagging juvenile rockfishes (Byerly 1999; Johnson 2000; Lomeli 2004). For fish of small size, (<50 mm total length (TL)) the high tag retention rate, low mortality, and ease of identification of elastomer tags contribute to their suitability. Previous studies have demonstrated 100% VIE tag retention rates for rockfish and that mean growth rate and survivorship did not differ between tagged and non-tagged fish (Lomeli 2004). A study on juvenile bluegills showed that tagging did not affect the growth or survival and the marks were visible for at least 6 months (Dewey and Zigler 1996).

The overarching goal of this study was to investigate the habitat use of Yaquina Bay by juvenile rockfishes and determine whether YOY and juvenile rockfishes use this estuary throughout the year. The primary objectives were to (1) determine which species of juvenile rockfishes utilize Yaquina Bay as nursery habitat; (2) determine seasonal variations in juvenile rockfish abundance; (3) assess the use of natural versus anthropogenic estuarine habitat by juvenile rockfishes and (4) elucidate juvenile rockfish spatio-temporal distribution in Yaquina Bay nursery habitat.

Methods

Study site

Yaquina Bay (44°62' N 124°05' W), located adjacent to the City of Newport on the central Oregon coast, is a 15.82 km^2 marine-dominated estuary with mixed, semi-diurnal tides (Figure 2.1). The bay is classified as a ‘deep-draft development’ estuary which is dredged regularly and has a considerable amount of shoreline development (LCDC n.d.). Although there is little to no natural rocky structure in the bay, jetties, docks and riprap are present, and the extensive mudflats have established eelgrass (*Zostera* spp.) beds.

Sampling occurred at six different sites within Yaquina Bay (Figure 2.1): three located off anthropogenic habitat (piers), which are constantly submerged, and three located in natural habitat (eelgrass beds). The seagrass beds are often dewatered during the low spring tides. The pier sites were: (1) Hatfield Marine Science Center (HMSC) pump house (PH-D), (2) Englund Marine Supply (ENG-D) and (3) the Oregon State University ship pier (OSU-D). The PH-D has eelgrass beds in the vicinity, both east and west. There is no vegetation present near the ENG-D or OSU-D sites. All three pier sites have structure in the vicinity (i.e. floating docks, piers, etc.). The eelgrass bed sites were composed of native *Zostera marina*, and chosen for their accessibility during the low spring tides. Sites were located: (1) on the northeast end of the bay at Sally's Bend, in the vicinity of the Northwest Natural Gas Company (NWGAS-E) storage facility, (2) near the National Oceanic and Atmospheric Administration (NOAA) Marine Operations Center–Pacific (MOC-P) eelgrass restoration site (NOAA-E) and (3) next to the HMSC PH pier (PH-E). Only NOAA-E does not have structure (i.e. pier, dock, etc.) within 30 m.

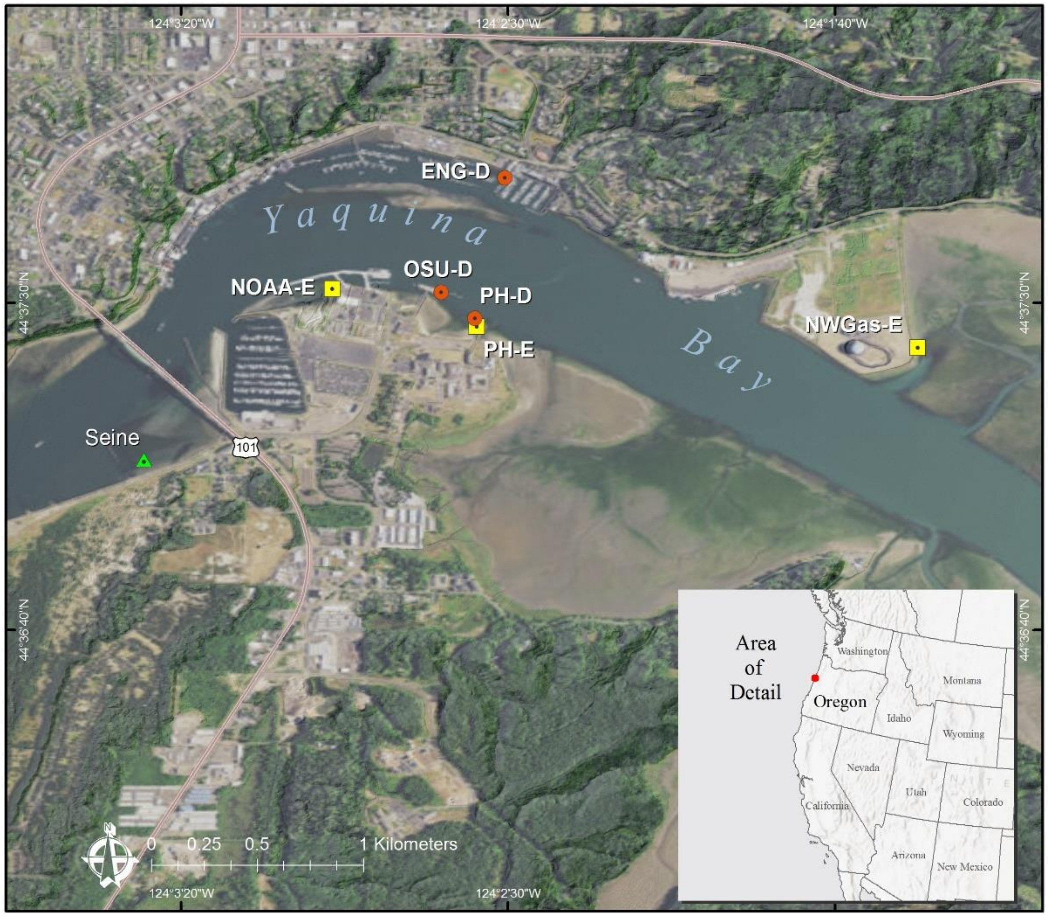

Figure 2.1. Sampling sites for juvenile *Sebastes* in Yaquina Bay. The pier sites (anthropogenic habitat; red circles) were: (1) Hatfield Marine Science Center (HMSC) pump house (PH-D), (2) Englund Marine Supply (ENG-D) and (3) the Oregon State University ship pier (OSU-D). The eelgrass bed sites (*Zostera marina*, natural habitat; yellow boxes) were: (1) on the northeast end of the bay at Sally's Bend, in the vicinity of the Northwest Natural Gas Company (NWGAS-E) storage facility, (2) near the National Oceanic and Atmospheric Administration (NOAA) Marine Operations Center–Pacific (MOC-P) eelgrass restoration site (NOAA-E) and (3) next to the HMSC PH pier (PH-E). The one seining site (green triangle) was near the south jetty.

Methodology

Square minnow traps (Aquatic Ecosystems, Inc.) constructed of wood and galvanized steel and measuring 65x65x45 cm, with a 19.5 mm wide mouth vertical opening, were deployed to collect YOY and juvenile rockfish for tagging. Preliminary trapping began March 2012 to determine appropriate site location and capture technique; 18 trapping events (TE) occurred during this pilot period (TE 1-18). Trap sites were choosen primarily for accessibility (access to eelgrass sites from the shore) and security (sites where traps would not be disturbed by the public). By October 2012, the trapping technique and six sites for the project were established. For the six sites mentioned above, complete data were collected for a total of fifteen months between October 2012 and December 2013, comprising TE 19-44. Trapping typically occurred twice a month during the spring-tide cycle with two replicate traps set at each location during each trapping event. The frequency of trapping was limited by the ability to gain access to the eelgrass sites, which were only accessible during the low spring tides. The traps were set unbaited for 24h to encompass a complete daily tide cycle (Schlosser and Bloeser 2006; Dauble 2010). The traps deployed from piers were dropped to the bay floor and secured to the pier with line. The traps in the eelgrass sites were set upon the bay floor and attached with line to a 1” diameter pipe anchor that was embedded into the substrate with about 2’ above the bay floor. Weight was added to the bottom of each trap to reduce movement, thereby minimizing habitat disturbance.

Following the 24h soak, traps were retrieved and any captured fish were emptied into a bucket containing water freshly collected at the trapping site. Each rockfish captured was visually identified to species, if possible, measured for length (TL to the nearest mm), and weighed (to the nearest gram). Photograhs were taken from a subsample to assist with visual identificaiton. Visual identification to the species level in the field is extremely challenging because some species exhibit differences in pigmentation depending on the type of habitat (Anderson 1983). Due to the difficulty of identifying YOY rockfish based on morphological characteristics (West *et al.* 1994; Love *et al.* 2002), fin clips were taken from the second dorsal fin of a subsample of rockfish in order to confirm identity using genetic analysis (Gallagher and Heppell 2010; Dauble *et al.* 2012). The fin clips were stored in 95% non-denatured ethanol.

Rockfish >30 mm were VIE-tagged (Northwest Marine Technology, Washington) using a 0.3 cc syringe with a 29-gauge needle (Griffiths 2002). VIE is a fluorescent pigment that forms a permanent mark and is available in a variety of colors so that a combination of colors may be used to identify fish (Griffiths 2002). Rockfish were batch marked, with each of the six trap sites and each trapping event having a unique color combination of VIE to distinguish the site and date (Byerly 1999). All fish were then released at the site. Recaptures were identified by the VIE mark. The original date of capture was determined, and weight and length measurements were retaken. Any recaptured rockfish were then marked with a new VIE combination to denote its recapture day and were subsequently released.

Additional sampling methods

Large gap traps

Large gap square minnow traps (Aquatic Ecosystems, Inc.) constructed of wood and galvanized steel and measuring 65x65x45cm, one with a 31.75 mm and one with 38.1 mm wide mouth vertical opening, were deployed to collect YOY and juvenile rockfish for potential PIT-tagging. These large gap (LGGap) traps were deployed with the same schedule and technique as the other minnow traps, although only at the ENG-D and PH-D sites (Figure 2.1). Each rockfish captured was visually identified to species, measured, weighed, VIE-tagged, and a subsample had photographs and fin clips taken (same methods as trapping technique). The large gap traps were used with the intent to capture larger rockfish. The trapping was conducted from March through December 2013, with a total of 202 rockfish captured.

Seining

Shore seining was conducted from March through September 2013, during the trapping cycle, at very low spring tides. There were a total of eight sampling days, with a total 25 seining events. A 25’ seine net with 6.35 mm mesh was used to sample a site near the Yaquina south jetty near the entrance of the bay, in *Z. marina* habitat (Figure 2.1). Each rockfish captured was visually identified to species, measured, weighed, VIE tagged, and a subsample had photographs and fin clips taken (same methods as trapping technique). The goal of this sampling technique was to try to recapture VIE-tagged rockfish that might be exiting the bay and to assess general habitat use by rockfish in this area. No VIE-tagged rockfish were captured, although an additional 121 rockfish were captured during this effort.

Analytical methods

This project consists of three sampling components: trapping, trapping with large gap traps and seining. Preliminary trapping (TE 1-18) was conducted to determine appropriate and accessible sites, began in March 2012 and was concluded in September 2012. The subsample of fin clipped rockfish for genetic identification and all VIE-tagged rockfish were from the entire project, all three sampling components. For the various analyses subsets of the data are used, as noted below. For the majority of analyses (e.g. abundance, rate of capture, habitat composition, etc.) it was important to only analyze the dataset for which there was equal trapping effort across sites (TE 19-44). Total fish count and length measurements were used for analyses. For rockfish analysis total catch numbers were used. For this study, catch-per-unit-effort (CPUE) is defined as total catch of rockfish per trapping event (two traps at six sites) which standardizes effort.

Two seasonal analyses were completed; a full analysis across the entire 15-month trapping period that was divided into 5 seasons, and a separate analysis with the trapping period divided by physical oceanographic transition dates. The transition dates are when the ocean shifts between downwelling and upwelling states (NOAA n.d.). The physical oceanographic transitions create three periods during the 15-month trapping project, the upwelling state creates the spring season (April-September 2012) and two downwelling transitions create the fall seasons (October 2012-March 2013 and October-December 2013) (Table 2.1). The 5 seasonal division were fall 2012 (October-December), winter 2013 (January-March), spring 2013 (April-June), summer 2013 (July-September) and fall 2013 (October-December) (Table 2.2). There is seasonal variability in the CPUE, summer 2013 had the fewest trapping events (4) due to the lower number of spring tides occurring during that season.

Table 2.1. The 15 month trapping period for juvenile *Sebastes* is divided into spring and fall by the physical oceanographic transitions. The number of trapping events per season (# TE), the months trapping occurred (Months), the trapping event number (TE #), and the total number of *Sebastes* captured each season (Total Fish), the mean number of juvenile *Sebastes* captured each season (Mean), and the standard error of the mean (SE). (TE 1-18 are not used in this analyses). (NOAA n.d.)

Season	**# TE**	**Months**	**TE #**	**Total Fish**	**Mean**	**SE**
Fall 2012	10	Oct-Mar	19-28	115	11.5	3.8
Spring 2013	11	Apr-Sep	29-39	162	15	2.9
Fall 2013	5	Oct-Dec	40-44	122	24.4	4.9

Table 2.2. The 15 month trapping period for juvenile *Sebastes* is divided into 5 seasons: the number of trapping events per season (# TE), the months trapping occurred (Months), the trapping event number (TE #), the total number of juvenile *Sebastes* captured during the trapping events (Total Fish), the mean of the total number of juvenile *Sebastes* captured each season (Mean), and the standard error of the mean (SE). (TE 1-18 are not used in this analyses).

Season	**# TE**	**Months**	**TE #**	**Total Fish**	**Mean**	**SE**
Fall 2012	5	Oct-Dec	19-23	100	20	5.1
Winter 2013	5	Jan-Mar	24-28	15	3	1.2
Spring 2013	6	Apr-Jun	29-34	60	10	3.8
Summer 2013	5	Jul-Sep	35-39	102	20.4	2.98
Fall 2013	5	Oct-Dec	40-44	122	24.4	4.88

Data were analyzed with R statistical package (https://www.r-project.org/). Figures and tables were created in Microsoft Excel and R. A negative binomial generalized additive model was used to analyze rockfish catch seasonal-effect-by-site relationship per species of TE 19-44. The model places emphasis that the location effects and the seasonal effects are being added to arrive at the predicted catch. The predicted catch depends both on the location (trap site, explanatory variable) and on the day of the year represented as a curve (Appendix B).

