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Characterizing Changes In Participation And Diversification In Virginia's Small-Scale Commercial Fishing Industry

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Characterizing Changes in Participation and Diversification in Virginia's Small-Scale Commercial Fishing Industry

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ABSTRACT

Small-scale fisheries represent a diverse and dynamic portion of the global commercial fishing population and serve as a source of food security, income, and livelihood for many individuals and contribute to the development of local community and regional identities. Virginia's small-scale commercial fisheries offer similar benefits, accounting for a significant portion of the state's total annual landings and employing thousands of individuals. Despite the value of these fisheries, the number of commercial licenses has declined over the past few decades. Declines are attributed to various factors but indicate potential shifts in participation and resource dependence that may be consequential. Similar to other occupations dependent on natural resources, small-scale fishermen[1] are vulnerable to shocks but can employ diversification strategies within and outside of the fishing sector to increase resilience. This dissertation serves to contribute to a knowledge gap on the extent of diversification and changes in participation and diversification patterns over time in Virginia's small-scale commercial fisheries. In Chapters I and II, state licensing and permitting data, as well as commercial landings data, are used to investigate participation and diversification in wild fisheries and marine-related businesses through structural change, multiple correspondence analyses, and the development of diversification models. In Chapter III, a survey instrument is used to determine the willingness of fishermen to diversify into an emerging species fishery. Chapter IV uses ethnographic interviews to further investigate the role of diversification as a livelihood strategy. The findings of this dissertation indicate that diversification within and outside of Virginia's small-scale commercial fishing industry can serve as an important adaptive strategy. Fishermen who were more diversified had higher and less variable annual incomes than fishermen who were less diversified. Likewise, more diversified individuals tended to remain in the commercial fishing industry for longer. There is evidence of instability in participation and diversification in some wild fisheries and marine-related businesses, however, that reflects the volatility of the commercial fishing industry. Further investigation of the individual diversification behavior indicates a suite of influential factors such as participation in a limited entry fishery or marine-related business, annual income, and socio-demographic variables. These drivers of diversification behavior are useful to managers in predicting responses to adverse events or estimating participation in the future. The findings from Chapter III indicate that ex-vessel price plays an important role in the decision to diversify into an emerging fishery. This dissertation indicates that fishermen are heterogenous in their response to economic, environmental, and social changes and these differences can ultimately influence levels of participation and diversification. Understanding individual decision-making behavior and livelihood strategies of small-scale commercial fishermen is integral in addressing the socio-economic impacts of environmental and management changes. Furthermore, it is important for fishery managers to understand how management and policy decisions influence livelihood strategies, resource dependence, and vulnerability as these constraints threaten the long-term sustainability and resiliency of commercial fishermen, the commercial fishing industry, and coastal communities dependent on commercial fishing.

[1] The term "fishermen" and "watermen" are colloquially appropriate in Virginia and intended to be gender-neutral throughout this dissertation.

Characterizing Changes in Participation and Diversification in Virginia's Small-Scale Commercial Fishing Industry

INTRODUCTION

Characterizing Small-Scale Fisheries on a Global Scale

The role of small-scale fisheries in seafood production and fisheries management is a growing topic in contemporary scientific literature. Small-scale fisheries represent a diverse and dynamic portion of the global commercial fishing population that serve as a source of food security, income, and livelihood for many individuals worldwide (Allison and Ellis 2001; Béné et al. 2007). In addition, small-scale fisheries are often associated with strong, cultural ties that contribute to the development of local community and regional identities (Basurto et al. 2017). The Food and Agriculture Organization (FAO) estimates the number of individuals involved in capture fisheries worldwide to be approximately 38 million people in 2020, however, this estimate increases nearly seven-fold when direct and indirect (e.g., seafood sales and processing) sectors are considered (Teh and Sumaila 2013; FAO 2022). The contribution of small-scale fisheries alone may equate to more than 90 percent of the global commercial fishing population, although it is difficult to assess the extent of participation due to ambiguities in defining a small-scale fishery (Panayotou 1985; McGoodwin 2001; Kleiber et al. 2015; Basurto et al. 2017; Frangoudes et al. 2018). While readily distinguishable from large-scale industrial fleets, definitions of small-scale fisheries can vary greatly across localities as small-scale fisheries in one country may vary drastically from those in another. Nonetheless, there are common economic and socio-cultural characteristics that can be used to identify small-scale fisheries in both developing and developed regions.

The research focus on small-scale commercial fisheries has shifted over time with initial efforts to promote resource exploitation as a means of poverty alleviation and food security, particularly in developing regions, to concerns of overexploitation and needs for increased management and accountability with anticipated large-scale environmental changes (McGoodwin 2001; Béné et al. 2009; Worm et al. 2009). Furthermore, the socio-cultural and economic value of small-scale commercial fisheries within the competitive blue economy has garnered attention in more recent years (Voyer and van Leeuwen 2019). The knowledge surrounding small-scale fisheries is considerably less than that of large-scale industrialized fleets as research has traditionally focused on larger stocks of high economic value, despite the fact that both small- and large-scale fisheries coexist and can overlap in resource use (Berkes et al. 2001).

Furthermore, small-scale fisheries are subject to marginalization as large-scale industrial fisheries tend to disproportionally conjure more political, social and economic power (Chuenpagdee 2011).

Traditional, resource-focused fisheries management often overlooks the role of social institutions in small-scale fisheries, including the importance of fisheries to the cultural and social well-being of individuals and small-scale fishing communities (McGoodwin 2001; Béné 2006; Carothers 2010; Khakzad and Griffith 2016). This approach can result in unintended consequences that reduce the overall political and biological efficacy of management and create broad societal losses (Jentoft and McCay 1995; Allison and Ellis 2001; Crosson 2011). Therefore, it is critical for fisheries scientists and managers to consider the complex interactions between the environment and human systems, as well as the various livelihood strategies that exist within small-scale fisheries (Berkes et al. 2001; Berkes 2003; Jentoft and Chuenpagdee 2009).

The risks associated with small-scale fisheries are similar to other natural resource-based occupations where adverse economic and environmental impacts are often unpredictable (Flint and Luloff 2005; Hurlbert et al. 2019). Despite constant exposure to adverse environmental, management, and economic changes, small-scale fisheries tend to be resilient and capable of adapting to uncertainties (Béné and Friend 2011; Sethi et al. 2014). It is worth considering, however, how resiliency will change or evolve as stressors become more frequent and severe (Allison et al. 2009). Understanding the potential vulnerability of small-scale fisheries is a two-fold process combining the likelihood of risk exposure and the ability to cope with the exposure (Chambers 1989). To reduce vulnerability and increase resilience, a number of natural resource-based occupations, including timber extraction and rural agriculture, implement diversification strategies as a means of stabilizing revenues and countering uncertainty (Vyas 1996; Hurmekoski et al. 2018; Waha et al. 2018). Similar diversification strategies have been noted in small-scale fisheries, although there is limited consideration on drivers regarding diversifications decisions within and outside of commercial fisheries, especially for small-scale fisheries in developed countries.

Diversification across species, gears, or locations is thought to stabilize incomes and reduce vulnerability in commercial fisheries (Kasperski and Holland 2013; Anderson et al. 2017; Cline et al 2017).

Likewise, diversification outside of the commercial fishing industry can provide similar benefits and be used to supplement income when fishing conditions are unfavorable (Allison and Ellis 2001). Although the proposed benefits of diversification have been well-documented, an individual's ability to diversify can be constrained by management regimes (e.g., privatized fisheries), knowledge, financial and social capital, and market factors (Kasperski and Holland 2013; Anderson et al. 2017). In developing countries, where top-down management of small-scale fisheries is often ineffective, community-based management may exclude certain individuals from participating and diversifying across fisheries based on social and cultural norms (Panayotou 1982).

An enhanced understanding of participation and diversification decisions across small-scale fisheries, and the extent to which diversification is occurring, is necessary to increase resilience to adverse impacts in the future (Fuller et al. 2017). Acknowledging the extent to which diversification occurs may be even more pertinent as ongoing environmental changes force fishermen to switch between locations and species (Pinsky and Fogarty 2012; Papaioannou et al. 2021). Furthermore, the drivers of participation in small-scale fisheries may not mirror decisions of those in large-scale fisheries, as small-scale fisheries may be less responsive to market incentives given reduced access to information, increased cultural dependence, or limited employment alternatives outside of fishing (Panayotou 1982; Berkes 2001; Neis et al. 2013). These differences should be considered in management and policy development as a means of ensuring equitable impacts or anticipating individual and community responses to sudden shocks (Pollnac et al. 2012).

Diversification and Participation in Virginia's Small-Scale Commercial Fisheries

Although a majority of research focuses on small-scale fisheries in developing countries, small-scale fisheries also occur in developed regions such as the United States (TBTI 2018). Located in the Mid-Atlantic region of the United States, Virginia is frequently recognized for its abundance of marine resources with annual landings that are considerably larger (likely driven by Atlantic menhaden, *Brevoortia tyrannus*, landings) and of high economic value compared to other states in the region (NMFS 2018). Virginia's small-scale commercial fisheries contribute significantly to the state's total annual landings and economy through harvest of nearshore and inshore coastal species, such as blue crab (*Callinectes sapidus*), eastern oyster (*Crassostrea virginica*), and striped bass (*Morone saxatilis*). These fisheries are considered small-scale due to characteristics of the fishery and the fishermen who target them. For example, these species are commonly inshore or nearshore and are targeted utilizing a variety of labor-intensive gears and methods. Fishermen often complete a fishing trip in less than 24 hours, tend to have smaller crew sizes (if any crew members at all), and fish using smaller vessels (i.e., ~ 20–35 foot vessels). Similar to small-scale fisheries around the world, Virginia's small-scale commercial fisheries provide food security and livelihoods for thousands of individuals, while supporting socio-cultural norms in coastal communities reliant on commercial fishing.

Over the last two decades, participation in Virginia's small-scale commercial fisheries has declined more than 15 percent (VMRC 2018). Several factors may be contributing to the decline, including decreases in species abundances, loss of working waterfronts, habitat degradation, and increasing regulatory pressure (Limburg and Waldman 2009; Andreatta and Parlier 2010; Khakzad and Griffith 2016; Stoll et al. 2016). In addition, a "graying of the fleet" phenomenon has been noted in several small-scale fisheries across the United States, creating a disproportionate population of older fishermen (Donkersloot and Carothers 2016; Cramer et al. 2018; Johnson and Mazur 2018). Likewise, there is anecdotal evidence of shifts in participation as part-time fishermen, who might hold additional employment or earn income through other means, including pension or retirement, appear to be increasing. These shifts in participation, diversification, and resource dependence are potentially problematic for coastal communities, where commercial fisheries are frequently important sources of employment and income (Kirkley 1997). Furthermore, small-scale coastal fisheries are often associated with individual and regional identity and culture (McGoodwin 2001; Poe et al. 2014), suggesting the effects of industry declines may hold broad societal consequences.

There is limited knowledge on levels of resource dependence and diversification strategies implemented in Virginia's small-scale commercial fisheries, although it is likely that diversification strategies and individual decision-making may be similar to those of other reasons. It is also probable that diversification in Virginia's small-scale commercial fisheries has served as a means of adapting to adverse events since the development of the commercial fishing industry. There is evidence that drastic declines of sturgeon (*Acipenser spp.*) in the 1900's drove fishermen to seek stability through other finfish and shellfish species, while fluctuations in eastern oyster populations caused individuals to switch from tonging to other viable fisheries (Burrell et al. 1972; Kirkley 1997). Diversification strategies likely remain integral to Virginia's small-scale fishing industry, although it is unclear how diversification patterns and resource dependence have changed throughout time or how these aspects will continue to evolve in response to changing ecological and environmental conditions. It is valuable to acknowledge levels of resource dependence in small-scale commercial fisheries, as individuals and fishing communities with higher dependence tend to be more vulnerable and less able to rebound from sudden shocks (Marshall et al. 2007). Furthermore, an enhanced understanding of resource dependence and diversification decisions is useful to predict and plan for responses to adverse events, such as abrupt changes in the environment or market fluctuations, and can serve to increase resiliency of individuals and coastal fishing communities.

Background on the Development of Virginia's Small-Scale Commercial Fishing Industry

As Native Americans and early colonists settled along the coast of Virginia, the bountiful natural resources of the Chesapeake Bay provided a means of subsistence and recreation (Wharton 1957). Along Virginia's Eastern Shore, recollections of primitive fishing techniques include riding horseback to corral "rockfish" (likely striped bass) into shallow waters for spearing (Wharton 1957; Burrell et al. 1972). As dependence on Virginia's marine resources increased, colonists recognized the need for conservation and enacted one of the first fishery laws in 1680, which outlawed specific gears to prevent overfishing (Cowdrey 1996). There are few detailed references accounting the commerce of marine resources during earlier periods, although some form of trade likely existed on smaller, localized levels (McHugh and Bailey 1957).

The development of Virginia's small-scale commercial fishing industry followed the Revolutionary War with the authorization of the Potomac River Compact of 1785 (or Maryland-Virginia Compact of

1785). This authorization enabled the expansion of viable fishing territories by allowing Virginia fishermen to legally harvest in the Potomac River (owned by Maryland) in exchange for ship passage (Potomac River Compact §§ 28.2-1001 through 28.2-1007). Industrial expansion allowed for further utilization of the water for commerce with technological developments that permitted efficient harvest of various marine species. Many of these species are still economically and culturally valuable to Virginia's small-scale commercial fishing industry, including the eastern oyster, blue crab, striped bass, hard clam (*Mercenaria mercenaria*), and summer flounder (*Paralichthys dentatus*). The fishing methods used in these fisheries have also remained relatively unchanged, although gears have been adapted in response to advances in mechanization. As Virginia's small-scale commercial fishing industry continued to expand, life on the water became integral to the livelihoods of those residing along the Virginia coastline. In the early 1980's, nearly 8,000 individuals were considered "watermen" and thousands of others were employed in processing plants or other seafood-related industries (Virginia General Assembly 1984).

The Chesapeake Bay is the largest estuarine system in the United States, covering approximately 166,000 km^2 in surface area and serving as viable habitat for many marine species (Bratton et al. 2003; Rick et al. 2016). The state of Virginia is home to a large portion of the Bay and its tributaries. Similar to other estuarine systems, Chesapeake Bay has suffered drastic declines in notable species due to various natural and anthropogenic impacts, including overfishing, pollution, and habitat degradation (Kirby 2004; Rick et al. 2016). Nonetheless, the Chesapeake Bay and its tributaries have, and continue to, support extensive large (i.e., menhaden reduction fishery) and small-scale commercial fisheries. Management of these fisheries occurs through a combination of state, federal, and interstate agencies. Established in 1875 as the Virginia Fish Commission, the Virginia Marine Resources Commission (VMRC) oversees commercial landings, as well as licensing and permitting, of state-managed marine resources such as eastern oyster, blue crab, hard clam, and various finfish species. The VMRC is also responsible for licensing and permitting for processing entities (i.e., shucking houses, shedding operations), charters operating in state waters, and aquaculture. The National Oceanic and Atmospheric Administration (NOAA) is a federal entity that oversees management of fishing harvest outside of state waters, including highly migratory species' fisheries such as tunas, sharks, and billfishes. Most federal fisheries are managed jointly between NOAA and regional fishery management councils. The Atlantic States Marine Fisheries Commission (ASMFC) is an interstate agency that manages species occurring in the state waters of multiple states (e.g., tautog, *Tautoga onitis*), some of which also occur in federal waters (e.g., bluefish, *Pomatomus saltatrix*). Both federal and interstate managed fisheries can provide additional diversification opportunities for Virginia's small-scale commercial fishermen, although participation may be constrained by licensing and permitting requirements, distance from preferred fishing locations, or capital investment.

Abbreviated History of Notable Small-Scale Commercial Fisheries in the Chesapeake Bay

Eastern Oyster (Crassostrea virginica)

Perhaps the most notable of all fisheries in Virginia, the eastern oyster represents one of the earliest commercial fisheries that contributed to the development of the state's coastal communities. Although initially used for subsistence, oyster harvest increased in the mid-1600's for use as lime in construction and agriculture (Bailey 1938; Haven et al. 1973). The early (1700's) commercial oyster fishery primarily utilized hand tongs for harvest, a two-handled device with metal-toothed rakes to scrape small portions of an oyster reef (Kennedy 2018). Localized anthropogenic impacts to oyster reefs were relatively limited and somewhat unrecognized until New England oystermen expanded southward to the Chesapeake Bay in 1808 and employed dredging techniques after depleting northern populations (Alford 1975; Rick et al. 2016). Compared to hand tongs, dredges cover more vertical and horizontal distance by dragging metal-toothed frames along oyster reefs and bottom habitat. Dredging for oysters was banned around 1810, reopened with increased regulations that restricted dredging to waters deeper than 6.1 meters in the mid-1800's, and deemed illegal on public grounds in 1879 (Schulte 2017; Kennedy 2018). However, marine law enforcement was eradicated shortly after in the Chesapeake Bay and illegal dredge harvest displaced many local tong fishermen.

As the commercial fishing industry expanded along Virginia's coast, the oyster remained a primary target and source of income for many individuals. The development of railroads and preservation techniques allowed processors to distribute the species across the United States at a rapid pace, thus furthering the demand for harvest and arguably creating a large-scale oyster fishery during this time period. Additional regulations were implemented in 1866 and included seasonal bushel limits, seasonal harvest bans, and license and tax fees for oyster harvest and oyster processing activities (Schulte 2017). In 1880, peak oyster harvest occurred with 6.3 million bushels of market oysters and 1.9 million bushels of seed oysters (Schulte 2017). Estimates suggest that Virginia and Maryland produced nearly half of the world's oysters around this time (Stevenson 1894; MacKenzie et al. 1997). Also, during this time, a private lease holder system was developed to protect private use oyster planters from poaching by creating permits that allowed individuals to rent subaqueous land in exchange for exclusive cultivation and use rights.

After the Civil War ended, the oyster fishery grew substantially as unemployed individuals sought income from the commercial fishing industry. Towards the end of the 1880's, there were 12,421 tong fishers, 3,221 dredgers (legal at this time), and more than 18,000 individuals employed in the processing and transporting sector of the Virginia oyster fishery (Kennedy 2018). As participation increased, declines in the public oyster fishery were observed by both researchers and fishermen, noting changes in oyster size and abundance (Schulte 2017). Fishery managers responded to these declines with the establishment of Baylor Survey Grounds in 1894 to locate, map, and preserve natural oyster bottom habitat as a public trust (Haven et al. 1978). Nonetheless, Virginia had solidified its position as the largest producer of oysters along the Atlantic coast in the early 1900's (Haven et al. 1978).

In 1904, public oyster harvest almost reached peak levels once more, but fell shortly after due to market fluctuations and increased public fear of oyster-related illnesses correlated with an increase in coastal pollution and displacement of raw sewage on oysters reefs (McHugh and Bailey 1957; Mackenzie and Burrell 1997; Schulte 2017). As public fear subsided and the demand for oysters increased, more regulations were placed on the fishery, including the 1910 "cull law" that allowed fishermen to only retain oysters greater than 76 millimeters in length and return shells and undersized individuals, with the exception of seedlings, to the reef (Schulte 2017). Public and private oyster harvest drastically diminished after World War I, invoking widespread concerns for both fishermen and managers. Declines in public harvest were likely attributed to constant harvest pressure with little to no replenishment or management recourse (Schulte 2017). In addition to population declines, the Great Depression likely decreased demand for oysters and disincentivized harvest due to low market values (Haven et al. 1978). In an effort to rebuild the oyster population, Virginia enacted the Oyster Repletion Act of 1928, a replenishment program focused on shell planting in specific areas (Haven et al. 1978). Although the program had relatively little impact on restoring harvest to peak levels, it likely supported harvest despite resource declines and allowed fishermen to remain in the fishery. A similar version of the replenishment program is ongoing and has been subsidized by the public since 1947 (Schulte 2017).