Results

Juvenile rockfish present in Yaquina Bay

Juvenile rockfish were present year-round in Yaquina Bay. From October 2012 through December 2013 (TE 19-44), all 26 trapping events captured at least one rockfish, with a total of 399 juvenile rockfish captured throughout the study period (Figure 2.2). Genetic analysis confirmed the presence of quillback (*S. maliger*), black (*S. melanops*), copper (*S. caurinus*), yellowtail (*S. flavidus*), brown (*S. auriculatus*), and canary rockfish (*S. pinniger)*, and bocaccio (*S. paucispinis*). The rockfish not genetically identified were visually identified and grouped into either the *S. caurinus/maliger* complex (CM complex) or the *S. melanops/flavidus* complex (MF complex) (Appendix A). The CM complex is comprised of the rockfishes that were visually identified as *S. caurinus* and *S. maliger*, and also the four species that were genetically identified but deemed questionable (*S. atrovirens*, *S. chrysomelas*, *S. saxicola*¸ and *S. semicinctus*) (Appendix A). The MF complex comprises all the rockfishes visually identified as *S. melanops* and *S. flavidus*.

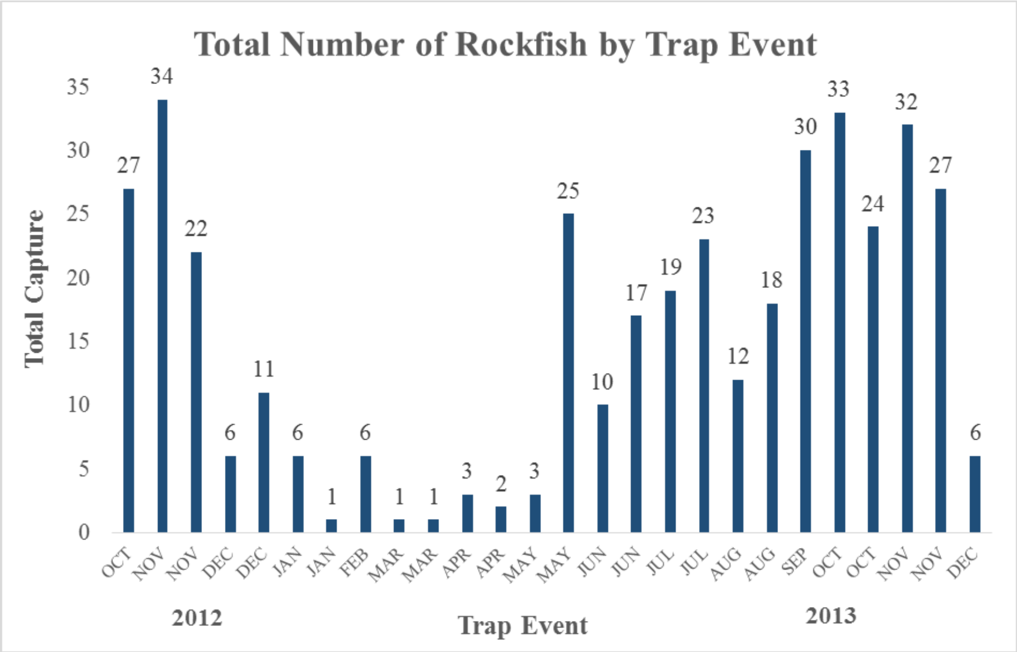

Figure 2.2. Total juvenile rockfish captured for trapping events 19-44 in Yaquina Bay. Each month listed is one trapping event (two traps at six sites); during some months two sampling events occurred.

For all rockfish (TE 1-44, large gap traps, and seining) captured in Yaquina Bay, the majority of genetically identified fish were *S. maliger* (17.2%) and *S. melanops* (17.1%), with *S. caurinus* (12.4%) being the third most abundant (Figure 2.3a). Other species genetically identified include *S. paucispinis* (1.9%), *S. nebulosus* (1.0%), *S. flavidus* (1.8%), and *S. auriculatus* (0.24%) and *S. pinniger* (0.12%). A greater percentage of rockfish were visually identified as being in the MF complex (25.1%) than the CM complex (21.9%). Only 2.2% of the captured rockfish were unknown, being unidentifiable either genetically or visually. For rockfish captured during TE 19-44, the majority were genetically identified as *S. maliger* (21.6%), then *S. caurinus* (17.2%), with *S. melanops* (13.9%) being third most prevalent (Figure 2.3b).

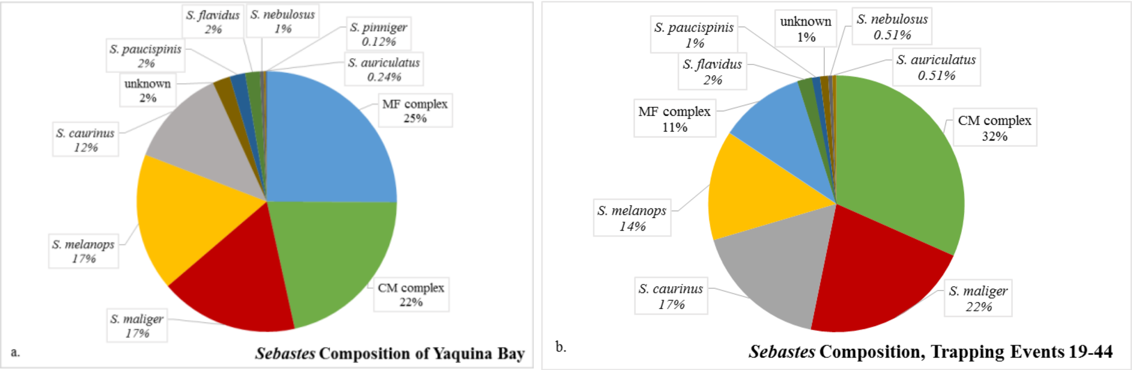

Figure 2.3. (a) Proportional representation of each taxonomic group of all (TE 1-44, large gap traps, and seining) juvenile rockfish captured in Yaquina Bay between March 2012 - December 2013. (b) Proportional representation of each taxonomic group of juvenile rockfish captured in Yaquina Bay during trapping events 19-44 (TE 19-44). Genetically identified fish are identified to species. The *S. caurinus/maliger* complex (CM complex) comprises the rockfishes that were visually identified as *S. caurinus* and *S. maliger*, and also the four species that were genetically identified but deemed questionable (*S. atrovirens*, *S. chrysomelas*, *S. saxicola*¸ and *S. semicinctus*). The *S. melanops/flavidus* complex (MF complex) comprises the rockfishes visually identified as *S. melanops* and *S. flavidus* (Appendix A).

Juvenile rockfish abundance

The abundance of (Figure 2.4) and CPUE for (Table 2.2) juvenile rockfish (TE 19-44) varies by season. Seasonally, the lowest abundance and CPUE occurs in the winter with only 2 fish caught in March. The highest abundance was in the fall, with peak catch in November (Figure 2.2).

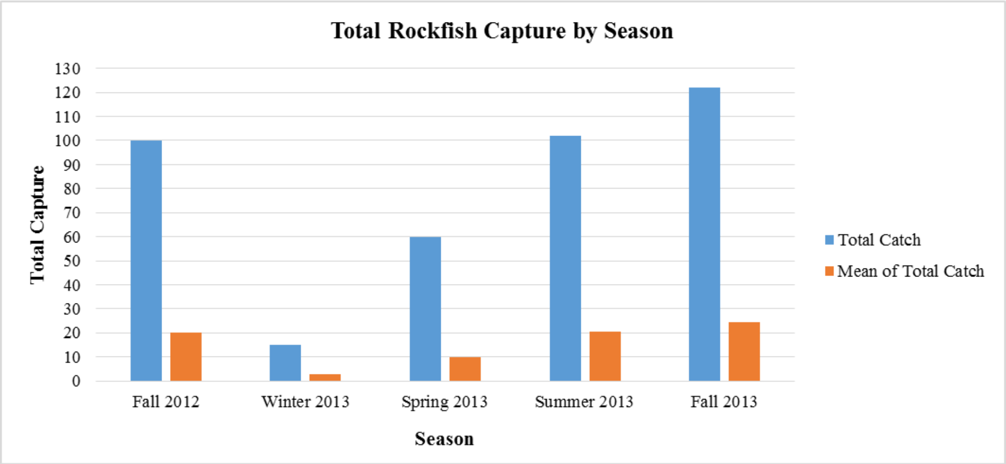

Figure 2.4. The total catch of juvenile rockfish by season (TE 19-44). The mean of total catch is shown to account for unequal trapping events per season (Table 2.2).

Analyzing the abundance of the periods based on the physical oceanographic transitions that occurred during TE 19-44, demonstrate that an average of 13 juvenile rockfish are caught during spring (upwelling season) and during the fall (downwelling season) 12 in 2012 and 24 in 2013 (Table 2.1).

Seasonal variability by size class

The size distribution for all rockfish captured in Yaquina Bay ranged from 26–300 mm TL, while for TE 19-44, juvenile rockfish ranged in size from 26–114 mm (Table 2.3; Figure 2.5). Most of the rockfish captured during TE 19-44 were in the 40–84 mm size range (87%), with the majority falling between 50–54 mm (22.8%) (Figure 2.6). The largest range of size classes occurred during spring (25–109 mm) and the smallest was during the winter (35–84 mm) (Figure 2.6). In the late spring, through the summer, there is an influx of smaller rockfish (<35 mm) (Figure 2.5b). Spring was also when the largest rockfishes, the 200 and 300 mm were captured (Figure 2.5a). During TE 19-44, the fall seasons have an increase in YOY, especially in 2013 (Figure 2.6).

Table 2.3. Statistics of juvenile *Sebastes* lengths (mm) captured in Yaquina Bay, standard error of mean (SE).

Sample set	Range of Lengths	Mean of Lengths	SE of Mean Lengths	Median of Lengths	Mode of Lengths	n
TE 19-44	26-114	57.96	0.76	55	54	390
ALL	26-300	60.3	0.74	54	54	825

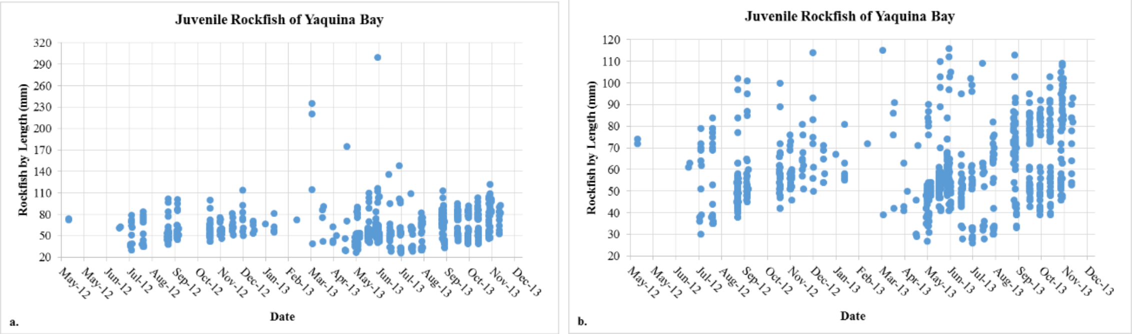

Figure 2.5. (a) Length in mm of all juvenile *Sebastes* captured in Yaquina Bay. (b) Length of all *Sebastes* up to 120 mm, the 7 rockfish from 122-300 mm are removed.

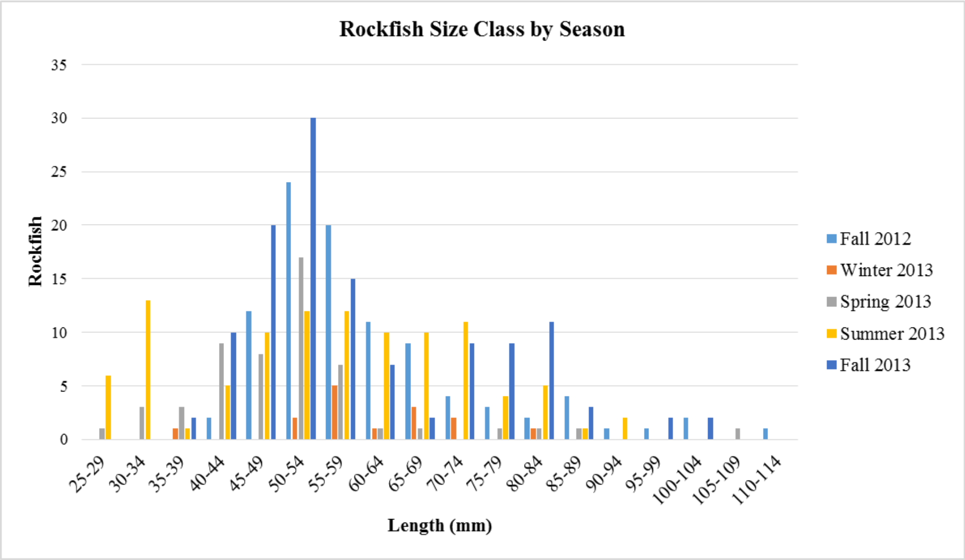

Figure 2.6. Size distribution histogram for juvenile *Sebastes* captured during TE 19-44, divided into 5 mm size classes.

Anthropogenic and natural habitats of Yaquina Bay

There is seasonal variability in the use of Yaquina Bay nursery habitat. The anthropogenic, pier habitat had a higher proportion of total captures (55%) than the natural, eelgrass (*Z. marina*) habitat (45%) (TE 19-44) (Figure 2.7a). These two habitats are very diverse, the natural creates a complex and dynamic ecosystem due to its spatial patchiness and ephemeral existence while the anthropogenic provides a more consistent environment with greater vertical relief and less heterogeneity. Juvenile rockfish are present during all months in anthropogenic habitat (Figure 2.7b), with a more consistent and heavier usage of this habitat in the fall (Figure 2.8a). Rockfish are absent in the natural habitat from the middle of November through March (Figure 2.8b). Spring shows an almost equal amount of usage in both habitats. Only during the summer is the natural habitat more utilized, by nearly 3 times that of the anthropogenic habitat (Figure 2.8b).