Efforts to restore the oyster fishery were not only hindered by the loss of viable habitat, but also the impact of two notable diseases, Dermo (*Perkinsus marinus*) and MSX (*Haplosporidium nelsoni*) (Haven et al. 1978). Both Dermo and MSX resulted in elevated mortality of sub-market and market-sized adults in high salinity regions, incentivizing fishers to harvest the species before succumbing to disease at larger sizes. The spread of MSX, in particular, resulted in the lowest recorded harvest on public grounds in history (1962), spurring the first of three Federal economic subsidies to Virginia's oyster fishery (Schulte 2017). MSX also greatly affected private oyster harvest with continuous declines from the 1960's through early 2000's, although Bosch and Shabman (1989) noted that declines may also be linked to rising seed prices that decreased participation. In the early years of MSX exposure, oyster mortality estimates were greater than 90 percent in the Delaware and Chesapeake Bay regions (Haskin and Andrew 1988; Carnegie and Burreson 2011). Tropical Storm Agnes (1972) further exacerbated oyster mortalities throughout the Bay, with nearly 50 percent loss in the Rappahannock and 70 percent loss in the Potomac tributaries of Virginia (Haven et al. 1978). Between 1972 and 1980, harvest rebounded roughly 170 percent, citing the last prominent peak for oyster harvest in Virginia waters, although recent landings in the public fishery have increased (Schulte 2017; NOAA 2023). A report by the Joint Legislative Audit and Review Commission (Virginia General Assembly 1984) noted that the fishery had suffered declines since the 1960's and was likely to remain "stagnant" without change, although none of the proposed policy options were effective enough to restore harvest to peak levels. Even with management actions to increase oyster populations and enhance market opportunities, oyster mortality from Dermo and MSX remained destructive and diminished the ability of fishermen to profit and continue participation in the oyster fishery.

To sustain participation and harvest, hand scrapes were legalized in many areas in 1987. Hand scrapes are a smaller form of dredging, but function more effectively than tongs in areas with lower oyster densities (Tarnowski 2004; Schulte 2017). While the addition of hand scrapes allowed fishermen to remain in the oyster industry with participation increasing nearly three-fold between 1987 and 1988 (VMRC 2018), harvest continued to decline. By the early 1990's, there was little hope for the reestablishment of a viable oyster fishery. In 1991, Virginia drastically reduced funding to the Oyster Repletion Program, likely due to a lack of measurable impacts on habitat and oyster population enhancement. A significant increase in state funding to the program was established in 2013, following the decline in federal funding (Schulte 2017). In addition to shell repletion and habitat enhancement, a rotational harvest system was implemented for the lower Rappahannock River and Tangier/Pocomoke Sound region in 2007 (VAC 20-720-10 ET SEQ.). These public oyster grounds are "rested" between annual harvest to maximize future harvest and aid in coordinating repletion programs (Schulte 2017).

Despite declines in harvest due to resource loss, anthropogenic impacts, and disease, many aspects of Virginia's small-scale oyster fishery have remained relatively unchanged throughout time, with fishermen utilizing similar gears and methods for harvest (Haven et al. 1978; Mackenzie et al. 1997). The oyster fishery remains state-managed with seasonal bans, bushel limits, gear restrictions, closed areas, and subsidized public restoration funding (VAC 20-720-10 ET SEQ.). In 2021, recorded landings of 3.6 million pounds were valued at $30.3 million dollars with the expansion of shellfish aquaculture contributing to a substantial portion of landings (NOAA 2023). As one of the fastest growing marine-related industries in Virginia, aquaculture accounts for nearly two-thirds of total oyster harvest and can potentially be used to supplement limitations in the wild fishery.

Hard Clam (Mercenaria mercenaria)

The hard clam (or northern quahog), like the eastern oyster, is a bivalve mollusk in the Chesapeake Bay with historical importance to Virginia's small-scale commercial fishing industry. The hard clam fishery faces challenges similar to the oyster fishery with degradation of habitat and water quality and overharvesting pressure stemming from increased participation that followed declines in eastern oyster populations (Harding 2007). The history of the hard clam is marked by relatively stable catches, although a lack of abundance measures and research on the hard clam make it difficult to assess changes in the population and drivers of changes in participation.

The first harvest of hard clams dates back to early Native Americans where the species was either consumed or crafted as tools (Mackenzie Jr. et al. 2001). Native Americans and colonists harvested hard clams by treading (i.e., using hands and feet) to locate and capture the species in shallow waters, a technique still utilized by some fishers along the Atlantic coast (Mackenzie Jr. et al. 2001). Early settlers were likely the first to implement the use of metal rakes, allowing for harvest at greater depths (Mackenzie et al. 1997; Mackenzie Jr. et al. 2001). The hard clam was not considered a notable commercial fishery until the late 1880's, when the demand for littlenecks (hard clams < 60 mm) rose during the off-season for oysters (Belding 1912; Mackenzie Jr. et al. 2001). Although littlenecks were initially sought in the market, hard clams were also harvested as chowders (large clams) or cherrystones that could be consumed raw or on the half shell (Kvaternik and DuPaul 1982). This classification system remains based on local markets that determine size categories and value. Despite the increased demand for littlenecks, the hard clam fishery did not hold significant economic value until after World War II (Kirkley 1997). Wild hard clam harvest is historically prominent in the Eastern Shore region, where up to 86 percent of Virginia's total production occurred in some years (Burrell et al. 1972). Harvest along the Eastern Shore occurred primarily by signing (searching for siphon holes and fecal pellets) with clam picks and rakes or treading (Castagna and Haven 1972; Kvaternik et al. 1983). The processing and transporting of hard clams in the Eastern Shore region likely had an even larger impact on the economy, especially in Chincoteague, which was previously home to the largest clam packer in the world (Burrell et al. 1972).

The hard clam fishery in Virginia's Chesapeake Bay is constrained by environmental conditions (e.g., salinity) with historical harvests concentrated in areas of the James, York, and Rappahannock Rivers, Mobjack Bay, and Eastern Shore (Burrell et al. 1972; Haven et al. 1973; Roegner and Mann 1991). The hard clam has often served as supplemental, or part-time, income during months when other species or job opportunities were not available as it was thought to be a simple and inexpensive fishery to enter (Burrell et al. 1972; Mackenzie Jr. et al. 2001). Andrews and Wood (1967) and Andrews (1979) noted evidence of diversification between the shellfish fisheries, as increased production of hard clams followed the decimation of the eastern oyster populations from MSX disease in the 1960's. MSX and Dermo diseases had little effect on hard clam populations and thus, fishermen shifted participation to hard clam as a means of income stabilization (Andrews 1954). The peak production of hard clams in Virginia occurred in 1965, coinciding with increased disease prevalence in eastern oyster populations, at approximately 2.5 million pounds valued at $1.4 million ($13.4 million adjusted for inflation) (Lyles 1966; Ritchie 1976; Kvaternik and DuPaul 1982). This increase in production may also be attributed to the implementation of more efficient gears for harvest as patent hand tongs, engine-powered patent tongs, and clam dredges were developed and implemented throughout the early 1900's (Mackenzie et a. 1997).

Hard clam landings throughout much of the 1900's were relatively consistent and averaged less than one million pounds each year (Kirkley 1997). Despite declines in landings, the value of hard clams increased nearly 245 percent in value after adjusting for inflation since the 1960's (Kirkley 1997). Kvaternik and DuPaul (1982) hypothesized that declines in production were the result of decreased fishing effort rather than declines in populations, although Mann et al. (2005) suggests declines in population that might not have been accounted for in previous years. Nonetheless, only 100 vessels were harvesting hard clams with patent tongs in Virginia towards the late 1990's, with almost two-thirds concentrated in the Hampton Roads area (i.e., James River). Similar to eastern oyster, wild hard clam harvest has been outpaced by aquaculture. Hard clam aquaculture has largely replaced participation in the wild fishery and represents a multi-million dollar industry with $38.8 million in revenues in 2018 (Hudson 2019).

Blue crab (Callinectes sapidus)

Although developed as a commercial fishery later than the eastern oyster, blue crabs are increasingly vital to the stability of the commercial fishing industry in Virginia. Marketed in various forms, the blue crab has been a substantial source of economic revenue for the state since its expansion as a commercial fishery in the late 1940's (Kirkley 1997). In 2021, 17.2 million pounds of blue crab were landed in Virginia with a value of $33.5 million (NOAA 2023). The blue crab fishery is generally divided into hard shell, soft shell and peeler fisheries, with each denoting a significant portion of the life cycle of the species and retaining various market values. Demand for soft shell blue crabs in the early 1870's expanded to include hard crabs with the establishment of a cannery in Virginia in 1878, likely initializing the development of the blue crab commercial fishery in the Chesapeake Bay (Stagg and Whilden 2009). From the early to mid-1900's, the blue crab fishery employed thousands of individuals directly as fishermen and through the seafood sales and processing sector, with the market for both hard and soft shell crabs more than doubling during this period (Van Engel 1950; Van Engel 1958).

In 1898, Virginia developed a licensing system, although it is thought that this system was primarily used to generate revenues from widespread participation in the blue crab fishery rather than control harvest (Stagg and Whilden 2009). In the earlier years of the fishery, fluctuations in harvest went unnoticed as fishers regularly landed sizable quantities (Van Engel 1958). As demand for blue crab products increased, the species became the highest landed value shellfish in the Bay following declines in eastern oyster production (Kirkley 1997). Blue crabs move along the depth gradients of the Chesapeake Bay and its tributaries, remaining in shallower waters during the summer and moving to deeper waters during the winter months (Churchill 1919). These seasonal movements enabled fishermen in earlier years of the fishery to fish year-round with changes in habitat. The blue crab fishery is highly contingent on environmental conditions that affect recruitment and life history characteristics on an annual basis. Thus, the market value of blue crab can fluctuate significantly within and across years.