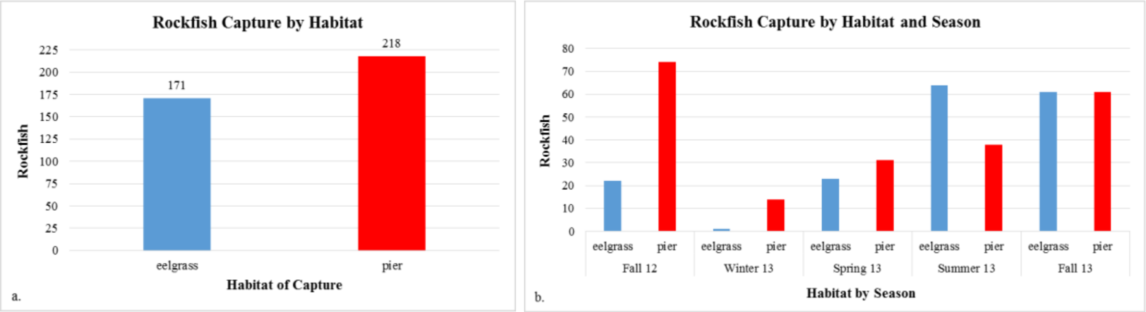

Figure. 2.7. (a) Total juvenile *Sebastes* captured by habtiat type, either natural- eelgrass or anthropogenic- pier, for TE 19-44. (b) Captures of juvenile *Sebastes* by habitat and season for TE 19-44.

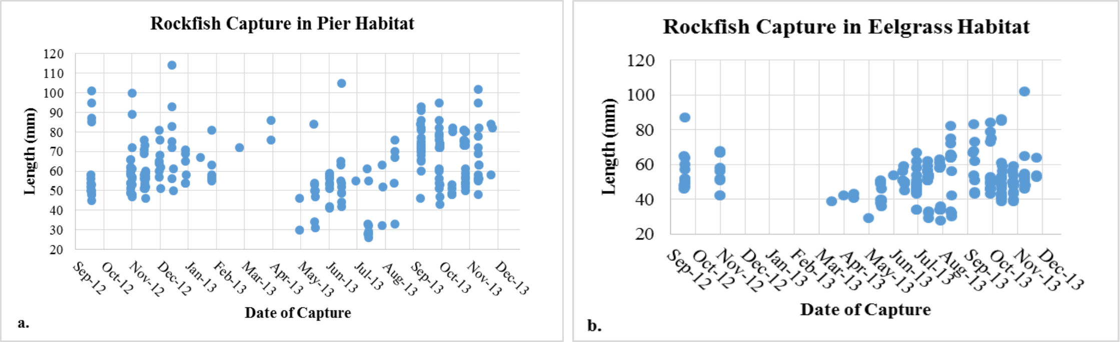

Figure 2.8. Total *Sebastes* capture in each habitat by date and length (mm), (a) anthorpogenic habitat-pier and (b) natural habitat-eelgrass, TE 19-44.

There is seasonal variability in juvenile rockfish size distribution. Overall the anthropogenic habitat sites had larger fish in all seasons compared to the eelgrass sites.

Rockfish in the natural habitat are primarily from ~30-70 mm, with larger (70-90 mm) fish present in the anthropogenic habitat (Figure 2.8; Table 2.4).

Table 2.4. Length ranges for all *Sebastes* captured, by habitat type, for TE 19-44. Total number of rockfish captured (Total), range of lengths in mm (Range), and percentage of rockfish over 70 mm (% 70 mm+).

TE 19-44	**Total**	**Range**	**% 70 mm+**
Pier	218	26-114 mm	32.5
Eelgrass	171	28-102 mm	7.6

All eight *Sebastes* species captured are present in the natural, *Z. marina* habitat, while *S. pinniger* and *S. auriculatus* are absent from the anthropogenic, pier habitat (Figure 2.9). The MF complex (76%) and *S. melanops* (65%) demonstrated a greater use of anthropogenic habitat than other taxa (Figure 2.9).

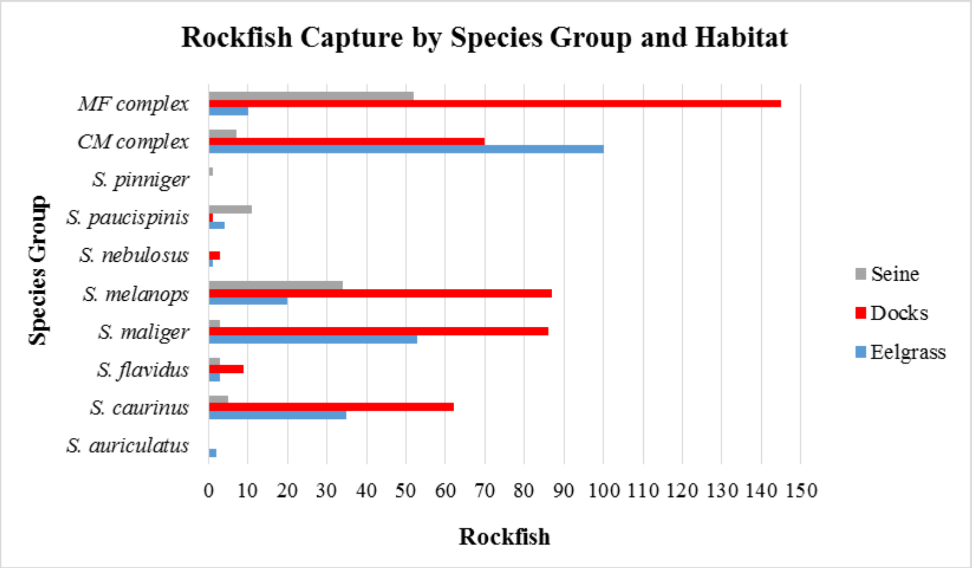

Figure 2.9. All *Sebastes* and complexes captured in Yaquina Bay by habitat type. Minnow traps were used for the dock and eelgrass locations. The shore seine captures were only in *Zostera marina* beds.

Individual rockfish species accounts

Beginning in May, smaller (~30 mm) *S. caurinus* were captured, with age-1, possible age-2 class capture beginning the end of June. During the beginning of June a wide class size range from ~30 to ~140 mm of *S. caurinus* are present. From May-September a general increase in length is noted (Figure 2.10a). *S. caurinus* does not exhibit statistical significance of seasonality (chi-square = 0.019, p = 0.354, df = 8, r^2 = 0.054) (Figure 2.11b).

During the first year of trapping in Yaquina Bay, *S. maliger* was captured primarily August-December, while the following year capture was from May-December (Figure 2.10b). There are age-1 year class present during the spring and in November. There was a general increase in cohort length from August-December in both years, besides that similarity, 2012 and 2013 had very different abundance trends. *S. maliger* exhibits significant seasonality in capture pattern (chi-square = 16.64, $p < 0.001$, df = 8, r^2 = 0.15) (Figure 2.11c).

Sebastes flavidus did not use Yaquina Bay during fall or winter (Figure 2.10c). The size classes captured were limited, primarily YOY.

There were few *S. paucispinis* captured (Figure 2.10d). The majority of these were captured during seining (69%), which only occurred in 2013 (Figure 2.9). All but one was captured in natural habitat, with caputres happening primarily during spring. The lengths were varied from 39-74 mm, indicating YOY and perhaps age-1 year class (Moser and Boehlert 1991).

Yaquina Bay is consistently used by *S. melanops* with some age-1 present by November (Figure 2.10e). There is also a general increase in lengths from August-September 2012 and from May-December 2013. A couple of rockfish in the age-2 to age-4 class (175-300 mm) (Leaman 1976) were captured, in spring and early summer, respectively. *S. melanops* exhibits significant seasonality in capture pattern (chi-square = 15.89, p = 0.001, df = 8, r^2 = 0.259) (Figure 2.11a).

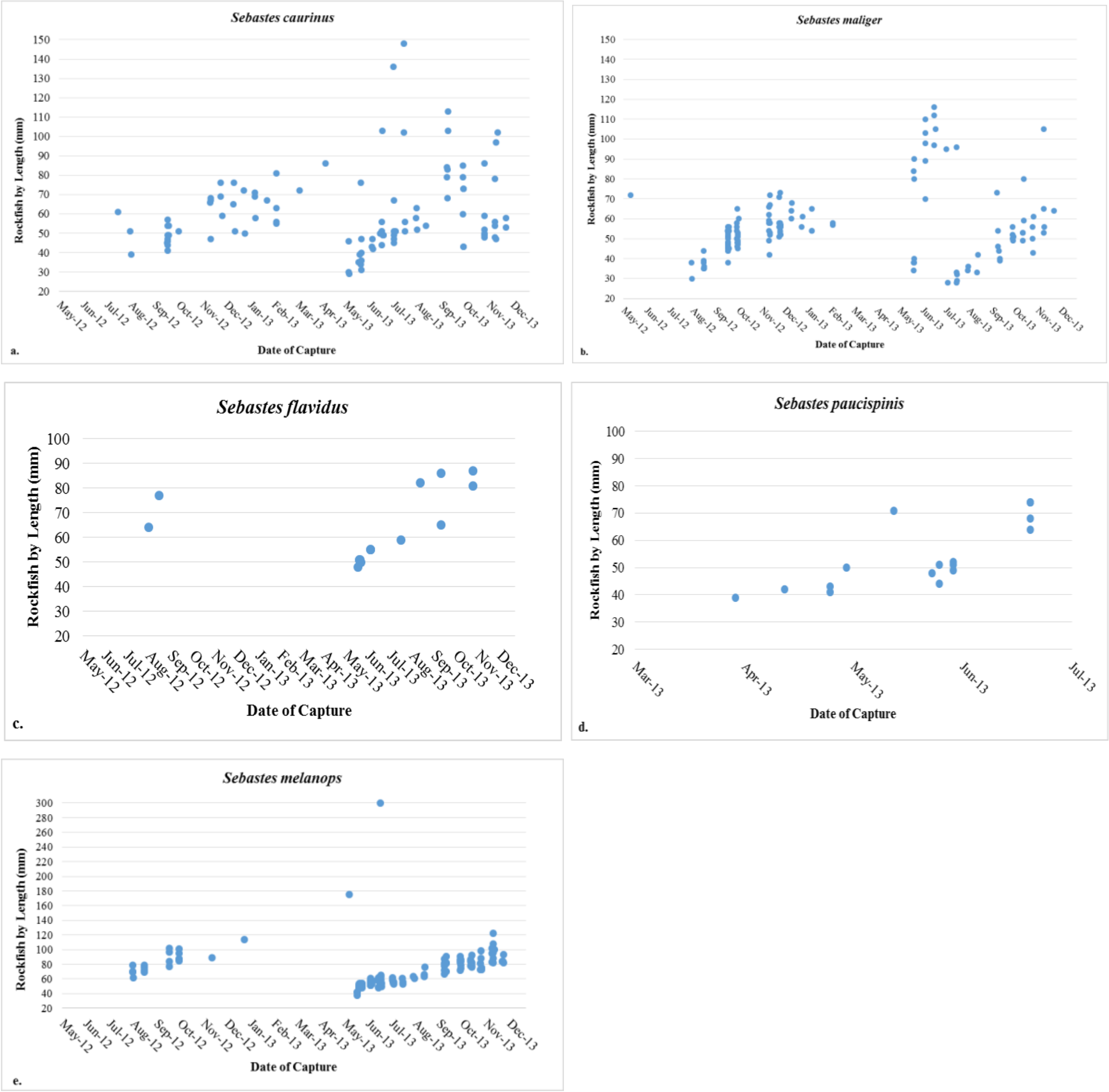

Figure 2.10. *Sebastes* genetically identified by length (mm) and by date of capture. (a) *S. caurinus* (b) *S. maliger* (c) *S. flavidus* (d) *S. paucispinis* (e) *S. melanops*.

Rockfish in the CM complex ranged from 26-109 mm, with 71% between 40-60 mm (Figure 2.12a). During winter and spring seasons no fish of the CM complex are present in Yaquina Bay. Summer and fall is the period of main activity for these species in Yaquina Bay. There is a general increase in length in 2013 from the end of July through November. The CM complex exhibits significant seasonality in capture pattern (chi-square = 16.57, $p < 0.001$, df = 8, $r^2 = 0.271$) (Figure 2.11d).

The MF complex is predominantly present from end of May through the middle of November (Figure 2.12b), with a general increase of length during this time. There are several age-1 (Leaman 1976) fish present in November. The MF complex exhibits significant seasonality in capture pattern (chi-square = 11.58, $p = 0.003$, df = 8, $r^2 = 0.192$) (Figure 2.11e).

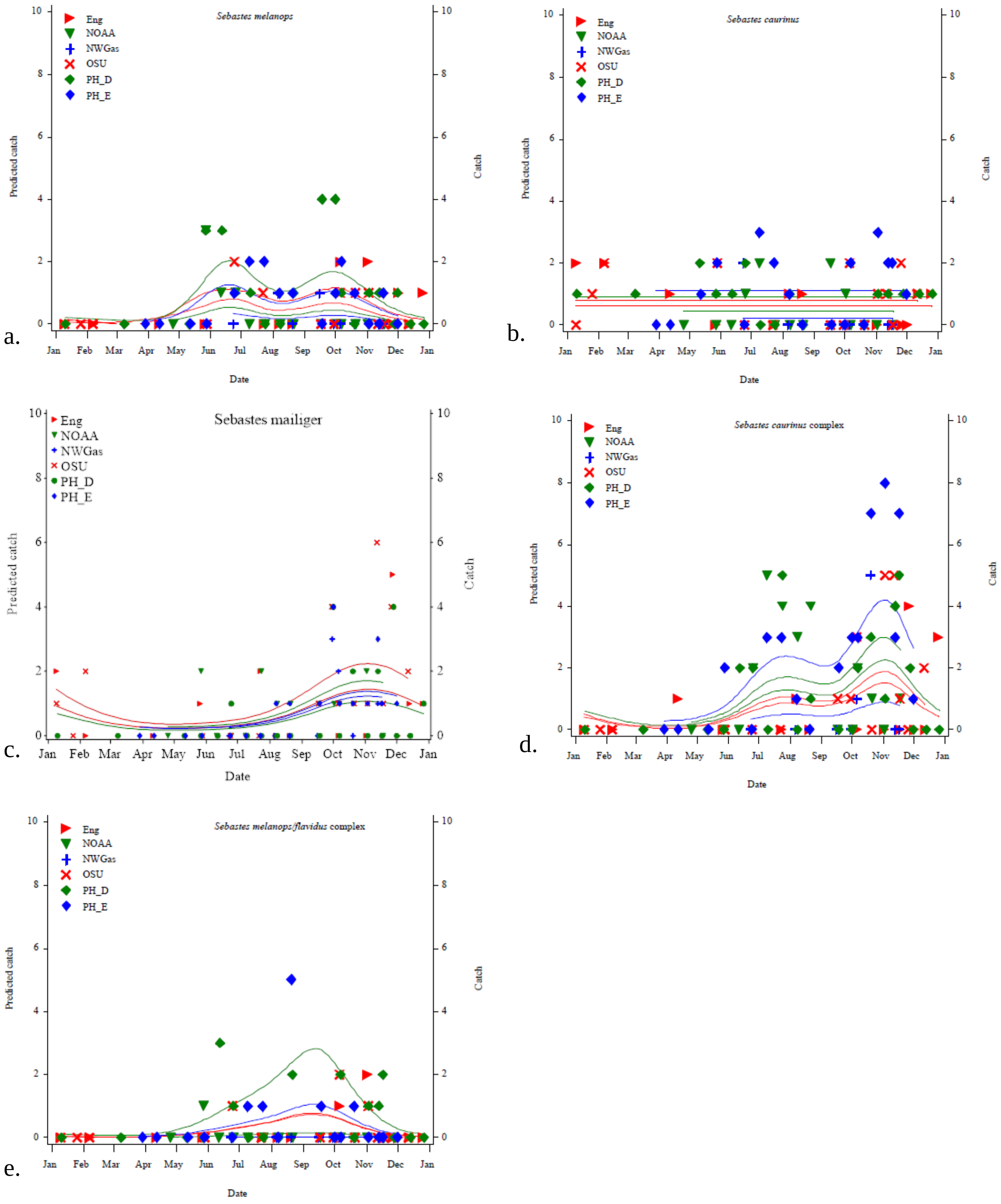

Figure 2.11. Actual catch and negative binomial generalized additive modeled catch rates for juvenile *Sebastes* in Yaquina Bay (TE 19-44). Symbols represent true capture data (up to 10 indivduals). The lines are the predicted catch of rockfish at each site versus day-of-year. The pier sites (anthropogenic habitat) are: (1) Hatfield Marine Science Center (HMSC) pump house (PH_D), (2) Englund Marine Supply pier (Eng) and (3) the Oregon State University ship pier (OSU). The eelgrass bed sites (*Zostera marina*, natural habitat) are: (1) on the northeast end of the bay at Sally's Bend, in the vicinity of the Northwest Natural Gas Company (NWGas) storage facility, (2) near the National Oceanic and Atmospheric Administration (NOAA) Marine Operations Center–Pacific (MOC-P)