The Chesapeake Bay region accounted for more than 75 percent of national blue crab harvest until the 1950's (Stagg and Whilden 2009). Landings of blue crabs peaked in the mid-1970's, although catches regularly exceeded 40 million pounds between 1965 and 1990 (Kirkley 1997). In more recent years, the Chesapeake Bay has accounted for 35 percent of total harvest, although this could be due to the expansion of fisheries in other states (Stagg and Whilden 2009). In 1983, Maryland and Virginia developed a reciprocity agreement for obtaining a blue crab license for commercial harvest in both states, likely increasing fishing pressure throughout the Bay with increased opportunities for participation.

In the 1990's, declines in the blue crab population prompted abrupt management action to control participation in the fishery such as the replacement of the voluntary landing reporting system with a mandatory one (Stagg and Whilden 2009). Other commercial management measures included licenses for peeler pot and soft shell fishermen, delayed and limited entry requirements, catch limits for the blue crab dredge fishery, and implementation of cull rings to control the size of blue crabs harvested (Stagg and Whilden 2009). Between 1994 and 2008, VMRC implemented 22 regulations for the blue crab fishery and a number of these regulations are still implemented in the current fishery including pot limits, seasonal closures, daily time restrictions (including Sunday harvest prohibition), size limits, and area closures (VAC 20-270-10 et seq.). Increases in regulation were likely due, at least in part, to the development of the Chesapeake Bay Commission's Bi-State Blue Crab Advisory Committee (BBCAC), which was formed to assess the status of the blue crab fishery in 1999. The BBCAC, in conjunction with stakeholders and governing effort from Virginia, Maryland, and the Potomac River Fisheries Commission, concluded that the fishing effort for blue crab should be constrained and managers should adopt thresholds to help better manage future populations (Chesapeake Bay Commission 2001).

Despite regulations, however, harvests and revenues continued to decline and the National Marine Fisheries Service (NMFS) declared the Virginia blue crab fishery a Fishery Resource Disaster in 2008 (VMRC 2017). Results from the annual winter dredge survey indicated blue crab population declines of approximately 70 percent within fifteen years, prompting nearly $15 million dollars in disaster relief funds (VMRC 2017). Disaster relief funds allowed commercial fishermen to seek financial relief in the form of habitat and environmental restoration efforts between 2009 and 2016 (VMRC 2017). Efforts included a derelict blue crab pot and marine debris removal program that enabled fishermen to retain winter employment (in lieu of the winter dredge closure) throughout a four-year period and a license buyback program for fishermen using hard crab and peeler pots (Havens et al. 2011; VMRC 2017). The license buyback program was an effort to consolidate the fishery and thus reduce biological impacts. Funds for this program resulted in 665 bids allocated to fishermen based on previous harvest, although it is unclear if all bid submissions were accepted (VMRC 2009).

Common gears used in the Virginia hard blue crab fishery included crab pots, trot lines, and dredges, with crab pots accounting for a majority of harvest (Burrell et al. 1972). Crab pots were initially introduced in the 1930's, replacing early use of trot lines during the summer months, and still remain the primary gear used in the fishery today (Burrell et al. 1972; Stagg and Whilden 2009). The crab dredge, adapted from oyster dredge gear, served primarily as a winter gear when crabs are dormant in deeper waters. The crab dredge fishery supported up to 375 licensed participants in the mid-1990's, but participation paralleled declines in the blue crab population and the dredge fishery was banned in 2008 (VMRC 2018). Prohibition of the winter crab dredge displaced a number of fishermen, although it is unclear as to how behavior shifted following the closure of the dredge fishery. The peeler and soft shell fisheries utilize scrapes and peeler pots with occasional harvest as bycatch in the crab pot fishery (Paolisso 2002). Controlled shedding operations in which peeler crabs are held until molting and subsequently marketed as soft shells are also an economically valuable component of the blue crab fishery (Oesterling 1995). Fishermen are able to purchase multiple gear licenses for blue crab harvest and more than half of those registered in the fishery were found to have more than one license type (Rhodes et al. 2001). However, the blue crab fishery is managed as limited entry and there is evidence that entry into the fishery can be difficult and costly.

Inshore and Nearshore Finfish Species

The inshore and nearshore finfish fisheries of Virginia encompass a wide variety of species that can be harvested using multiple gear types. Commercial finfish fisheries are perhaps the most variable with changes in population abundance and species distributions. A number of historically valuable finfish species no longer viably support commercial fisheries due to declines in abundance or excessive regulations resulting from aforementioned declines (Kirkley 1997). Notable historic species that contributed to the development of Virginia's commercial fishing industry, but are now under moratoria, include river herring (*Alosa spp.)* and American shad (*Alosa sapidissima*) and sturgeon (Hoagman et al. 1975; Foerster and Reagan 1977; Schmidt 2003; Nitlitschek et al. 2005; Hilton et al. 2014). More recent developed fisheries include spot (*Leiostomus xanthurus*), Atlantic croaker (*Micropogonias undulatus*), striped bass, summer flounder, and black drum (*Pogonias cromis*). Due to similarities in gear types used, fishermen participating in finfish fisheries tend to be more diversified across species in comparison to individuals participating in the Virginia shellfish fisheries. Gears utilized in the inshore and nearshore finfish fisheries include, but are not limited to, gill nets, fyke nets, seines, and pound nets.

It is beyond the scope of this dissertation to review the historical fisheries for each finfish species and thus, this section serves to acknowledge that many inshore and nearshore finfish species are susceptible to extreme fluctuations in abundance, as well as changes in market values, which necessitate the ability of fishermen to diversify between species and gears as a livelihood strategy. Likewise, finfish species are mobile with variable thermal tolerances and as a result, can respond to environmental changes through changes in large-scale shifts in distribution (Lucey and Nye 2010). These shifts could alter diversification behavior in Virginia with fluctuations in species availability.

Dissertation Structure

The goal of this dissertation is to characterize changes in participation and diversification in Virginia's small-scale coastal commercial fishing industry, as well as evaluate drivers of behavior change. The dissertation structure begins with broad characterizations of the commercial fishing industry and concludes with individual perspectives on participation and diversification. Chapter I utilizes state licensing and permitting data from the Virginia Marine Resources Commission to evaluate trends and instability in participation and diversification for various wild fisheries and marine-related industries, as well as the degree of overlap, in terms of license and permit holdings, between commercial fishermen participating in small-scale fisheries and individuals participating in marine-related industries. This portion of the dissertation was published in *Coastal Management* (White and Scheld 2021). Chapter II assesses diversification outcomes and behavior in Virginia's small-scale commercial fisheries by evaluating levels of individual and fleet diversification using Herfindahl-Hirschman Indices (HHI) and examining factors related to individual diversification decision-making. Chapter III explores variables influencing the development of an emerging small-scale commercial fishery for an invasive species using a survey instrument distributed to licensed commercial fishermen in Virginia. Chapter IV utilizes an ethnographic approach to better understand the role of individual decision-making and diversification as a livelihood strategy. The summarized findings of this dissertation are presented in a concluding statement that offers potential avenues for future research. The combination of these chapters can be used to better understand drivers of participation and diversification behavior in Virginia's small-scale fisheries, a topic which has not previously been investigated in detail.

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CHAPTER I

CHARACTERIZING PARTICIPATION AND DIVERSIFICATION IN SMALL-SCALE COMMERCIAL FISHERIES OF VIRGINIA, USA

Introduction

Virginia's small-scale coastal fisheries provide a significant portion of the state's total annual landings and are comprised of a diverse, extensive fleet of smaller vessels (i.e., ~ 20–35 foot vessels) utilizing a variety of labor-intensive gears and methods. Reliance on various species and fishing practices are embedded in the culture of coastal Virginia, especially within the individuals and communities dependent upon these resources as a livelihood (McGoodwin 2001; Paolisso 2007; Ross 2015). Virginia's small-scale fisheries provide benefits similar to the other small-scale commercial fishing populations around the world, including food security and livelihood for thousands of individuals (Allison and Ellis 2001; Béné et al 2005; TBTI 2018). Virginia's small-scale fishermen often target nearshore and inshore species, including eastern oyster (*Crassostrea virginica*), blue crab (*Callinectes sapidus*), striped bass (*Morone saxatilis*), summer flounder (*Paralichthys dentatus*), and Atlantic croaker (*Micropogonias undulatus*). The above-mentioned species had combined landings of roughly 27.6 million pounds valued at over $50 million in 2018, with a majority attributed to small-scale coastal fisheries (Kirkley 1997; NOAA 2020).[2] In addition to the economic value of landings, Virginia's small-scale fisheries employ thousands of individuals, both directly as colloquially termed "watermen" and through post-harvest sales and processing. In 2016, commercial harvest and post-harvest services throughout Virginia (with a substantial portion being small-scale coastal fisheries; Kirkley 1997) are estimated to have generated nearly $1 billion in total sales impacts (direct, indirect, and induced impacts) with more than $500 million in value added and the creation of 15,852 jobs (NMFS 2018).

Despite the economic and cultural value of these fisheries, the number of commercial licenses sold in Virginia has declined more than 15 percent in the past two decades (VMRC 2018). This trend mirrors many developed countries (FAO 2018) and coastal regions of the United States, where participation has been impacted by effort control and promotion of catch share and limited access privilege programs (NOAA

[2] Estimates for eastern oyster are for wild, public harvest, which accounts for one-third of total harvest (public and private) in Virginia in 2018 (K. Hudson, Marine Advisory Program, e-mail to author, July 17, 2020).