eelgrass restoration site (NOAA) and (3) next to the HMSC PH pier (PH_E). (a) *S. melanops* (b) *S. caurinus* (c) *S. maliger* (d) *S. caurinus/maliger* complex (CM complex) (e) *S. melanops/flavidus* complex (MF complex).

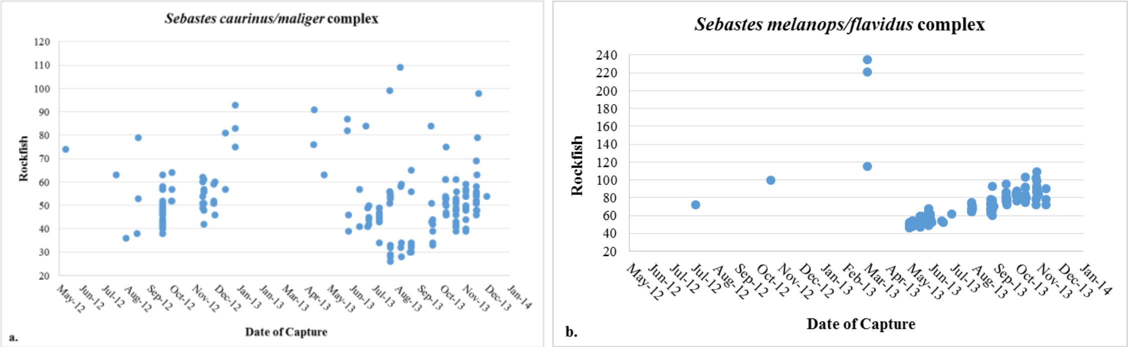

Figure 2.12. All *Sebastes* visually identified and the questionable genetic identifications grouped into complexes by date of capture and by lengths (mm). (a) *Sebastes caurinus/maliger* complex (CM complex) and (b) *Sebastes melanops/flavidus* complex (MF complex).

Spatio-temporal use of Yaquina Bay nursery habitat by juvenile rockfish

A total of 750 juvenile rockfish were VIE-tagged. Each of the 17 rockfish were recaptured (two had multiple recaptures) at the original tagging location (Table 2.5). The minimum, median, and maximum interval of time that elapsed between recaptures was 2, 35, and 413 days, respectively (Table 2.6). Juvenile rockfish utilize the estuary during all seasons of the year and the VIE-tagging demonstrates overwintering (Table 2.5).

Table 2.5. Mark recapture results for VIE-tagged juvenile rockfish. Species identified by genetic analysis (species listed) or by visual identification (complexes listed (MF complex, CM complex) (Species), location of site tagged (Site), original VIE tagging date (Tagged), date of recapture (Recapture), days at large: total days (d) between original tagging and recapture (Days) (d◊ denotes overwintering), and date of second recapture (2ND Recap). For the two fish with multiple recaptures, the date of the second recapture with the days between the recaptures is also included. (Due to inadvertently using the same VIE tag pattern twice, recapture date is conservative for some individuals *, **, ***. Date listed in table is the possible earlier date, the shortest possible duration; the other possible date, the longest duration possible is as follows: *12/27/12=106d; **11/28/12=181d; ***9/19/12=398d).

Species	**Site**	**Tagged**	**Recaptured**	**Days**	**2nd Recap**	**Days**
S. caurinus	PH-E	5/29/2013	7/24/2013	56		
CM complex	PH-E	10/21/2013	11/18/2013	28		
CM complex	NOAA-E	UNKWN	7/25/2013	NA		
CM complex	NOAA-E	7/25/13	8/9/2013	16		
CM complex	NOAA-E	8/22/2013	9/18/2013	28	10/8/2013	20
S. caurinus	ENG-D	1/10/2013	4/12/2013*	92◊		
CM complex	ENG-D	12/14/2012	5/28/2013**	151◊		
S. melanops	ENG-D	10/21/2013	11/3/2013	13		
S. melanops	PH-D	9/19/2012	5/14/2013	238◊		
S. melanops	PH-D	UNKWN	6/24/2013	NA		
S. caurinus	PH-D	6/11/2013	6/26/2013	15		
MF cmlpx	PH-D	9/17/2013	9/19/2013	2		
MF cmlpx	PH-D	9/17/2013	10/7/2013	20	10/22/2013	15
MF cmlpx	PH-D	12/28/2012	10/22/2013***	298◊		
MF cmlpx	PH-D	10/8/2013	10/22/2013	14		
MF cmlpx	PH-D	10/2/2012	11/19/2013	413◊		
MF cmlpx	PH-D	10/22/2013	11/19/2013	28		

Table 2.6. Juvenile rockfish VIE tagging results by habitat type. Data for anthropogenic (pier) and natural (eelgrass- *Z. marina*) sites and combined habitat totals (Habitat), total number of rockfish VIE-tagged (VIE), number of recaptures (Recap), recapture rate (Rate), days at large: total days (d) between original tagging and recapture (Days), the maximum number of days between tagging and recapture (Max), the minimum number of days between tagging and recapture (Min), the mean of days between tagging and recapture (Mean) and the median of days between tagging and recapture (Median).

Habitat	**VIE**	**Recap**	**Rate**	**Days**	**Max**	**Min**	**Mean**	**SE**	**Median**
Pier	434	13	3.0%	1299d	413d	2d	108.3	39.8	24
Eelgrass	316	6	1.9%	148d	56d	16d	29.6	7	28
Combined	750	19	2.5%	1447d	413d	2d	85.1	29.2	28

Recaptures of VIE-tagged rockfish occurred at both eelgrass and pier sites. The recapture rate was higher for the pier habitat (3.0%) versus the eelgrass (1.9%) (Table 2.6). The longest time between recaptures (413 days) occurred in the pier habitat, while the longest time between recapture in the eelgrass habitat was only 56 days. *Sebastes caurinus* and the CM complex were recaptured in both natural and anthropogenic habitat, while *S. melanops* and the MF complex were recaptured only in the anthropogenic habitat (Table 2.5).

Table 2.7. Early life history parameters for those juvenile rockfish species captured and genetically identified in Yaquina Bay. Species, known distribution range (Range), length of fish, age and/or habitat parameters of pelagic juveniles (Pelagic Phase), time of year, size, and/or habitat parameters of juvenile settlement and YOY information (Settle/Habitat), size of all rockfish captured in Yaquina Bay (Yaquina Bay Size), time periods juvenile species present in Yaquina Bay, from all rockfish captured (Yaquina Bay Presence), peak abundance in Yaquina Bay during TE 19-44 (Yaquina Bay Peak Abundance), and habitat species captured in Yaquina Bay (Yaquina Bay Habitat). The information for range, pelagic juveniles, and settle/habitat is from Love *et al.* 2002. The last three columns of Yaquina Bay data are the findings from this study, data are from all rockfish (trapping, LGGap, and seining) and for peak abundance it is only TE 19-44.

Species	**Range**	**Pelagic Phase**	**Settle/Habitat**	**Yaquina Bay Size**	**Yaquina Bay Presence**	**Yaquina Bay Peak Abundance**	**Yaquina Bay Habitat**
S. auriculatus	N Gulf of AK to S Baja CA; abundant Puget Sound & N CA to S Baja CA	In water column 2.5-3 mo.	May settle shallow water (up to ~36 m) over rocks, hard strata & bottom drift algae	47, 62 mm	July & Sept 2013	NA	eelgrass
S. caurinus	N Gulf of AK to C Baja CA; common Gulf of AK to N Baja CA	Recruit to nearshore 1.8-2.0 cm	Settle: C CA late Apr/May; Strait of GA Jul/Aug; settle around large algae, eelgrass; within few mos. young descend to bottom- sand or low rock, along reef-sand interface	29-148 mm	July 2012-Dec 2013	November 2013	dock and eelgrass
S. flavidus	Aleutian Islands to S CA; common SE AK to C CA	Duration 3.5 mo.; in water column until 4-5 cm; (off C CA, recruit to nearshore 2.8 cm, Apr-Aug)	Off C CA rocky areas with marine veg. such as kelp; N CA YOY leave shallow water in fall	48-87 mm	Aug 2012; May-Sept 2013; Nov 2013	NA	dock and eelgrass
S. maliger	Kenai Peninsula to S CA; common SE AK to N CA	UNKNOWN	Puget Sound YOY Jul - Nov, shallow (2-20 m) rocks; may 1st recruit to detached veg. on sand; older juveniles move inshore most abundant on bull kelp-covered rocky outcrops; eelgrass beds	28-116 mm	May 2012; July 2012-Feb 2013; May-Dec 2013	November 2012	dock and eelgrass

Sebastes	Range	Pelagic Phase	Settle/Habitat	Yaquina Bay Size	Yaquina Bay Presence	Yaquina Bay Peak Abundance	Yaquina Bay Habitat
S. melanops	Aleutian Islands to S CA; common SE AK to N CA	Nearshore intertidal & estuarine 4-6 mo.; drifting algae & seagrass	OR settle Jun & Jul; C CA settle May, 3-4 cm; nearshore intertidal, estuarine, drifting algae & seagrass; water <20 m kelp beds	38-122 mm, 175 mm, 300 mm	Aug-Dec 2012; May-Dec 2013	June	dock and eelgrass
S. nebulosus	N Gulf of Alaska to S CA; abundant Prince William Sound, AK to N CA	UNKNOWN	Juveniles live in shallow subtidal during summer and early fall	43-109 mm	Aug-Sep & Mar 2013	September	dock and eelgrass
S. paucispinis	AK Peninsula to C Baja CA; historically most abundant OR to N Baja CA	Found close to surface; stay in water column until 3.5-5.5 mo.	3-4 cm (small as 1.9 cm) recruit to inshore waters (Feb-Aug), peak May-Jul; shallow water; rocks covered with algae or sandy zones w/ eelgrass or drift algae; YOY drifting kelp mats	39-74 mm	Mar-June 2013	April	eelgrass (1 of 16 captured at dock)
S. pinniger	W Gulf of AK to N Baja CA; abundant BC to C CA	Upper 100 m of water column for 3-4 mo.; (off OR, some remain in water column through Jul)	Intertidal, tidepools & kelp beds in Apr; ~4 cm occur in groups at 15-20 m at interface of sand & rock outcrop; end of summer- move from shallow water	45 mm	May 2013	NA	eelgrass

Discussion

Juvenile rockfish utilize Yaquina Bay as nursery habitat year-round, demonstrated by rockfish capture at each trapping event (Figure 2.2). There is an increase in species richness as I document for the first time the presence of *S. paucispinis*, *S. maliger*, *S. auriculatus*, *S. nebulosus*, and *S. pinniger* in the bay (Table 2.7; Table 2.8). In previous studies *S. melanops* was the dominant species (Appy and Collson 2000; Schlosser and Bloeser 2006; Gallagher and Heppell 2010; Dauble *et al.* 2012), while here it was only the third most prevalent (Figure 2.3b); *S. maliger* and *S. caurinus* were the two most common rockfishes captured during this study (TE 19-44), but are poorly represented in previous research (Table 2.8). Juvenile rockfish abundance in Yaquina Bay varies by season (Table 2.7), with the highest abundance occurring during the fall (Figure 2.4; Table 2.2) and peak catch in November (Figure 2.2). There is seasonal variability in rockfish use of the anthropogenic and natural habitats of Yaquina Bay. The anthropogenic habitats have an overall higher capture rate and a higher occurrence of larger rockfish (Figure 2.7; Table 2.4). Multiple size classes occur in the bay (Figure 2.6) and there is evidence that distinct cohorts are present and increasing in length (Figure 2.5b), illustrated by *S. maliger* and *S. melanops* (Figure 2.10b; Figure 2.10e). No movement was detected between sampling sites and I had multiple recaptures at some of the sampling sites, indicating prolonged residence for at least some portion of the population (Table 2.5).

Table 2.8. Juvenile rockfish captures in Yaquina Bay. Species and proportional representation of rockfish captured (*Sebastes* in Yaquina Bay), length of rockfish captured in mm (Size), time periods juvenile species present in Yaquina Bay (Presence), and author of paper and year published (Author). WEVZ complex is comprised of *S. wilsoni/ emphaeus/ variegatus/ zacentrus*.