2017). Reasons for declining participation are likely interrelated and complex but decreases in species availability (Limburg and Waldman 2009), loss of working waterfronts (Khakzad and Griffith 2016), increases in regulation (Andreatta and Parlier 2010; Stoll et al. 2016), and lack of new entry into the sector may be responsible (Donkersloot and Carothers 2016; Ringer et al. 2018). In Alaskan fisheries, overall participation and diversification has decreased in response to individual quota systems and limited entry programs (Carothers 2010; Beaudreau et al. 2017). Similar declines in Maine's small-scale fisheries are thought to be due to increases in the number of required licenses that have had the unintended consequence of reducing participation and the ability of fishermen to switch between fisheries (Stoll et al. 2016).

Declines in small-scale fishery participation are noteworthy as they can result in an array of economic and societal consequences (Berkes et al. 2001; Chuenpagdee 2011). For example, lack of small-scale domestic harvest creates unmet demand for local seafood increasingly being met by imported products, despite the value placed on local catch availability in coastal communities (Andreatta and Parlier 2010; Nash et al. 2011). In addition, small-scale fishing communities are often associated with occupational identity, place attachment, and individual well-being, all of which are difficult to quantify but serve as foundations for establishing social and cultural norms (Khakzad and Griffith 2016). Small-scale fisheries are often based in rural communities with limited alternative employment opportunities and increased social dependence on fishing (Marshall et al. 2007). Fishermen may see themselves as unemployable or be unwilling to seek alternative employment because of lack of transferable skills, place attachment, or personal career goals, and thus some individuals may continue fishing even when economic and environmental conditions are unfavorable (Marshall et al. 2007). Changes in participation may signify broader demographic and socio-economic shifts in commercial fishing communities. In several US small-scale fisheries, the average age of commercial fishermen is increasing (Russell et al. 2014; Donkersloot and Carothers 2016; Cramer et al. 2018; Johnson and Mazur 2018; Ringer et al. 2018). Financial barriers, lack of knowledge, and regulation (e.g., limited entry, individual fishing quotas, etc.) inhibit younger individuals from entering the sector, resulting in a disproportionally larger population of aging fishermen (Donkersloot and Carothers 2016; Cramer et al. 2018; Johnson and Mazur 2018). This "graying of the fleet" phenomenon threatens the resiliency of fishing communities as generational gaps create social memory loss (Folke 2006) and older, experienced fishermen cannot transfer knowledge to younger generations (Johnson and Mazur 2018).

To understand and effectively manage small-scale fisheries in the United States, one must acknowledge how vulnerability and resiliency relates to individual decision-making (e.g., participation) and broader livelihood strategies (e.g., diversification) in a socio-ecological context (Young et al. 2006; McClanahan et al. 2009; Fuller et al. 2017). The risks associated with participation in small-scale fisheries are similar to other occupations dependent on natural resources, where adverse environmental and economic shocks are often unpredictable (Flint and Luloff 2005). As part of a sustainable livelihoods approach, many fishermen employ diversification strategies within and outside of the fishing sector (Allison and Ellis 2001). Diversification strategies for fisheries have been studied in various parts of the world, including Baja California Sur, Mexico (Finkbeiner 2015), the Philippines (Selgrath et al. 2018), Kenya (Olale and Henson 2013), United States (Kasperski and Holland 2013; Sethi et al. 2014; Cline et al. 2017), and Thailand (Panayotou 1985). Diversifying across income sources is found to stabilize revenues and reduce the impact of adverse events and vulnerability in fishery dependent communities if the random shocks are negatively correlated (Kasperski and Holland 2013; Sethi et al. 2014; Cline et al. 2017). Likewise, the extent of diversification can affect the resiliency and ability of individuals and fishing communities to adapt to economic and environmental perturbations (Fuller et al. 2017).

There is limited knowledge on how patterns of participation and diversification in commercial fishing communities throughout Virginia and the broader Mid-Atlantic region have changed over time. Understanding individual behavior can help characterize intra-industry dynamics and predict how fishermen will respond and adapt to future economic, regulatory, and environmental shocks. It is likely that many fishermen employ diversification strategies similar to those of other small-scale fisheries worldwide, but it is unclear as to how individuals are choosing to diversify (e.g., within or outside of the commercial fishing industry) and how these patterns, as well as patterns of participation, have changed throughout time. An enhanced understanding of these changes is useful for assessing temporal dynamics and responses to management or exogenous factors (e.g., markets, environment), which can increase the ability of coastal communities to adapt to emerging stressors (Allison et al. 2009; Jurjonas and Seekamp 2018; Fisher et al. 2021). Likewise, understanding levels of resource dependence is imperative to addressing the human dimension of ecosystem-based management (Pikitch et al. 2004), as dependence is related to social well-being, vulnerability, and resiliency (Jepson and Colburn 2013). The lack of knowledge surrounding diversification strategies, especially outside of the commercial fishing industry, represents a gap in fisheries management that could be used to assess resource dependency, reasons for exit (or entry) and socio-economic relationships in coastal communities.

This research characterized participation and diversification in Virginia's small-scale commercial fisheries by 1) assessing the overlap of license and permit holdings between individuals participating in wild small-scale fisheries and a subset of marine-related industries including recreational charter fishing ("chartering"), aquaculture, and seafood sales and processing and 2) evaluating trends and instability in participation and diversification for various wild fisheries and marine-related industries. Characterizing patterns of participation and diversification within and outside of the commercial fishing industry can be useful to managers for preserving social and cultural norms, as well as assessing the impacts of adverse events (e.g., management, economic, or environmental changes) to individuals and fishing communities.

Methods

Data

License and permit data from the Virginia Marine Resources Commission (VMRC) was used to evaluate trends and instability in participation and diversification for various wild fisheries and marine-related industries, as well as the degree of overlap, in terms of license and permit holdings, between commercial fishermen participating in small-scale fisheries and individuals participating in marine-related industries. VMRC oversees state commercial harvest licensing and permitting, as well as licenses and permits for processing entities (i.e., shucking houses, crab shedding, etc.), fish dealers, charters operating in state waters, and aquaculture. In Virginia, a commercial registration license is the overarching license required to participate in wild harvest, while additional licenses are required to participate in specific fisheries and sectors. Permits provide extra eligibility and are no-cost (i.e., gear licenses are required to harvest finfish, though certain species like striped bass require an additional permit). Licenses and permits are renewed on an annual basis and availability varies between fisheries (e.g., the blue crab fishery is limited entry while wild oyster harvest is not). The dataset contained a unique VMRC ID number for each individual, and for each individual and year indicated the licenses or permit types held. The available data spanned over two decades (1993-2018), with the first year reflecting the start of electronic license record-keeping by VMRC. The first year (1993) was omitted from analysis, however, as many license and permit types only existed in this year and were subsequently recategorized. The data was further restricted by only including licenses and permits that were available for all years between 1994-2018 (with the exception of aquaculture licensing beginning in 2007 and two oyster fisheries beginning in 1996 and 1999).[3] Gears, species, and locations that require an additional no-cost permit or authorization for extra eligibility in wild fisheries were not included to eliminate redundancy. Licenses and permits that are solely used for administrative purposes by VMRC were also not included in analysis (e.g., replacement licenses, refunded licenses, etc.). The restricted VMRC license and permit data contained commercial fishing, chartering, aquaculture, crab shedding (molting crabs for retail), processing, and buyer licenses.

To evaluate commercial fishing participation and diversification, licenses and permits were grouped into categories based on descriptions provided by the VMRC (http://www.mrc.virginia.gov/). License and permit types were aggregated into marine-related industry categories, including commercial fishing, chartering, aquaculture, or seafood sales and processing (Table A1.1; N = 20 unique licenses and permits). Licenses and permits required for various gears in wild species fisheries were aggregated into target species groups considered to be small-scale fisheries, including blue crab, eastern oyster, hard clam

[3] Oyster harvest with dredge (1996) and hand tongs (1999) were included as they constitute a large portion of the oyster fishery. The VMRC dataset was also restricted to exclude recreational licenses and permits, as they are not the focus of this study.

(*Mercenaria mercenaria*), and finfish (Table A1.2; N = 33).[4] For example, gill nets, pound nets, and haul seines are used for finfish harvest and a commercial license for these gears would indicate participation in wild finfish fisheries. There are multiple species of finfish (e.g., striped bass, summer flounder, Atlantic croaker) that can be harvested with a single gear type (e.g., gill net, pound net) and, therefore, finfish was treated as an aggregate category for these analyses. A complete list of included licenses and permits is found in the Appendix (Tables A1.1, A1.2).

Using sector and species license and permit groupings, a dataset was created such that each observation corresponded to a licensed individual and the year of licensure, and indicated participation (held license or permit) for each sector and species considered. The resulting dataset included the variables: VMRC ID number, year license or permit was held, and sector and species categories treated as binary variables with “1” representing that a license or permit was held for a given year and “0” indicating that the individual did not have the license or permit. This dataset contained 10,025 unique VMRC identification numbers with a total of 86,118 observations and 6,824 licensed commercial fishermen between 1994 and 2018.

The license and permit dataset was further manipulated to evaluate both individual-level correlations as well as aggregate dynamics. To explore the disaggregated, individual-level data, two matrices were developed - one for wild fisheries and another for marine-related industries. Each matrix included a row for each unique license or permit holder and specified the year of entry, the total number of years an individual was present in the dataset, and the average number of wild fisheries or marine-related industries participated in across all years in which at least one license or permit was held by the individual. Entry was identified as the first year an individual appeared in the dataset with any license or permit.[5] The total number of years an individual was present in the dataset was determined by summing all years for

[4] Individuals holding a commercial registration could also participate in several other fisheries (e.g., American eel *Anguilla rostrata*, channeled whelk *Busycotypus canaliculatus*, and others) that are not considered here based on low overall levels of participation and limited economic importance.
[5] Entry/exit and total years of participation were calculated based on available license and permitting data (1994-2018) and may not represent the entire time a fisherman held a license or permit (i.e., a fisherman could have held a license or permit before 1994 or after 2018).

which an individual had any license or permit. Pearson correlation tests were used to evaluate the relationship between the year of entry and total number of years an individual was present in the dataset and the average number of wild fisheries or marine-related industries an individual participated in. An additional disaggregated dataset was also used for multiple correspondence analyses where participation was again denoted as a binary variable with two levels – participation (indicated as “1”) or no participation (indicated as “0”). In this dataset, an individual was considered to have participated in a particular wild harvest fishery or marine-related industry if they ever held a license or permit for the associated species or sector within a specific time period.

An aggregate dataset was constructed for structural change analyses by summing the number of individuals with licenses or permits held for a given year (denoted by a binary variable of “1”) for each wild harvest fishery and marine-related industry for each year in the time series (Table 1.1). Diversification across species or sectors was assessed by evaluating the proportion of individuals having licenses or permits in more than one wild species fishery or marine-related industry in a given year

Multiple Correspondence Analysis (MCA)

Multiple correspondence analysis (MCA) is an extension of correspondence analysis that is used to analyze multivariate characteristics between qualitative or nominal variables (Greenacre and Blasius 2006; Abdi and Valentin 2007). Silver and Stoll (2019) applied this methodology to evaluate individual diversification portfolios in Canadian fisheries, though examples in fisheries literature are otherwise limited. In this study, MCA is used to produce a low-dimensional representation of participation characteristics of commercial fishermen in wild species fisheries and between all individuals (i.e., regardless of holding a commercial license) in marine-related industries for two time periods (1994-2006 and 2007-2018). It is reasonable to divide the time series in half for this analysis as there were several notable events occurring in the mid-2000’s that may have influenced participation and diversification, including major regulatory changes for blue crab, oysters, and finfish fisheries, the onset of aquaculture permitting, and the Great Recession financial crisis. An individual was considered to have participated in a wild harvest fishery or marine-related industry if they ever held a license or permit for the associated species or sector between 1994-2006 or 2007-2018. Assessing individual participation across multiple years allowed for clearer interpretation by removing inter-annual variability in license or permit holdings.

The similarity between individuals, in terms of license and permit holdings, is represented by their Euclidean distance on the multidimensional MCA map. Individuals that are close in location have similar participation characteristics (i.e., overlap of ellipses or quadrants), while those that are farther apart have differing participation characteristics. MCA analyses were performed using the FactoMineR (Lê et al. 2008) and factoextra (Kassambara and Mundt 2017) packages in R (R Core Team 2018).

Structural Change Analysis

Structural changes are shifts within a time series that may be correlated with internal dynamics or external events (Bai 1997). The aggregated dataset (see "Data" in Methods section, Table 1.1) was used to evaluate structural change in participation and diversification between 1994-2018 for each of the marine-related economic industries and wild species fisheries. A simple linear trend model was specified as:

Equation 1. $$Y_t = \beta_0 + \beta_1 \, Year_t + \varepsilon,$$

where Y_t is equal to the number of participants or the level of diversification in year *t*, β_0 is the intercept, $Year_t$ specifies the year[6], β_1 is the annual trend, and ε is the associated error term. Under a null hypothesis of no structural change, the intercept and trend parameters would be expected to be constant throughout the time series. Methods to precisely determine the year(s) that structural changes occur are available, however, these tests may overestimate break dates in a limited time series, such as our aggregated license dataset for 1994-2018 (T=25; Bai and Perron 2006). Thus, a Chow test (Chow 1960) was determined to be the most appropriate method, as it is able to account for smaller sample sizes with "known" break dates, though requires homoskedasticity (Aronu and Nworuh 2019). The underlying methodology of a Chow test

[6] To allow the intercept to correspond to the number of licenses at the beginning to the time series, $Year_t$ was rescaled by subtracting 1994 such that in 1994 $Year_t$ equaled 0.

determines whether the parameter coefficients of a model are equal across subsets of the data or whether the data is better represented with two regressions.

Models for participation in each marine-related industry and wild harvest category, as well as diversification trends, were first fitted and tested ($\alpha = 0.05$) for homoskedasticity using a Goldfeld-Quandt test with a standard 20% removal of observations (Goldfeld and Quandt 1965). All cases of participation and diversification for wild species harvest and marine-related industries were homoskedastic and thus, a Chow test was used to evaluate whether intercept and trend parameters were constant between two halves of the time series (1994-2006 and 2007-2018 for all categories, except aquaculture where the data was halved between 2007-2012 and 2013-2018 and wild oyster where the data was halved between 1999-2008 and 2009-2018). Dividing the time series is consistent with the MCA methodology and was implemented for similar reasons. The package strucchange and function "sctest" (Zeileis et al. 2002) in R (R Core Team 2018) were used to conduct Chow tests and assess whether a significant structural change in participation and diversification occurred between two segments of the time series.

Results

Data Summary

The average number of years an individual was present in the dataset was 8.59 ± 7.88, while commercial fishermen were present in the dataset for an average of 9.79 ± 7.86 years. There were 1,942 commercial fishermen who entered the dataset in a given year and held a license or permit until the terminal year (i.e., at least 2018). Commercial fishermen participated in 1.43 wild species fisheries (i.e., clam, crab, finfish, oyster) and all individuals participated in 1.11 sectors (i.e., aquaculture, chartering, commercial fishing, and seafood sales and processing) when averaging across years. The total number of commercial fishing licenses sold in Virginia has decreased from 3,198 in 1994 to 2,683 in 2018. When licenses are divided into non-senior commercial registration (<65 years) and senior commercial registration (≥65 years), the decline in non-senior commercial registration becomes greater with 25.4 non-senior fishermen exiting each year or becoming senior commercial registration holders on average (based on a linear regression and p value <0.001 for an annual trend). Senior commercial registrations, however, are increasing by 10.6 fishermen per year on average (p value <0.001), indicating that there is a potential demographic shift occurring in the age of commercial fishermen in Virginia in addition to an overall decline in participation. It is important to note that the population of senior commercial registrations is only a small fraction (~10-16%) of the total commercial fishing population for all years (Figure 1.1).

The percentage of commercial fishermen with diverse fishing portfolios accounts for less than half of licensed fishermen in Virginia (only 35% in 2018) and has not varied widely (ranging from 31-42% 1994-2018), despite the overall decline in participation. A Pearson correlation test indicated a negative relationship between the year a fisherman entered the dataset and the average number of wild species fisheries participated in, meaning that fishermen who obtained an initial license or permit later were less diversified in wild fisheries than those who had held a license earlier in the dataset (p value <0.001; correlation -0.17). Furthermore, there was a positive relationship between the total number of years a fisherman was in the dataset and the average number of wild species fisheries the fisherman participated in, indicating that fishermen retaining a license or permit for longer periods of time were more diversified than those who held a license or permit for fewer years (p value <0.001; correlation 0.39). When considering diversification across sectors for all licensed individuals (not just commercial fishermen), less than 10% of individuals were diversified in a given year. There is a significant negative relationship between the year an individual entered the dataset and the average number of marine-related industries participated in (p value <0.001, correlation -0.18) and a positive significant relationship between the total number of years an individual was in the dataset and diversification into marine-related industries (p value <0.001, correlation 0.37).

The proportion of individuals participating in marine-related industries (regardless of holding a commercial fishing license or permit) across all years was examined using the aggregated dataset to further contextualize diversification (Table 1.2). The percentage of individuals in seafood sales and processing is largely comprised of individuals also holding a commercial fishing license or permit (71.6%). This is similar to participation in aquaculture, where 48.6% of individuals with an aquaculture license or permit also hold a commercial fishing license or permit. Only a small proportion of the total commercial fishing population, however, has diversified into seafood sales and processing and aquaculture industries between 1994-2018 (15.4% and 12.9%, respectively). There is little overlap in participation from individuals participating in the chartering sector and other marine-related industries, although 18.6% of individuals with a charter license or permit have participated in commercial fishing.

The proportion of commercial fishermen participating in wild species fisheries across all years was also examined to assess intra-industry diversification (Table 1.3). A majority of fishermen participating in the clam fishery also hold a license or permit for crab, finfish, or oyster fisheries (49.1%, 49.4%, and 53.3%, respectively), while only a small proportion of fishermen in the crab, finfish, and oyster fisheries hold a license or permit for wild clam between 1994-2018. Almost half (45.4%) of fishermen with a license or permit for crab fisheries also hold a license or permit for finfish fisheries and vice versa (45.4% of fishermen with a finfish license or permit also participate in the crab fishery). There is a large proportion of fishermen in the oyster fishery also participating in the crab fishery (61%).

Multiple Correspondence Analysis (MCA)

Four multiple correspondence analyses (MCA) were performed to determine similarities between individuals in different wild species fisheries and marine-related industries between two time periods (1994-2006 and 2007-2018). The first MCA analysis was performed on 5,059 individuals and describes similarities between commercial fishermen participating in wild species fisheries between 1994-2006. During this time period, the first principle axis explained 37% of the variance, or principal inertia, and the second principle axis explained 27%. The remaining two principle axes cumulatively explained 36.1% (21% and 15.1%, respectively), indicating that a two-dimensional structure was appropriate. The second analysis describing similarities between commercial fishermen participating in wild species fisheries between 2007-2018 was performed on 4,724 individuals. The first principle axis explained 36.7% of the variance and the second principle axis explained 26.6%. The remaining principle axes cumulatively explained 36.8% of the variance (19.6% and 17.2%, respectively).