***Sebastes* in Yaquina Bay**	**Size**	**Presence**	**Author**
Sebastes spp.	35-92 mm	Apr-Oct 1980	Boehlert and Yoklavich 1983
S. melanops 402 fish; *S. caurinus* 18 fish	NA	May-Aug 2000	Appy and Collson 2000
S. melanops 181 fish; *S. caurinus* 58 fish; *S. rastrelliger* 1 fish	NA	Jun 2003-Dec 2005	Schlosser and Blosser 2006
S. melanops 63.7%; *S. flavidus* 3.0%	~50-80 mm	Jun-Sep 2004	Gallagher 2007
	~55-75 mm	Jun-Aug 2005	
S. melanops 96.1%; WEVZ complex 1.5%; No ID 3.0%	46-80 mm	Jun-Oct 2008	Dauble 2011
S. melanops 84.2%; *S. caurinus* 4.0%	44-74 mm	Apr-Nov 2009	
S. maliger 21.6%; *S. caurinus* 17.2%; *S. melanops* 13.9%; *S. flavidus* 1.8%; *S. paucispinis* 1.0%; *S. nebulosus 0.5*%; *S. auriculatus* 0.5%; *S. pinniger* <0.25%	26-300 mm	Apr 2012-Dec 2013	*This study*

The results of this study demonstrate that juvenile rockfishes use Yaquina Bay as nursery habitat, utilize both natural and anthropogenic structure, and some likely remain in the same general area for an extended period of time. The occurrence of recaptures illustrates persistence, and indicates site fidelity and possible small home ranges for these individuals. Thirty-one percent (0.67% of all VIE-tagged fish) of the juvenile rockfish that I recaptured overwintered in the estuary (Table 2.5) , therefore at least some portion of the rockfish population uses Yaquina Bay over the winter. Estuarine habitats therefore appear to be viable nursery habitat for juvenile rockfishes, specifically *S. melanops* and *S. caurinus*. Similar to what was found for *S. melanops* in British Columbia (Leaman 1976) and for *S. melanops*, *S. caurinus*, and *S. flavidus* in Puget Sound (Moulton 1977 *cited in* Love *et al.* 1991). The survival and recapture of juveniles in both natural (*Z. marina*) and anthropogenic habitat (piers) demonstrates rockfishes' successful use of multiple habitat types in Yaquina Bay as nursery grounds.

The two habitats investigated in this study provide very different habitat attributes. The natural, eelgrass (*Z. marina*) habitat is a complex ecosystem due to it being an ephemeral habitat. The tides create great flux in this habitat, as the water depth increases and decreases continually which creates greater temperature extremes because of the shallowness of the habitat. Seasonal changes in productivity of the eelgrass creates a highly inconstant habitat, creating seasonally variability in: temperatures; percent cover and amount of structure, which influences refuge; and resource availability, including potential prey items. The variable *Z. marina* habitat is very different from the more consistent anthropogenic habitat of manmade piers, which provide vertical relief. The piers are pilings which support floating docks erected in the estuary floor of mudflats. Although the anthropogenic habitat is also tidally influenced, there is not the vast temperature extremes or highly variable structure and/or productivity through the seasons, as this habitat is constantly underwater. These two habitats provide very different structure for refuge and offer very different habitat attributes.

Yaquina Bay provides habitat for multiple year classes, and during all of the seasons except winter there are a minimum of two year classes present. The broadest size range occurs in spring with the influx of smaller rockfish and continues through the summer (Figure 2.6). Large quantities (100s) of small (~20 mm) YOY rockfish were observed aggregated near docks in Yaquina Bay (e.g. PH-D) during May, indicating an initial settlement pulse, although our sampling gear was not equipped to capture them at this stage (*personal observation*; Appy and Collson 2000). The highest abundance of YOY occurred in the fall (Figure 2.6).

The overall length distribution of rockfish captured during this project ranged from 26-300 mm (Table 2.3). The April-October length distribution (30-101 mm) (Figure 2.5b) agrees with that previously observed in Yaquina Bay (Boehlert and Yoklavich 1983). Generally, the June-October length distribution was greater in this study for *S. caurinus* (39-148 mm vs from 20-33 mm) (Figure 2.10a) and *S. melanops* (48-300 mm vs 20-61 mm) (Figure 2.10e) than was shown previously using light traps for collection (Miller and Shanks 2004).

The abundance of the different rockfishes varies seasonally (Figure 2.10; Figure 2.11; Table 2.7) and is likely related to variable parturition periods for each species. Parturition timing in *Sebastes* varies by species and across latitudes. For the eight species genetically identified in this study partition occurs as early as October and as late as July

(Table 2.9; FishBase 2016). For example, *S. melanops* parturition off Oregon occurs between January-March, while in North-Central California it is January-May (FishBase 2016). Parturition date can be back calculated based on otolith daily growth increments, however it was not measured in this study because all fish were captured and released alive. *Sebastes melanops* and *S. caurinus* both have their highest abundances in the middle/end of May. This is when the bulk of recruitment occurs in central California (Table 2.10; Anderson 1983).

Table 2.9. Parturition data of the eight genetically identified species (*Sebastes* Species), month of parturition (Month), and location (Locality) (FishBase 2016).

***Sebastes* Species**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Oct**	**Nov**	**Dec**	**Locality**
S. auriculatus		X	X	X	X						CA Current region
S. caurinus		X	X	X	X						CA Current region
S. flavidus	X	X	X	X	X						Cordell Bank, CA
S. maliger				X	X	X	X				North-Central CA
S. melanops	X	X	X								off Oregon
S. nebulosus	X	X	X	X	X	X					North-Central CA
S. paucispinis	X	X	X	X	X			X	X	X	CA Current region
S. pinniger	X	X	X							X	CA Current region

Table 2.10. Juvenile rockfish settlement and recruitment in Oregon and central California including time period and size at recruitment or settlement.

Species	**Location**	**Settle/Recruit**	**Size**	**Citation**
S. melanops	Oregon	Mid-May		Gallagher 2007
S. melanops	Central California	June	35 mm	Anderson 1983
S. flavidus	Oregon	April		Gallagher 2007
S. flavidus	Central California	Late April-May	28 mm	Anderson 1983
S. caurinus	Central California	Early April-May	18 mm	Anderson 1983
S. pinniger	Central California	Early April-May	25 mm	Anderson 1983
S. paucispinis	Central California	February-August	25–30 mm	Anderson 1983

The general increase in size observed across seasons for *S. maliger* (August-December), *S. caurinus* (May-September), and *S. melanops* (May-September) likely represents growth for a single cohort of post-settlement juveniles and is similar to that observed by Gallagher (2010) (Figure 2.10). Juvenile rockfishes settle into their benthic habitats at a variety of sizes, depending on habitat and species. Settlement may be driven by behavioral changes, suggesting that pelagic juveniles may attain species-specific stages that enable them to settle (Anderson 1983). In Yaquina Bay, the transition to benthic habitat in this study for *S. melanops* was 38 mm and for *S. flavidus* was 48 mm, similar to what Laroche and Richardson (1980) found (Table 2.8).

Fish demonstrate relatively equal use of both habitats in the spring, while summer demonstrates higher usage of the natural habitat (Figure 2.7b). In Alaska juveniles moved into natural habitats in May (Byerly 1999; Johnson 2000). This is similar to what I may have observed in Yaquina Bay, a movement into natural habitat occurring in April-June. In the fall there is more consistent use of the estuary, with a heavier occupancy in the anthropogenic habitat. Use of the natural habitat decreases greatly during the end of fall into winter, and during winter there is minimal occupation of the estuary, with only the anthropogenic sites utilized (Figure 2.7a).

Within Yaquina Bay, habitat-specific densities of rockfish (as measured by CPUE) have been shown to vary greatly (Gallagher 2007). The largest numbers of juvenile rockfish are in areas of highest habitat complexity, including pilings, and other man-made structures (Gallagher and Heppell 2010; Dauble *et al*. 2012). Appy and Collson (2000) found that the most productive rockfish sites in the estuaries were within 35 m of solid structure. These findings are similar to our highest abundance at the pier sites (Figure 2.7a).

While we identified eight species of rockfish in Yaquina Bay, *S. pinniger* and *S. auriculatus* were only found in the natural habitat, in addition to the majoirty of *S. paucispinis* (Figure 2.9). *Zostera marina* beds are complex ecosystems that provide multifaceted functions, including food, habitat and protection. Seasonally variable temperatures, and greater temperature extremes because of the shallowness of the habitat, combined with seasonal changes in productivity of the seagrass creates a highly variable habitat. This likely affects seasonal patterns of rockfish abundance and use of the beds. Rockfish captured in natural habitats were smaller in length across seasons, denoting habitat suitability of structure for certain sizes of fish (Figure 2.8; Table 2.4). In Yaquina Bay, juvenile rockfish move away from shallow vegetated areas in the late fall and winter, similar to the findings of Murphy *et al.* (2000).

Outmigration of at least some of the population likely occurs after the first summer growing season. *Sebastes caurinus* and *S. maliger* abundances declined in Yaquina Bay in the late fall (Figure 2.10), similar to the findings of Miller and Geibel (1973) and Love *et al.* (1991); they also observed this with *S. melanops*, *S. paucispinis*, *S. pinniger*, and *S. flavidus*, and postulate that the outmigration is cued by the arrival of winter storms and more turbulent conditions. Although these declines could be associated with mortality.

All recaptures occurred at the original tagging site; no movement between sites was demonstrated. Rockfish are known to have established home ranges (Parker *et al.* 2007) and exhibit site fidelity (Jorgensen *et al*. 2006; Mitamura *et al.* 2009). This pattern in Yaquina Bay is similar to that observed in Monterey (Miller and Geibel 1973), where post-settlement juvenile blue (*S. mystinus)* rockfish remained close to their settlement location, displaying minimal (~60-90 m) or no movement, within a narrow range of habitat types that likely provided adequate food and cover. In northern California, *S. melanops* demonstrated site fidelity in intertidal areas (Lomeli 2009) and they have been shown to remain at the initial settlement location in the nearshore environment from 5 months to at least a year (Hobson *et al.* 2001). Young-of-the-year *S. flavidus* also exhibited high sight fidelity (Hobson *et al.* 2001).

Yaquina Bay rockfishes were recaptured at a higher rate at the anthropogenic sites (Table 2.6), although both habitats had at least one rockfish recaptured twice. Elsewhere, recapture rates for juvenile *S. caurinus*, *S. maliger*, *S. melanops* and *S. flavidus* rockfishes in eelgrass and kelp habitats in Alaska range between 13.5% and 24% (Byerly 1999; Johnson 2000), including recaptures of age-2+ fish from the previous year, with 72% of those recaptured at the original tagging location (Johnson 2000). Recapture rates of 38% were observed in California rocky intertidal areas, with some *S. melanops* rockfish recaptured multiple times (Lomeli 2004). The higher recapture rates with these studies may be due to differences in sampling site parameters: sites within four small semi-enclosed bays (Byerly 1999), or sites in small enclosed bays (Johnson 2000), a focus on age-1+ rockfish (Byerly 1999; Johnson 2000) which have a higher survival rate than YOY, or overall differences in sampling effort.

The occurrence of recaptures illustrates site fidelity, as has been observed elsewhere (Byerly 1999) although my recaptures in the seagrass beds also implies home ranges that include ephemeral habitats such as tidally exposed sea grass beds. The non-continuous nature of the monitoring strategy employed in this study makes it impossible to definitively conclude that these rockfish exhibit true site fidelity; however, my data show no evidence of migration between sampling sites. The PH-D and the PH-E are the two closest sites, approximately 30 m apart (Figure 2.1) and there was no migration documented between these sites.

The marine environment is highly dynamic. In addition to anthropogenic effects, anomalies such as “the blob” (Milstein 2014), and other factors such as *El Niño* and the Pacific Decadal Oscillation play important roles in the variable recruitment success of marine species. Community compositions shift population demographics change and species ranges expand or contract (Medred 2014). This study documented the presence of five additional rockfishes in Yaquina Bay and the shifting of the rockfish composition from the predominantly *S. melanops* to *S. maliger* and *S. caurinus*.

Rockfish are a species both commercially and recreationally fished, providing resources for many. As human populations increase, demand on this resource will also increase. Therefore, using the knowledge gained in this study to identify, manage, protect and potentially increase suitable habitat may increase rockfish (and other estuarine species) abundance, thereby helping to provide a consistent food source for mankind. Also, any habitat protections put in place to enhance rockfish populations will likely have positive effects on other species in the ecosystem, creating a healthy and holistic system, hence a more productive and stable food web. For instance, the RCAs which have been in place for over 13 years, provide potential increase in rectuitment. As the knowledge regarding YOY and juvenile rockfishes increases, this information may be applied to other marine species, helping to create a more complete picture of the northeast Pacific estuarine communities, their food webs, and their resources.

This study contributes information regarding the use of estuarine habitat as nursery grounds, by rockfishes in Yaquina Bay. In particular I provide more detailed information on the use of anthropogenic structure but also illustrates the importance and utilization of the natural *Z. marina* habitat. These data provide evidence that while some species exhibit a preference for anthropogenic structure it also demonstrates that certain rockfish species utilize only the natural habitat. Due to anthropogenic forces and the destruction and loss of estuarine habitat, it is imperative that these high-quality habitats are identified, conserved and managed. Between 2004 and 2009, an average of 80,000 acres were lost per year in the coastal watersheds of the Pacific, Atlantic, the Gulf of Mexico and the Great Lakes (EPA 2016). As of 2008, approximately 4,740 acres of estuarine and marine wetlands were lost annually (Lellis-Dibble *et al.* 2008). This indicates the importance of protecting and maintaining this natural habitat, yet illustrates the importance of both habitat types in the estuarine ecosystem for different species and year classes through the year. This information is useful for management and conservation of rockfish, other estuarine fish and invertebrate species for Yaquina Bay, estuaries along the Pacific Coast and other estuarine ecosystems. As coastal ecosystems are one of the more threatened habitats this knowledge provides information pertinent for habitat protection, improvement and species conservation.

Sampling limitations

As with all studies, there are sampling limitations that constrain the inference of the work. Our sole sampling gear was minnow traps, which likely have a selectivity that can bias species and sizes vulnerable to capture. Furthermore, there may be habitat effects on trap efficiency. Gallagher (2007) indicated that minnow traps may underestimate the total abundance of fish in highly complex habitats. Rockfish may use the traps as refuge, as there was no difference in CPUE with bait or without (Appy and Collson 2000). Therefore in highly complex habitats there is less need for refuge, so trap efficiency may be less. Another unknown factor is the result of trap avoidance, especially when using mark/recapture techniques. Furthermore, as various species use different depths in the water column, trap level is an important variable (Appy and Collson 2000). Given that our traps were deployed only on the bottom we may have missed some species and size classes that are further up in the water column. The issue of site location arises as the estuary is strongly influenced by tides, therefore trapping at numerous locations within the estuary and at numerous depths may provide different results. This study concentrated on only two habitat types within the estuary and it was spatially limited in scope, so further research is needed to develop a holistic view of rockfish use across the entire estuary ecosystem.