Visualization of the MCA biplots (i.e., individuals and variables) for wild species fisheries participation between the two time periods indicates commercial fishermen participating in finfish fisheries are similar (i.e., greater overlap in permit holdings) to fishermen that participate in wild crab fisheries (Figure 1.2). Fishermen holding a license or permit for finfish likely held an additional license or permit for wild crab rather than clam or oyster (licenses may have been held at different times or simultaneously between 1994-2006 and 2007-2018). Fishermen holding an oyster license or permit are similar to fishermen participating in any of the other wild species fisheries, while fishermen that never held an oyster license or permit are similar to individuals that have never participated in wild clam fisheries. Fishermen holding a license or permit for the wild clam fishery, however, have differing participation characteristics from fishermen without a license or permit for the clam fishery (i.e., no overlap of ellipses) between 2007-2018. Dimensional coordinates for the MCA wild species biplots are found in the Appendix (Table A1.4).

The third MCA analysis is explained by three variables (i.e., aquaculture is not included as licensing and permitting by VMRC did not begin until 2007) and was performed on 7,097 individuals to describe similarities between individuals participating in marine-related industries between 1994-2006. The first principle axis explained 49.5% of the variance and the second axis explained 40% (10.6% of the remaining variance was explained by an additional dimension). The fourth MCA analysis was performed on 8,362 individuals and describes similarities between individuals participating in four marine-related industries between 2007-2018. The first principal axis explained 34.6% of the variance, or principle inertia, and the second axis explained 30.2% of the variance. The remaining principle axes cumulatively explained 35.2% of the variance (25.7% and 9.5%, respectively).

Visualization of the MCA biplots indicates that there have been shifts in participation characteristics between the two time periods across marine-related industries. Although similarities exist between both time periods, individuals participating in commercial fishing are more similar to individuals who have participated in seafood sales and processing between 2007-2018 (Figure 1.3). There are extensive overlaps in seafood sales and processing between 2007-2018, indicating that participation characteristics in other marine-related industries do not differ based on whether an individual held a seafood sales and processing-related license or permit. This overlap in seafood sales and processing participation, as well as participation in commercial fishing, did not exist in earlier years (1994-2006). Individuals participating in the charter industry are the least similar to the other marine-related industries between both time periods. The MCA biplots indicate that there are significant differences (i.e., 95% ellipses not overlapping) between individuals that have held an aquaculture or charter license or permit and those that have not between 2007-2018. Individuals without a commercial license have similar participation characteristics in other sectors compared to individuals that have held a commercial fishing license. Dimensional coordinates for the MCA marine-related industries biplot are found in the Appendix (Table A1.5).

Structural Change Analysis

In addition to overall declines in commercial fishing licenses, similar trends are noted for three of the four wild species (Figure 1.4)[7]. There is evidence of differences in participation levels and trends for hard clam between the first and second half of the time series ($p < 0.001$ for Chow test; see Appendix Table A1.3 for Chow test and linear regression results). Participation in the clam fishery has declined overall since 1994 with only two periods of slight increases in participation (between 2-4 licenses) (Figure 1.4a). The trend line for the first half of the time series (1994-2006) represents larger declines which began to level off in the second half of the time series. There is evidence of structural change for participation in blue crab ($p < 0.001$) (Figure 1.4b). Despite a consistent downward trend, the level of participation appears to have shifted in the mid-2000's. There was no evidence of structural change for participation in finfish fisheries ($p > 0.05$), however, a declining trend is noted ($y=1461-16x$, $p < 0.001$ for trend between 1994-2018) (Figure 1.4c). Participation in finfish fisheries declined between 1999 and 2007 and increased between 2007 and 2010. Following 2010, participation in the finfish fishery declined to its lowest levels. Oyster licenses are the only wild harvest category that has increased in participation since 1995 ($y=209.6+41.6x$, $p < 0.001$),

[7] Structural change estimates may be biased based on post-hoc augmented Dickey-Fuller (ADF) tests for stationarity. However, results were broadly consistent when including a lagged dependent variable as an explanatory covariate.

although there is no difference in participation levels and trends during each half of the time series (1999-2008 and 2009-2018) (Figure 1.4d).

There is evidence of structural change for three of the four marine-related industry categories. A Chow test identified significant ($p < 0.01$) differences in participation level and trend in the first and second half of the aquaculture time series (Figure 1.5a). The number of aquaculture licenses held by individuals increased in the first half of the time series (2007-2013) and then declined in the second half (2014-2018). There were, however, two periods of notable increases in aquaculture participation between 2007-2008 and 2009-2011. There was also a structural change identified in chartering industry participation between the first and second half of the data set ($p < 0.001$). The number of charter licenses increased at the beginning of the time series and then declined in the second half (Figure 1.5b). The lowest level of participation occurred prior to 1996 (<140 licenses) but increased until 2004 and fluctuated in subsequent years. There was no evidence of a significant difference in participation level and trend during the first half of the time series compared to the second half for participation in the commercial fishing industry ($p > 0.05$) between 1994-2018 (Figure 1.5c). The average level of participation in the commercial fishing sector has declined overall ($y=3088-14.8x$, $p < 0.001$), with the last year of the time series representing the lowest level of participation. Participation level and trend in the seafood sales and processing industry was significantly different between each of half of the time series ($p < 0.001$). The first half of the time series suggests an insignificant declining trend in participation ($p > 0.05$). The decrease in participation following 2005 led to the lowest levels of participation between 2014-2018 (Figure 1.5d).

The level at which commercial fishermen were diversifying, or participating in more than one fishery, indicates structural change over the time series ($p < 0.01$) (Figure 1.6a). The percentage of commercial fishermen diversifying between wild species decreased between 1997 and 2006, with the lowest levels in the latter year. Since 2006, the percentage of commercial fishermen diversifying between wild species has fluctuated slightly. There is no evidence of structural change or that the level of diversification between individuals in marine-related industries has changed significantly over the time series ($p > 0.05$) (Figure 1.6b). Chow test and linear regression summaries can be found in the Appendix, Table A1.3.

Discussion

This study finds evidence of instability in participation and diversification in Virginia's small-scale commercial fisheries and marine-related industries. Although some changes can be characterized as trends with a general and consistent direction of change (e.g., participation in the commercial fishing industry), others indicate that changes participation and diversification can be dynamic. In addition, this study suggests that while there are shifts in participation characteristics across marine-related industries, participation characteristics in wild species fisheries has only varied slightly.

Levels of participation in commercial fishing and marine-related industries can be influenced by a suite of complex and interconnected factors, including regulation, rising costs associated with fishing (e.g., fuel, bait, capital investment), and declines in species abundances, as well as other less apparent factors (e.g., social and cultural norms). For example, the decline in wild blue crab participation in 2008 coincides with the federal declaration of a Fishery Resource Disaster for blue crab and the closure of the dredge fishery in the same year. During this time period, the United States also experienced the Great Recession, which resulted in a rise in unemployment and loss of household net worth nationwide (Kalleberg and Von Wachter 2017). Despite literature that suggests small-scale commercial fishing can act as an economic buffer when alternative employment opportunities are limited (Allison and Ellis 2001), analysis of VMRC license data shows the number of individuals exiting the commercial fishing industry in 2007 and 2008 is higher compared to most other years. This decline could also be related to other exogenous factors (e.g., regulation) that made it difficult or unprofitable for fishermen to remain in the industry. An extended time series would allow for a more extensive analysis of structural change and may be used to see the potential effects of exogenous factors on participation more precisely.

The drivers of changes in participation and diversification require further investigation but could indicate shifts in industry structure or resource dependence, as fishermen find other sources of employment and income to supplement commercial fishing. By diversifying into multiple fisheries, fishermen can fish year-round rather than restricting participation to a particular season, and thus reduce income variability and risk (Kasperski and Holland 2013; Anderson et al. 2017; Selgrath et al. 2018). Likewise, fishermen diversifying into other sectors can choose to fish when conditions are favorable and remain employed outside of the industry when conditions are unfavorable. Diversification in wild fisheries and marine-related industries was found to be correlated with the total number of years an individual has participated in commercial fishing or marine-related industries, as well as the initial year of participation. Fishermen who participated in commercial fishing for more years and were licensed earlier in the dataset were found to be more diversified across species and sectors than those who were not. This suggests that there is some benefit to diversification with individuals possibly remaining in the industry longer because they are more diversified or that individuals remaining in the industry longer have more opportunities to diversify. Fishermen in the industry for longer periods of time may have the ability to invest capital and knowledge into other fisheries or sectors when faced with volatile changes in market price, regulation, and species abundance, whereas those entering later may not have the resources to diversify. This is likely the case for younger individuals entering the commercial fishing industry or fishermen participating part-time to supplement income where the opportunity or need to diversify is negligible. Increased regulatory constraints may also make it more difficult for those entering later to diversify into certain fisheries (e.g., limited entry fisheries) despite the desire to do so.

Characteristics of fishery participants may also drive patterns and changes in participation observed over time. Despite changes and declines within individual fisheries, there are noted similarities between participation in all wild harvest fisheries for both time periods, indicating that fishermen may switch from one fishery to the next within or across years. For example, fishermen who have held a crab license or permit are more similar to those who have held a finfish license or permit, suggesting that diversification between the two fisheries may be occurring. In this study, participation characteristics were assessed across years for two time periods (1994-2006 and 2007-2018), meaning that a fisherman could have a finfish and crab license or permit simultaneously, or at discrete times. Fishermen targeting crabs and finfish may be similar because of the seasonality in which these fisheries occur. Fishermen can target crab and some finfish during the spring and summer seasons and then continue to target finfish during months when crab harvest slows. Compared to other wild fisheries in the second half of the dataset, individuals with a clam license or permit are least similar to other fisheries, which mirrors the declining trend for participation in the wild clam fishery. Historically, the hard clam served as supplemental, or part-time, income during months when other species (i.e., oyster, crab, etc.) (Burrell et al. 1972) or job opportunities (Mackenzie Jr. et al. 2001) were not available. Declines in hard clam participation may be coupled with declines in species abundance and habitat (Mann et al. 2005), or the growth of the hard clam aquaculture sector that decreased profitability of wild harvest.