Conclusion

My work presents a new temporal view of estuarine nursery habitat use by juvenile rockfishes, revealing new insights into the seasonal cycles of juvenile rockfish populations, including the peak of abundance in November. This study provides evidence for limited home ranges, high site fidelity, and overwinter survival and residence of juvenile rockfish in the Yaquina Bay estuary. *Sebastes paucispinis, S. maliger, S. auriculatus, S. nebulosus,* and *S. pinniger* were documented for the first time in the estuary. Insight into the seasonal cycle of the rockfish community and the role that natural and anthropogenic influences play in estuarine settlement dynamics was achieved. The value of the data generated from my and others' work, collected over a long temporal scale, offers the ability to elucidate significant information on these fishes' life cycle and the nursery functions of Pacific Northwest estuaries.

Acknowledgements

I would like to thank the following folks for their assistance in the field: David Loomis, Christina Bailey, Josh Etherton and Scarlett Arbuckle. I would like to thank Jim Power, Jessica Miller and Ric Brodeur for guidance and input. This work was conducted under approved Oregon State University Animal Care and Use Protocol #4188, approved sampling permit #16896 M2 from the Oregon Department of Fish and Wildlife and the Department of State Lands application #50592. I would like to thank the Hatfield Marine Science Center for the Mamie Markham Research Award, the Oregon Chapter of the American Fisheries Society for the Master's Student Award and the Carl Bond Award, and the Oregon State University Department of Fisheries and Wildlife for the Munson Travel Award and the Laurels Scholarship.

Literature Cited

Able, K. 1999. Measures of juvenile fish habitat quality: examples from a national estuarine research reserve. American Fisheries Society Symposium 22:134-147.

Anderson, T.W. 1983. Identification and development of nearshore juvenile rockfish (genus *Sebastes*) in central California kelp forests. MS thesis, California State University, Fresno. 215pp.

Anderson, T.W., E.E. DeMartini and D.A. Roberts. 1989. The relationship between habitat structure, body size, and distribution of fishes at a temperate artificial reef. Bulletin of Marine Science 44:681-697.

Appy, M. and P.J. Collson. 2000. Oregon coastal juvenile rockfish study (Draft). Estuarine Habitat, Marine Resources Division, Oregon Department of Fish and Wildlife.

Baltz, D.M. and R.F. Jones. 2003. Temporal and spatial patterns of microhabitat use by fishes and decapod crustaceans in a Louisiana estuary. Transactions of the American Fisheries Society 132(4):662-678.

Bayer, R.D. 1981. Shallow-water intertidal icthyofauna of the Yaquina Estuary, Oregon. Northwest Science Vol. 55, No. 3:182-193.

Beck, M.W., K.L. Heck Jr., K.W. Able, D.L. Childers, K. Hoshine, D.B. Eggleston, B.M. Gillanders, B. Halpern, C.G. Hays, K. Hoshine, T.J. Minello, R.J. Orth, P.F. Sheridan, and M.P. Weinstein. 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. BioScience 51(8): 633-641.

Boehlert, G.W. 1981. The effects of photoperiod and temperature on laboratory growth of juvenile *Sebastes diploproa* and a comparison with growth in the field. Fishery Bulletin 79: 789-979.

Boehlert, G.W. 1982. Ontogenetic changes in growth and their relationship with temperature and habitat change. *In* GUTSHOP 81, Fish food habits studies, proceedings of the Third Pacific Workshop, December 6-9, 1981, Pacific Grove, California. G.M. Cailliet and C.A. Simenstad (eds). Washington Sea Grant Publication, University of Washington Sea Grant Publication, Seattle, Washington. WSW-WO 82-2, pp. 115-123.

Boehlert, G.W. and M.M. Yoklavich. 1983. Effects of temperature, ration, and fish size on growth of juvenile black rockfish, *Sebastes melanops.* Environmental Biology of Fishes 8(1):17-28.

Boehlert, G.W. and B.C. Mundy. 1988. Roles of behavioral and physical factors in larval and juvenile fish recruitment to estuarine nursery area. American Fisheries Society Symposium 3:51-67.

Bylery, M. 1999. Residence time of juvenile rockfish in eelgrass/kelp habitats. Alaska Fisheries Science Center, National Marine Fisheries Service. Quarterly report for July-August-September.

Dahlgren, C.P. and D.B. Eggleston. 2000. Ecological processes underlying ontogenetic habitat shifts in a coral reef fish. Ecology 81(8):2227-2240.

Dahlgren, C.P., G.T. Kellison, A.J. Adams, B.M. Gillanders, M.S. Kendall, C.A. Layman, J.A. Ley, I. Nagelkerken, and J.E. Serafy. 2006. Marine nurseries and effective juvenile habitats: concepts and applications. Marine Ecology Progress Series 321:291-295.

Dauble, A.D. 2010. Young-of-the-year rockfish (*Sebastes* spp.) settlement dynamics in Oregon estuaries. MS thesis. Oregon State University, Corvallis, Oregon.

Dauble, A.D., S.A. Heppell, and M.L. Johansson. 2012. Settlement patterns of young-of-the-year rockfish among six Oregon estuaries experiencing different levels of human development. Marine and Ecology Progress Series Vol. 448:143-154.

De Ben, W.A., W.D. Clothier, G.R. Ditsworth, and D.J. Baumgartner. 1990. Spatio-temporal fluctuations in the distribution and abundance of demersal fish and epibenthic crustaceans in Yaquina Bay, Oregon. Estuaries 13(4):469-478.

Dewey, M.R. and S.J. Zigler. 1996. An evaluation of fluorescent elastomer for marking bluegills in experimental studies. The Progressive Fish-Culturist 58:219-220.

EPA (U.S. Environmental Protection Agency). 2016. Wetlands: coastal wetlands. Available: https://www.epa.gov/wetlands/coastal-wetlands#loss. (May 23, 2016).

FishBase. 2016. Available: http://www.fishbase.se/search.php. (June 21, 2016).

Frable, B.W., D.W. Wagman, T.N. Frierson, A. Aguilar, and B.L. Sidlauskas. 2015. A new species of Sebastes (Scorpaeniformes: Sebastidae) from the northeastern Pacific, with a redescription of the blue rockfish, *S. mystinus* (Jordan and Gilbert, 1881). Fishery Bulletin 113(4): 355-378.

Fuiman, L.A. and R.G. Werner (eds.). 2002. Fishery Science: The unique contributions of early life stages. Blackwell Science, Oxford. 326 pp.

Gallagher, M.B. 2007. Growth rates and species composition of juvenile rockfish (*Sebastes* spp.) in Oregon’s nearshore and estuarine habitats. MS thesis. Oregon State University, Corvallis, Oregon.

Gallagher, M.B. and S.S. Heppell. 2010. Essential habitat identification for age-0 rockfish along the central Oregon coast. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 2:60-72.

Gillanders, B.M., K.W. Able, J.A. Brown, D.B. Eggleston and P.F. Sheridan. 2003. Evidence of connectivity between juvenile and adult mobile marine fauna: an important component of nurseries. Marine Ecology Progress Series 247:281-295.

Griffiths, S.P. 2002. Retention of visible implant tags in small rockpool fishes. Marine Ecology Progress Series Vol. 236:307-309.

Heady, W.N., K. O'Connor, J. Kassakian, K. Doiron, C. Endris, D. Hudgens, R. P. Clark, J. Carter, and M. G. Gleason. 2014. An inventory and classification of U.S. West Coast estuaries. The Nature Conservancy. Arlington, VA. 81pp.

Heck, K.L., G. Hays, and R.J. Orth. 2003. Critical evaluation of the nursery role hypothesis for seagrass meadows. Marine Ecology Progress Series 253:123-136.

Hobson, E.S., J.R. Chess and D.F. Howard. 2001. Interannual variation in predation on first-year *Sebastes* spp. by three northern California predators. Fisheries Bulletin 99(2):292-302.

Hughes, B. B., M. D. Levey, J. A. Brown, M. C. Fountain, A. B. Carlisle, S. Y. Litvin, C. M. Greene, W. N. Heady and M. G. Gleason. 2014. Nursery functions of U.S. West Coast estuaries: The state of knowledge for juveniles of focal invertebrate and fish species. The Nature Conservancy. Arlington, VA. 168pp.

Jennings, S., M.J. Kaiser, and J.D. Reynolds. 2001. Marine Fisheries Ecology. Blackwell Publishing. Malden, MA. 417pp.

Johnson, K.A., M.M. Yoklavich, and G.M. Cailliet. 2001. Recruitment of three species of juvenile rockfish (*Sebastes* spp.) on soft benthic habitat in Monterey Bay, California. California Cooperative Oceanic Fisheries Investigations Report 42:153-166.

Johnson, S. 2000. Residence, diet, growth, and condition of juvenile rockfish in subtidal vegetated habitats southeast Alaska. Alaska Fisheries Science Center, National Marine Fisheries Service. Quarterly report for July-August-September.

Jorgensen, S.J., D.M. Kaplan, A.P. Klimley, S.G. Morgan, M.R. O'Farrell and L.W. Botsford. 2006. Limited movement in blue rockfish *Sebastes mystinus*: internal structure of home range. Marine Ecology Progress Series 327:157-170.

Kennish, M.J. 2002. Environmental threats and environmental future of estuaries. Environmental Conservation 29(1):78-107.

Laidig, T.E., J.R. Chess, and D.F. Howard. 2007. Relationship between abundance of juvenile rockfishes (*Sebastes* spp). and environmental variables documented off northern California and potential mechanisms for the covariation. Fisheries Bulletin 105:39-48.

Laroche, W.A. and S.L. Richardson. 1980. Development and occurrence of larvae and juveniles of the rockfishes *Sebastes flavidus* and *Sebastes melanops* (Scorpaenidae) off Oregon. Fishery Bulletin 77(4):901-924.

Larson, R. J., W. H. Lenarz, and S. Ralston. 1994. The distribution of pelagic juvenile rockfish of the genus *Sebastes* in the upwelling region off central California. California Cooperative Oceanic Fisheries Investigations Report 35:175-221.

LDLC (Oregon Department of Land Conservation and Development). No date. Estuaries. Oregon Coastal Management Program. Land Conservation and Development Commission. http://www.oregon.gov/LCD/OCMP/pages/est_intro.aspx. (July 24, 2015).

Leaman, B.M. 1976. The associate between the black rockfish (*Sebastes melanops* Girard) and beds of the giant kelp (*Macrocystis integrifolia* Bory) in Barkley Sound, British Columbia. M.Sc. Thesis, University of British Columbia, Vancouver. 109pp.

Lellis-Dibble, K.A., K.E. McGlynn and T.E. Bigford. 2008. Estuarine fish and shellfish species in U.S. commercial and recreational fisheries: economic value as an incentive to protect and restore estuarine habitat. National Marine Fisheries Service. National Oceanic and Atmospheric Administration Technical Memorandum NMFS-F/SPO-90.

Lenarz, W.H. 1987. A history of California rockfish fisheries. Pages 35-42 *in* Proceedings of the International Rockfish Symposium. Alaska Sea Grant Report 87-2, Anchorage.

Lomeli, M.J.M. 2004. Site fidelity of young-of-the-year black rockfish, *Sebastes melanops*, in rocky intertidal areas of northern California. Western Society of Naturalist 85th annual meeting, Rohnert Park, California.

Lomeli, M.J.M. 2009. The movement and growth patterns of young-of-the-year black rockfish, (*Sebastes melanops*) inhabiting two rocky intertidal areas off Northern California. MS thesis. Humboldt State University, Arcata, California.

Lotterhos, K.E., S.J. Dick and D.R. Haggarty. 2014. Evaluation of rockfish conservation area networks in the United States and Canada relative to the dispersal distance for black rockfish (*Sebastes melanops*). Evolutionary Applications 7:238-259.

Love, M.S., M.H. Carr, and L.J. Haldorson. 1991. The ecology of substrate-associated juveniles of the genus *Sebastes*. Environmental Biology of Fishes 30:225-243.

Love, M.S., M. Yoklavich, and L. Thorsteinson. 2002. The rockfishes of the northeast Pacific. University of California Press, Berkeley and Los Angeles, California. 405pp.

Matthews, K.R. 1989. A comparative study of habitat use by young-of-the-year, subadult, and adult rockfishes on four habitat types in central Puget Sound. Fishery Bulletin 88(2):223-239.

MacNeill, D.B. 2010. Why is fish habitat important? Fish habitat factsheet #1. Conservation strategy for enhancement of St. Lawrence River native fish populations. New York Sea Grant. State University of New York at Environmental School of Forestry.

McCain, B.B., S.D. Miller and W. W. Wakefield II. 2005. Life history, geographical distribution, and habitat associations of 82 West Coast groundfish species: a literature review. Pacific Coast groundfish fishery management plan for the California, Oregon, and Washington groundfish fishery, Appendix B Part 2, Groundfish life history descriptions. Pacific Fisheries Management Council. Portland, Oregon.

Melstein, M .2014. Unusual North Pacific warmth jostles marine food chain. Northwest Fisheries Science Center. National Oceanic and Atmospheric Administration. Available: https://www.nwfsc.noaa.gov/news/features/food_chain/. (April 21, 2016).

Medred, C. 2014. Unusual species in Alaska waters indicate parts of Pacific warming dramatically. Environment. Alaska Dispatch News Available: http://www.adn.com/article/20140914/unusual-species-alaska-waters-indicate-parts-pacific-warming-dramatically. (April 21, 2016).

Miller, D.J. and J.J. Geibel. 1973. Summary of blue rockfish and lingcod histories; A reef ecology study; and giant kelp, *Macrocycstis Pyrifera*, experiments in Montery Bay, California. The Resources Agency, Department of Fish and Game, State of California. Fish Bulletin 158. Available: http://www.oac.cdlib.org/view?docId=kt7489n8pd&brand=oac4&doc.view=entire_text. (July 24, 2014.)

Miller, J.A., J.S. Burke, and G.R. Fitzhugh. 1991. Early life history Patterns of Atlantic North American flatfish: likely (and unlikely) factors controlling recruitment. Netherlands Journal of Sea Research 27(3/4):261-275.

Miller, J.A. and A.L. Shanks. 2004. Ocean-estuary coupling in the Oregon upwelling region: abundance and transport of juvenile fish and of crab megalopae. Marine Ecology Progress Series 271:267-279.

Moser, H.G. and G.W. Boehlert. 1991. Ecology of pelagic larvae and juveniles of the genus *Sebasates*. Environmental Biology of Fishes 30:203-224.

Mitamura, H., K. Uchida, Y. Miyamoto, N. Arai, T. Kakihara, T. Yokota, J. Okuyama, Y. Kawabata and T. Yasuda. 2009. Preliminary study on homing, site fidelity, and diel movement of black rockfish *Sebastes inermis* measured by acoustic telemetry. Fisheries Science 75:1133-1140.

Murphy, M.L., S.W. Johnson, and D.J. Csepp. 2000. A comparison of fish assemblages in eelgrass and adjacent subtidal habitats near Craig, Alaska. Alaska Fishery Research Bulletin 7:11-21.

NOAA (National Oceanic and Atmospheric Administration). 2006. Magnuson-Stevens Act Provisions, fisheries off West Coast states, Pacific Coast groundfish fishery. Federal Register 50 CFR Part 660 (docket number 051213334-6119-02; I.D. 112905C), RIN 0648-AT98.

NOAA (National Oceanic and Atmospheric Administration). 2008. The future of estuaries: managing, protecting and restoring estuaries. Estuaries. http://oceanservice.noaa.gov/education/kits/estuaries/estuaries11_future.html. (April 15, 2015).

NOAA (National Oceanic and Atmospheric Administration). No date. Physical oceanographic considerations. Ocean ecosystem indicators. Northwest Fisheries Science Center. Available: https://www.nwfsc.noaa.gov/research/divisions/fe/estuarine/oeip/ja-physical-oceanographic-factors.cfm. (May 21, 2016).

PFMC (Pacific Fishery Management Council). 2015. Petrale sole and canary rockfish, important West Coast groundfish stocks, rebuilt to sustainable level. Groundfish. Available: http://www.pcouncil.org/2015/06/37408/petrale-sole-and-canary-rockfish-important-west-coast-groundfish-stocks-rebuild-to-sustainable-level/. (April 9, 2016.)

Parker, S.J., P.S. Rankin, J.M. Olson and R.W. Hannah. 2007. Movement patterns of black rockfish (*Sebastes melanops*) in Oregon coastal waters. Biology, assessment, and management of north Pacific rockfishes. Alaska Sea Grant College Program: AK-SG-07-01.

Pollard, D.A. 1984. A review of ecological studies on seagrass-fish communities, with particular reference to recent studies in Australia. Aquatic Botany 18:3-42.

Ralston, S., K.M. Sakuma, and J.C. Field. 2013. Interannual variation in pelagic juvenile rockfish (*Sebastes* spp.) abundance - going with the flow. Fisheries Oceanography 22(4):288-308.

Rooper, C.N., J.L. Boldt, S. Batten, and C. Gburski. 2012. Growth and production of Pacific ocean perch (*Sebastes alutus*) in nursery habitats of the Gulf of Alaska. Fisheries Oceanography 21(6):415-429.

Schlosser, S. and J. Bloeser. 2006. The collaborative study of juvenile rockfish, cabezon, and kelp greenling habitat associations between Morro Bay, California and Newport, Oregon. California Sea Grant and Pacific Marine Conservation Council Cooperative Research Project.

Staples, D.J. 1980. Ecology of juvenile and adolescent banana prawns, *Peraeus merguiensis*, in a mangrove estuary and adjacent off-shore area so the Gulf of Carpenteria. Australian Journal of Marine Freshwater Research 31:635-652.

TNC (The Nature Conservancy). 2008. History of the U.S. West Coast groundfish fishery. Available: http://www.morrobaycommunityquotafund.org/wpcontent/uploads/2012/10/CCGP_GroundfishFisheryHistory_080515-1.pdf. (June 29, 2014).

USOFR (U.S. Office of the Federal Register). 2010. Endangered and Threatened Wildlife and Plants: Threatened Status for the Puget Sound/Georgia Basin Distinct Population Segments of Yelloweye and Canary Rockfish and Endangered Status for the Puget Sound/Georgia Basin Distinct Population Segment of Bocaccio Rockfish Code of Federal Regulations, 50 CFR Parts 223 and 224. National Marine Fisheries and National Oceanic and Atmospheric Administration, United States Department of Commerce. Vol. 75(81):22276-22290.

USOFR (U.S. Office of the Federal Register). 2013. Title 50- Wildlife and Fisheries. Chapter VI: Fishery conservation and management, Sub-part C: West coast groundfish fisheries. Code of Federal Regulations, 660.40. National Oceanic and Atmospheric Administration, United States Department of Commerce. Available: http://cfr.vlex.com/vid/overfished-species-rebuilding-plans-300048238. (May 15, 2014).

Valentine, J.F. and Duffy, J.E. 2006. The central role of grazing is seagrass ecology. In: Larkum A.W.D, R.J. Orth, C.M. Duarte (eds.) Seagrasses: biology, ecology and conservation. Springer, Dordrecht p.463-501.

Waycott, M., C.M. Duarte, T.J.B. Carruthers, R.J. Orth, W.C. Dennison, S. Olyarnik, A. Calladine, J.W. Fourqurean, K.L. Heck Jr., A.R. Hughes, G.A. Kendrink, W.J. Kenworthy, F.T. Short, and S.L. Williams. 2009. Accelerating loss of seagrasses across the globe threatens coastal ecosystems. Proceeding of the National Academy of Sciences 106(30):12377-12381.

West, J.E., R.M. Buckley and D.C. Doty. 1994. Ecology and habitat use of juvenile rockfishes (*Sebastes* spp.) associated with artificial reefs in Puget Sound, Washington. Bulletin of Marine Science 55(2-3):344-350.

CHAPTER 3: GENERAL CONCLUSIONS

Juvenile rockfish (*Sebastes* spp.) inhabit estuaries on the Pacific Coast. Determining the ecological requirements for juvenile rockfish habitat that minimize mortality, maximize growth and increase population numbers will assist managers and biologists in managing and protecting critical habitats and guide further ecosystem studies. There is limited information regarding juvenile rockfish and their nurseries, so the information gained from this study helps advance our understanding of Oregon rockfish dynamics in estuary ecosystems.

In particular I provide more detailed information on rockfish use of anthropogenic structure but also illustrate the importance and utilization of natural habitat, eelgrass beds (*Zostera marina*). The two habitats are very diverse, the natural creates a complex and dynamic ecosystem due to its spatial patchiness and ephemeral existence while the anthropogenic provides a more consistent environment with greater vertical relief and less heterogeneity. These data provide evidence that while some species exploit anthropogenic structure it also demonstrates that certain rockfish species utilize only the natural habitat.

This study provides evidence for the presence of new rockfish species previously undocumented in the estuary, overwinter persistence of juvenile rockfish, some degree of site fidelity, and minimal movement of juvenile rockfish in the Yaquina Bay estuary during the period of this study. With this increase in species richness, there also appears to be a community shift away from *Sebastes melanops* as the dominant species (Gallagher 2007; Dauble 2010) to *S. maliger* and *S. caurinus* as the most abundant. The presence of the new species and the altered rockfish composition is important information regarding the *Sebastes* complex and is thought-provoking; is this an anomaly, natural variation or is this change in the rockfish assemblage occurring in other locales? As the estuaries are nursery grounds, the change in the estuarine community may impact nearshore assemblages. Or as natural systems are dynamic, the shifting of rockfish species may not have an impact on the marine ecosystem.

The recapture of juveniles in both natural (*Z. marina*) and anthropogenic (piers) habitat demonstrates rockfishes’ successful use of multiple Yaquina Bay habitat types as nursery grounds year-round. There is seasonal variability in rockfish use of the anthropogenic and natural habitat, with the anthropogenic habitats having an overall higher capture rate and a higher occurrence of larger rockfish (Table 2.4; Figure 2.7). All eight species are present in the natural, *Z. marina* habitat, while *S. pinniger* and *S. auriculatus* are not present in the anthropogenic, pier habitat (Figure 2.13). The occurrence of recaptures illustrates persistence, and indicates site fidelity and possibly small home ranges for these individuals, with no movement detected among sites sampled. The value of the data sets generated from my and others' work, collected over a long temporal scale offer the ability to elucidate significant information on these fishes life cycle and the nursery functions of Pacific Northwest estuaries.

Oregon estuaries are few in number, and therefore encroachment upon them for agriculture, land development, recreation, harbors, and waste disposal will be powerful (Pearcy and Myers 1974). In addition, the impacts from climate change, degraded water quality, coastal development and altering oceanic conditions will intensely modify estuarine ecosystems. For the last half of the 20th century Yaquina Bay has experienced intense shoreline development, creating alterations in 45% of the natural shoreline of the lower estuary (Heppell *et al. in review*). Both resident and migrant species which inhabit estuaries are potentially impacted by the numerous anthropogenic influences which may have a direct impact upon both abiotic and biotic components including distribution, breeding, survival, growth, abundance, behavior, diversity and food resources. Due to anthropogenic forces and the destruction and loss of estuarine habitat, it is imperative that these high-quality habitats are identified, conserved and managed. Between 1998 and 2004, in the United States, a total loss of 0.9% occurred in estuarine emergent wetlands, amounting to 5,540 acres per year (Lellis-Dibble 2008). This indicates the importance of protecting and maintaining this natural habitat, yet illustrates the importance of both habitat types in the estuarine ecosystem for different species and year classes through the year.

Future research

Many of the topics investigated here provide a baseline for future work. One goal for future studies of juvenile rockfish should be to determine which estuarine habitats are of highest quality that support juvenile contribution to the adult population. These critical habitats have been termed "effective juvenile habitat" (EJH), nursery habitats that help maintain adult populations because of their contributing role as a source of new recruits (Dahlgren *et al.* 2006). These areas enhance survival of young-of-the-year (YOY) to age-1 and beyond.

One critical missing link in our understanding of the ontogeny of rockfishes is the actual recruitment process to the adult population and more importantly the connectivity between the nursery and adult habitat. An understanding of the connectivity between juvenile and adult populations and habitats, especially those that supply recruits, has many implications for conservation and management of this species complex. For this reason, it is of great importance to measure ontogenetic movements, which will assist us in understanding the spatiotemporal role of nursery habitats. Investigating ontogenetic habitat shifts can be done in a variety of ways; our technique of visible implant elastomer (VIE) determined no movement, therefore another, possibly longer-term method would likely need to be used. These methods include stable isotope analysis (Cunjak *et al.* 2005), otolith chemistry (Elsdon *et al.* 2008; Miller *et al.* 2011), and acoustic and passive integrated transponder (PIT) tagging. The necessary equipment for electric tagging methods is expensive, as is monitoring, but more importantly YOY rockfish are typically small and tags appropriate for their size have very limited detection range. Similar limitations exist for other implantable or attachable tags. The tagging of age-2 year class and older juveniles would reduce the size issue (but not the monitoring issue), and would provide some knowledge about the movement of juveniles toward those deeper adult habitats. One of the main techniques used to infer habitat connectivity and movement are the progression of size classes and changes in abundance among habitats.

Longer term studies, perhaps with higher sampling frequencies at various depths, will improve our understanding of early life history, movement, and habitat requirements for juvenile rockfish in estuary ecosystems and provide insight to the estuary ecosystem as a whole. This information, coupled with water quality and chemistry, and weather and climate data will provide a more complete picture of estuarine conditions as they relate to rockfish residence. Movement, growth, recruitment, settlement, and survival can all be influenced by temperature, weather, salinity and ocean conditions. Inter-annual and seasonal fluctuations in environmental conditions may generate ecological filters which affect habitat conditions for early life stages which in turn may then influence recruitment for estuarine dependent species (Baltz and Jones 2003).

Zostera japonica, an invasive eelgrass, is now present in many areas in Yaquina Bay. As it has been determined that *Z. marina* provides viable nursery habitat, especially in the summer, it would be interesting to know whether this invasive species also provide suitable and productive habitat for rockfish. A study in Yaquina Bay has noted the exponential increase of *Z. japonica* in the intertidal zone, however it does not appear to have any effect upon the native *Z. marina* (Young *et al.* 2013). Nevertheless, it may be significant to determine what effect the invasive has upon the fish community and estuary ecosystem.

There is further need to determine the functional significance of estuaries and to increase our understanding of the biotic factors behind estuarine utliziation (Able 2005). My work, combined with future studies, will provide a better understanding of how individual species use microhabitats within the estuary, as well as offer valuable information in regards to the estuary ecosystem as a whole and how this might influence population demographics of nearshore fishes. As estuaries are one of the most threatened coastal ecosystem habitats, this knowledge provides information pertinent for habitat protection and improvement, for conservation and management of rockfish, other estuarine fish and invertebrate species for Yaquina Bay, estuaries along the Pacific Coast and other estuarine ecosystems.

LITERATURE CITED

Able, K.W. 2005. A re-examination of fish estuarine dependence: evidence for connectivity between estuarine and ocean habitats. Estuarine, Coastal and Shelf Science 64:5-17.

Baltz, D.M. and R.F. Jones. 2003. Temporal and spatial patterns of microhabitat use by fishes and decapod crustaceans in a Louisiana estuary. Transactions of the American Fisheries Society 132(4):662-678.

Cunjak, R.A., J.M. Roussel, M.A. Gray, J.P. Dietrich, D.F. Cartwright, K.R. Munkittrick and T.D. Jardine. 2005. Using stable isotope analysis with telemetry or mark-recapture data to identify fish movement and foraging. Oecologia 144.4:636-646. DOI 10.1007/s00442-005-0101-9.

Dahlgren, C.P., G.T. Kellison, A.J. Adams, B.M. Gillanders, M.S. Kendall, C.A. Layman, J.A. Ley, I. Nagelkerken, and J.E. Serafy. 2006. Marine nurseries and effective juvenile habitats: concepts and applications. Marine Ecology Progress Series 321:291-295.

Dauble, A.D. 2010. Young-of-the-year rockfish (*Sebastes* spp.) settlement dynamics in Oregon estuaries. MS thesis. Oregon State University, Corvallis, Oregon.

Elsdon, T. S., B.K. Wells, S.E. Campana, B.M. Gillanders, C.M. Jones, K.E. Limburg, and B.D. Walther. 2008. Otolith chemistry to describe movements and life-history parameters of fishes: hypotheses, assumptions, limitations and inferences. Oceanography and marine biology: an annual review 46(1):297-330.

Gallagher, M.B. 2007. Growth rates and species composition of juvenile rockfish (*Sebastes* spp.) in Oregon's nearshore and estuarine habitats. MS thesis. Oregon State University, Corvallis, Oregon.

Heppell, S.S., S.A. Heppell, and M.B. Gallagher. In review. A shift in benthic marine community dominance in Yaquina Bay, Oregon.

Lellis-Dibble, K.A., K.E. McGlynn and T.E. Bigford. 2008. Estuarine fish and shellfish species in U.S. commercial and recreational fisheries: economic value as an incentive to protect and restore estuarine habitat. National Marine Fisheries Service. National Oceanic and Atmospheric Administration Technical Memorandum NMFS-F/SPO-90.

Miller, J.A., V.L. Butler, C.A. Simenstad, D.H. Backus, and A.J.R. Kent. 2011. Life history variation in upper Columbia River Chinook salmon (*Oncorhynchus tshawytscha*): a comparison using modern and ~500-year-old archaeological otoliths. Canadian Journal of Fisheries and Aquatic Sciences 68.4:603-617.

Pearcy, W.G. and S.S. Myers. 1974. Larval fishes of Yaquina Bay, Oregon: a nursery ground for marine fishes. Fishery Bulletin 72(1):201-213.

Young, D., P. Clinton, D. Specht, and T. MochonCollura. 2013. Has the rapidly expanding invasive dwarf eelgrass *Zostera japonica* in Yaquina estuary, Oregon impacted the distribution of native eelgrass *Zostera marina* – a critical intertidal habitat? CERF. Presented at Coastal & Estuarine Research Federation Biennial Meeting. San Diego, CA. Available: https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=263037&CFID=70346472&CFTOKEN=85343958. (April 2, 2016).

APPENDICES

APPENDIX A

GENETIC RESULTS OF YAQUINA BAY JUVENILE ROCKFISH

From March 2012 through December 2013, we conducted a juvenile rockfish study in Yaquina Bay, Oregon. Yaquina Bay (44°62' N 124°05' W), located in Newport on the central Oregon coast, is a 15.82 km^2 marine-dominated estuary with mixed, semi-diurnal tides. The project itself included both fish trapping and shore seining in anthropogenic and natural habitats. Six different sampling sites for trapping were identified within Yaquina Bay: three located off anthropogenic habitat (piers), which are constantly submerged, and three located in natural habitat (eelgrass beds- *Zostera marina*), which are tidally influenced, therefore during the low spring tides, these sites are often dewatered. Square minnow traps (Aquatic Ecosystems, Inc.) constructed of wood and galvanized steel and measuring 65x65x45 cm, with 19.5, 31.75 and 38.1 mm wide mouth vertical openings, were deployed to collect juvenile rockfish, and other small and young-of-the-year (YOY) fish. Trapping typically occurred bi-monthly during the spring-tide cycle with two replicate traps set at each location during each trapping event. The traps were set unbaited for 24h to encompass a complete daily tide cycle (Schlosser and Bloeser 2006; Dauble 2010). Following the 24h soak, traps were brought to the surface and any trapped fish were emptied into a bucket containing water freshly collected at the trapping site. Shore seining was conducted from March through September 2013, during the trapping cycle, at very low spring tides. A 50’ shore seine was used to survey a site near the south jetty at the entrance of the bay in *Z. marina* habitat.

Each rockfish captured was visually identified to species, if possible, measured for length (TL to the nearest mm), and weighed (to the nearest gram). Visual identification to the species level in the field is extremely challenging because some species exhibit differences in pigmentation depending on the type of habitat (Anderson 1983). Due to the difficulty of identifying YOY rockfish using morphological characteristics (West *et al.* 1994; Love *et al.* 2002), fin clips were taken from the second dorsal fin of a subsample of rockfish in order to confirm identity using genetic analysis

(Gallagher and Heppell 2010; Dauble *et al.* 2012). A total of 825 rockfish were visually identified in the field; of those visually identified a subset of 440 juvenile rockfish were genetically identified.

Genetic analysis was completed at the National Oceanic Atmospheric Administration Southwest Fisheries Science Center (NOAA-SWFSC) using multilocus nuclear DNA genotypes (Pearse *et al.* 2007). The genetic analysis revealed that 12 species of *Sebastes* were captured in Yaquina Bay (Table A.1). Of the 12 species genetically identified, we believe that eight: *S. melanops*, *S. maliger*, *S. caurinus*, *S. paucispinis*, *S. flavidus*, *S. nebulosus*, *S. pinniger* and *S. auriculatus*, were correctly identified based on corroborating evidence. For the other four some question remains based on contrary lines of evidence. Genetic identifications for the eight species that we believe were correctly identified had a correct identification probability > 90% (Table A.1), were in line with expert review of supplemental photographic documentation (Tom Laidig, SWFSC-NOAA, *personal communication*) and the known species ranges for those individuals captured. For the four species we deemed questionable with regard to their genetic identification, they scored < 88% identification probability (Table A.1), expert review of photographic identification was counter to the genetic identification and the location of capture inconsistent with known species ranges. Personal communication with other experts created further doubt. Therefore it is believed that these species may have been incorrectly genetically identified (Table A.1).

Table A.1. Genetic identification of putative *Sebastes* collected in Yaquina Bay, Oregon. Fish genetically identified scientific name (Species), common name of rockfish (Common Name), the number of fish genetically identified as that species (# Genetically ID), genetic identification confirmed with supplemental data (Genetic ID (Y/N)), and percent probability of genetic identification (Genetic ID Probability).

Species	**Common Name**	**# Genetically ID**	**Genetic ID (Y/N)**	**Genetic ID Probability**
S. auriculatus	Brown	2	Y	100%
S. caurinus	Copper	99	Y	75-100%
S. flavidus	Yellowtail	15	Y	75-97%
S. maliger	Quillback	141	Y	50-100%
S. melanops	Black	143	Y	92-100%
S. nebulosus	China	4	Y	71-100%
S. paucispinis	Bocaccio	14	Y	100%
S. pinniger	Canary	1	Y	100%
S. atrovirens	Kelp	13	N	63-87%
S. chrysomelas	Black-and-yellow	1	N	probable
S. saxicola	Stripetail	2	N	probable
S. semicinctus	Halfbanded	1	N	81%

Of the thirteen individuals that were genetically identified as *S. atrovirens*, photographic evidence indicates that at least those two were likely *S. caurinus* (Tom Laidig, SWFSC-NOAA, *personal communication*). Furthermore, given the sampling location, if these fish were *S. atrovirens* this would represent a significant range expansion for this species. This was also true for the one *S. chrysomelas* and the one *S. semicinctus* sampled as well. Because of the contradictory evidence available for some individuals it is quite possible that these rockfish are not the species to which they were genetically assigned. Because of that uncertainty this would introduce into our analysis, regardless of the source of misidentification (genetics, photographic identification), we binned those fishes for which questions existed into species complexes instead of performing single-species analysis on those individuals.

The complexes are the *S. caurinus/maliger* complex (CM complex) and the *S. melanops/flavidus* complex (MF complex). The CM complex includes rockfish that were visually identified as *S. caurinus* and *S. maliger*, and the questionable genetic identifications: *S. atrovirens, S. chrysomelas*, *S. saxicola*, and *S. semicinctus*. The MF complex are the rockfish identified visually as *S. melanops* and *S. flavidus*, with the assumption that the majority of the MF complex are *S. melanops*. For the analysis in Chapter 2, only the 419 confirmed genetically identified rockfish and the complexes are discussed.

Given the significant discord we found between visual and genetic identification, more research is necessary to assist in the proper identification of YOY and juvenile rockfish, both in the field and through genetic analysis.

LITERATURE CITED

Anderson, T.W. 1983. Identification and development of nearshore juvenile rockfish (genus *Sebastes*) in central California kelp forests. MS thesis, California State University, Fresno. 215pp.

Dauble, A.D. 2010. Young-of-the-year rockfish (*Sebastes* spp.) settlement dynamics in Oregon estuaries. MS thesis. Oregon State University, Corvallis, Oregon. 103pp.

Dauble, A.D., S.A. Heppell, and M.L. Johansson. 2012. Settlement patterns of young-of-the-year rockfish among six Oregon estuaries experiencing different levels of human development. Marine and Ecology Progress Series Vol. 448:143-154.

Gallagher, M.B. and S.S. Heppell. 2010. Essential habitat identification for age-0 rockfish along the central Oregon coast. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science 2:60-72.

Love, M.S., M. Yoklavich, and L. Thorsteinson. 2002. The rockfishes of the northeast Pacific. University of California Press, Berkeley and Los Angeles, California. 405pp.

Pearse, D.E., L. Wooninck, C.A. Dean, and J.C. Garza. 2007. Identification of northeastern Pacific rockfish using multilocus nuclear DNA genotypes. Transactions of the American Fisheries Society 136(1):272-280. DOI: 10.1577/T06-051.1.

Schlosser, S. and J. Bloeser. 2006. The collaborative study of juvenile rockfish, cabezon, and kelp greenling habitat associations between Morro Bay, California and Newport, Oregon. California Sea Grant and Pacific Marine Conservation Council Cooperative Research Project.

West, J.E., R.M. Buckley and D.C. Doty. 1994. Ecology and habitat use of juvenile rockfishes (*Sebastes* spp.) associated with artificial reefs in Puget Sound, Washington. Bulletin of Marine Science 55(2-3):344-350.

APPENDIX B

STATISTICAL RESULTS OF YAQUINA BAY JUVENILE ROCKFISH ANALYSES

The following statistics represent the results generated from a negative binomial generalized additive model used to analyze a seasonal-effect-by-site relationship regarding rockfish catch in Yaquina Bay, Oregon, based on data collected during trapping events 19-44 (TE 19-44) (Chapter 2). Data was analyzed with R statistical package (https://www.r-project.org/). These results were presented in Chapter 2- The juvenile rockfishes of the Yaquina Bay in the "Individual rockfish species accounts" section.

Sebastes melanops

```
Family: Negative Binomial(10.528)
Link function: log
Formula:
fishcount ~ Location + s(Day, bs = "cc")

Parametric coefficients:
             Estimate Std. Error z value Pr(>|z|)
(Intercept)   -0.52628    0.39349  -1.337   0.1811
LocationNOAA  -0.96133    0.61170  -1.572   0.1161
LocationNWGas -1.41382    0.82409  -1.716   0.0862 .
LocationOSU   -0.54258    0.58130  -0.933   0.3506
LocationPH_D   0.36907    0.45830   0.805   0.4206
LocationPH_E  -0.09557    0.50035  -0.191   0.8485
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Approximate significance of smooth terms:
        edf Ref.df Chi.sq p-value
s(Day) 4.135      8  15.89 0.00149 **
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =  0.259   Deviance explained = 33.3%
-REML = 86.274  Scale est. = 1         n = 90
```

Sebastes caurinus

```
Family: Negative Binomial(81954.699)
Link function: log
Formula:
fishcount ~ Location + s(Day, bs = "cc")

Parametric coefficients:
             Estimate Std. Error z value Pr(>|z|)
(Intercept)    -0.4424     0.3334  -1.327    0.185
LocationNOAA   -0.4046     0.5272  -0.767    0.443
LocationNWGas  -1.0608     0.7818  -1.357    0.175
LocationOSU     0.2190     0.4410   0.497    0.619
LocationPH_D    0.3421     0.4047   0.845    0.398
LocationPH_E    0.5536     0.4047   1.368    0.171

Approximate significance of smooth terms:
         edf Ref.df Chi.sq p-value
s(Day) 0.0192      8  0.019   0.354
R-sq.(adj) =  0.0538   Deviance explained = 10.2%
-REML = 98.609  Scale est. = 1         n = 90
```

Sebastes maliger

```
Family: Negative Binomial(2.2)
Link function: log
Formula:
fishcount ~ Location + s(Day, bs = "cc")

Parametric coefficients:
             Estimate Std. Error z value Pr(>|z|)
(Intercept)   -0.30207    0.35873  -0.842    0.400
LocationNOAA   0.16972    0.50921   0.333    0.739
LocationNWGas -0.15888    0.56872  -0.279    0.780
LocationOSU    0.44007    0.44521   0.988    0.323
LocationPH_D  -0.29798    0.47075  -0.633    0.527
LocationPH_E  -0.04426    0.49041  -0.090    0.928

Approximate significance of smooth terms:
        edf Ref.df Chi.sq  p-value
s(Day) 2.493      8  16.64 9.21e-05 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

R-sq.(adj) =   0.15   Deviance explained = 25.2%
-REML =  112.4  Scale est. = 1         n = 90
```

***S. caurinus/maliger* complex (CM complex)**

```
Family: Negative Binomial(0.937)
Link function: log
Formula:
fishcount ~ Location + s(Day, bs = "cc")

Parametric coefficients:
             Estimate Std. Error z value Pr(>|z|)
(Intercept)    -0.3612     0.4425  -0.816   0.4143
LocationNOAA    0.6849     0.5842   1.172   0.2410
LocationNWGas  -0.5263     0.7204  -0.731   0.4650
LocationOSU     0.2153     0.5809   0.371   0.7109
LocationPH_D    0.4016     0.5383   0.746   0.4557
LocationPH_E    1.0213     0.5489   1.861   0.0628 .

Approximate significance of smooth terms:
         edf Ref.df Chi.sq p-value
s(Day) 3.784      8  16.57 0.00066 ***
R-sq.(adj) =  0.271   Deviance explained =   28%
-REML = 136.88  Scale est. = 1         n = 90
```

***S. melanops/flavidus* complex (MF complex)**

```
Family: Negative Binomial(0.5)
Link function: log
Formula:
fishcount ~ Location + s(Day, bs = "cc")

Parametric coefficients:
               Estimate Std. Error z value Pr(>|z|)
(Intercept)   -1.570e+00  7.672e-01  -2.047   0.0407 *
LocationNOAA  -1.589e+00  1.287e+00  -1.235   0.2168
LocationNWGas -3.802e+01  2.237e+07   0.000   1.0000
LocationOSU   -9.545e-03  1.021e+00  -0.009   0.9925
LocationPH_D   1.289e+00  8.644e-01   1.491   0.1360
LocationPH_E   3.149e-01  9.295e-01   0.339   0.7348
---
Approximate significance of smooth terms:
         edf Ref.df Chi.sq p-value
s(Day) 2.785      8  11.58 0.00314 **

R-sq.(adj) =  0.192   Deviance explained = 47.7%
```