Despite diversification between species in Virginia's small-scale fisheries occurring, less than half of commercial fishermen are diversified in a given year. This finding is similar to Beaudreau et al. (2019) and Kasperski and Holland (2013), who found an increase in specialization for various Alaskan fisheries, coupled with declines in overall participation. Diversification can be constrained by management, including limited entry and quota allotments, which lessen a fisher's capacity to switch between species and gears, or geographic ranges (Kasperski and Holland 2013; Anderson et al. 2017). In Virginia, various fisheries are limited entry including blue crab, striped bass (also managed with individual fishing quotas), and black sea bass, while other species and gears require purchasing multiple permits or obtaining endorsements in addition to the standard commercial registration. Other factors potentially limiting diversification include lack of knowledge, geographic location, market forces, investment costs, and potential revenues (Panayotou 1982; Sethi et al. 2014; Anderson et al. 2017). If fishers are dependent on, or have high investment in, a particular fishery, they may be more likely to specialize in effort to increase returns, especially during favorable conditions (i.e., high species abundance, high market prices) (Allison and Ellis 2001; Kasperski and Holland 2013; Finkbeiner 2015). If there is a sudden shock to the fishery, however, specialized fishermen may be forced to exit the industry (Beaudreau et al. 2019). In Virginia, the decrease in diversification is slight and has not varied widely, indicating that fishermen remained diversified, though diversification is limited in general, despite changes in regulation (i.e., limited entry and quotas).

The percentage of commercial fishermen diversifying into marine-related industries (e.g., aquaculture, chartering, and seafood sales and processing) in Virginia has been less than one-third since 1995. This percentage has steadily increased from the lowest level of diversification in 2006 (~15%) to the highest level in 2016 (~28.5%). The rise in marine-related diversification since 2006 reflects in part an increase in aquaculture production, as the VMRC began designating aquaculture permits in 2007 (Beckensteiner et al. 2020). In 2018, only 13% of the commercial fishing population also held an aquaculture license or permit, but approximately 48.6% of those in the aquaculture sector were commercial fishermen (Appendix Table F). This is contrary to Stoll et al. (2019), who find that entry into Maine's aquaculture sector is largely from individuals outside of the commercial fishing industry. Similar patterns are present for diversification into seafood sales and processing, with only 15.4% of the total commercial fishing population holding a related license or permit in 2018, but nearly 72% of individuals in the seafood sales and processing industry holding a commercial fishing registration. The number of commercial fishermen with seafood sales and processing (e.g., processing, shedding, buying) licenses or permits has decreased in the last two decades, likely reflecting supply chain consolidation and the closure of many processing houses due to increases in imports, labor shortages, regulation, and environmental or biological changes (Garrity-Blake and Nash 2007). There is anecdotal evidence that a number of fishermen maintain seafood sales and processing licenses (e.g., buyer's license) so that landings can be directly sold to consumers at higher prices, rather than selling to fish houses or processors. Participation characteristics between individuals holding a seafood sales and processing or commercial fishing license or permit were more similar in later years, providing further evidence of this relationship. While commercial fishermen are diversifying into aquaculture and seafood sales and processing, fishermen only account for a minimal portion of the charter sector (18.6% of individuals in the charter sector also held a commercial registration in 2018). This suggests that there may be more overlap in participation among the seafood industries (commercial fishing, aquaculture, and seafood sales and processing), especially in the commercial fishing and seafood sales and processing industries where each is dependent on the other for purchasing, processing, and distributing product. It may be that commercial fishermen are diversifying into seafood sales and processing by leveraging resources and existing relationships, and thus, creating economies of scale and scope across these industries. When considering diversification across sectors for all licensed individuals (not just commercial fishermen), less than 10% of individuals are diversified in a given year. There are significant differences in participation characteristics between individuals with an aquaculture license or permit and those without. Similar characteristics are found for individuals with a chartering license or permit, indicating that individuals participating in the chartering or aquaculture sector do not typically hold a license or permit in another sector and vice versa. Participation characteristics for marine-related business have shifted between 1994-2018, potentially reflecting the expansion of aquaculture, consolidation, or closure of processing houses.

Within commercial fisheries, the benefits of diversifying are dependent on various factors, including location, resource abundance, and socio-economic conditions (Ward and Sutinen 1994; Sethi et al. 2014). A caveat to this analysis is how less studied factors, such as social and cultural relationships, may drive individual diversification decisions and influence broader coastal communities. It is likely that many fishermen are supplementing income through non-marine related sectors and thus, diversification rates (e.g., outside of marine industries considered here) may be greater than suggested. In addition, diversification was treated as a binary variable (participation in one wild fishery or marine-related industry versus participation in more than one wild fishery or marine-related industry) and an enhanced understanding of diversification may be obtained by exploring various levels of diversification. Likewise, diversification between species may differ with a narrower analysis using a disaggregated finfish category or the inclusion of more socio-demographic characteristics to evaluate similarities in license or permit holdings. The ability to assess individual fisherman behavior in conjunction with quantitative stock measures could reduce unintended consequences of management, including social and cultural tensions, asset losses, and inequitable distribution of benefits (Fulton et al. 2011; Bennett and Dearden 2014; Stoll et al. 2016). This study was not able to account for changes earlier than 1993 or spatial differences in participation and diversification, although there is likely varying levels of resource dependency across Virginia’s coastal communities that has changed throughout time. Rural communities tend to have higher dependence on natural resource extraction and individuals within these communities that are socially and economically dependent on commercial fishing tend to be more vulnerable and less able to cope with sudden changes (Marshall et al. 2007). Fishery managers would benefit from an increased understanding of shifts in participation and diversification, as these changes can alter individual well-being and community structure, resulting in the disruption of social and cultural norms (McGoodwin 2001; Béné 2006; Carothers 2010; Khakzad and Griffith 2016).

There is an opportunity for future research to expand this study by investigating the dynamic culture of the commercial fishing industry and drivers of individual decision-making in Virginia's fishing communities. In the past two decades, participation and diversification in Virginia's small-scale commercial fishing industry and marine-related industries have undergone periods of change due to economic, regulatory, and environmental drivers within and outside of the industry. There are also broader socio-demographic trends, such as the "graying of the fleet" phenomenon that are becoming more prevalent in Virginia's small-scale commercial fishing industry and will likely impact participation and diversification characteristics in the future. While fishermen have limited capacity to adapt to changes in the industry through diversification within and outside of the commercial fishing industry, levels of diversification remain relatively low with substantial room for fishery managers to enhance diversification opportunities. An enhanced understanding of participation and diversification patterns can be used to assess impacts to individuals and fishing communities during adverse events, such as regulatory or market changes, and create more resilient commercial fishing communities throughout Virginia.

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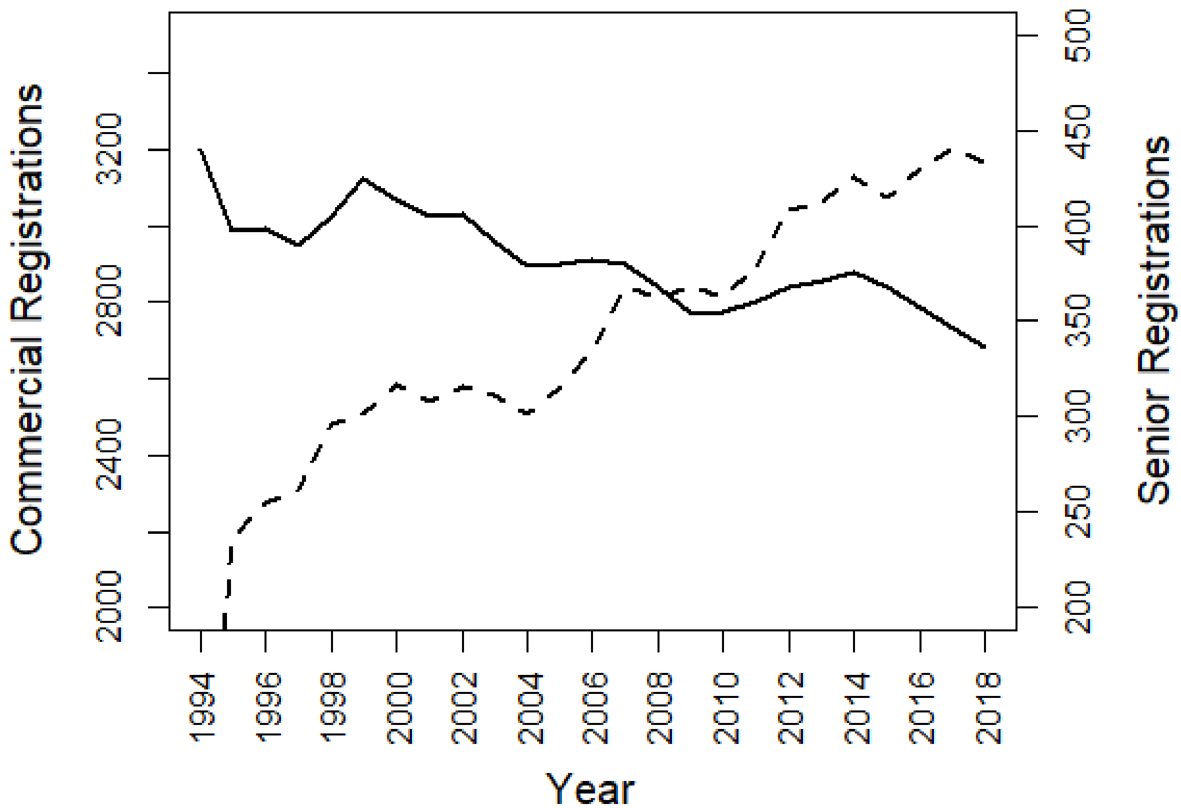

Figure 1.1. Total number of commercial registrations (solid line) and senior registrations (dashed line) in Virginia between 1994-2018.

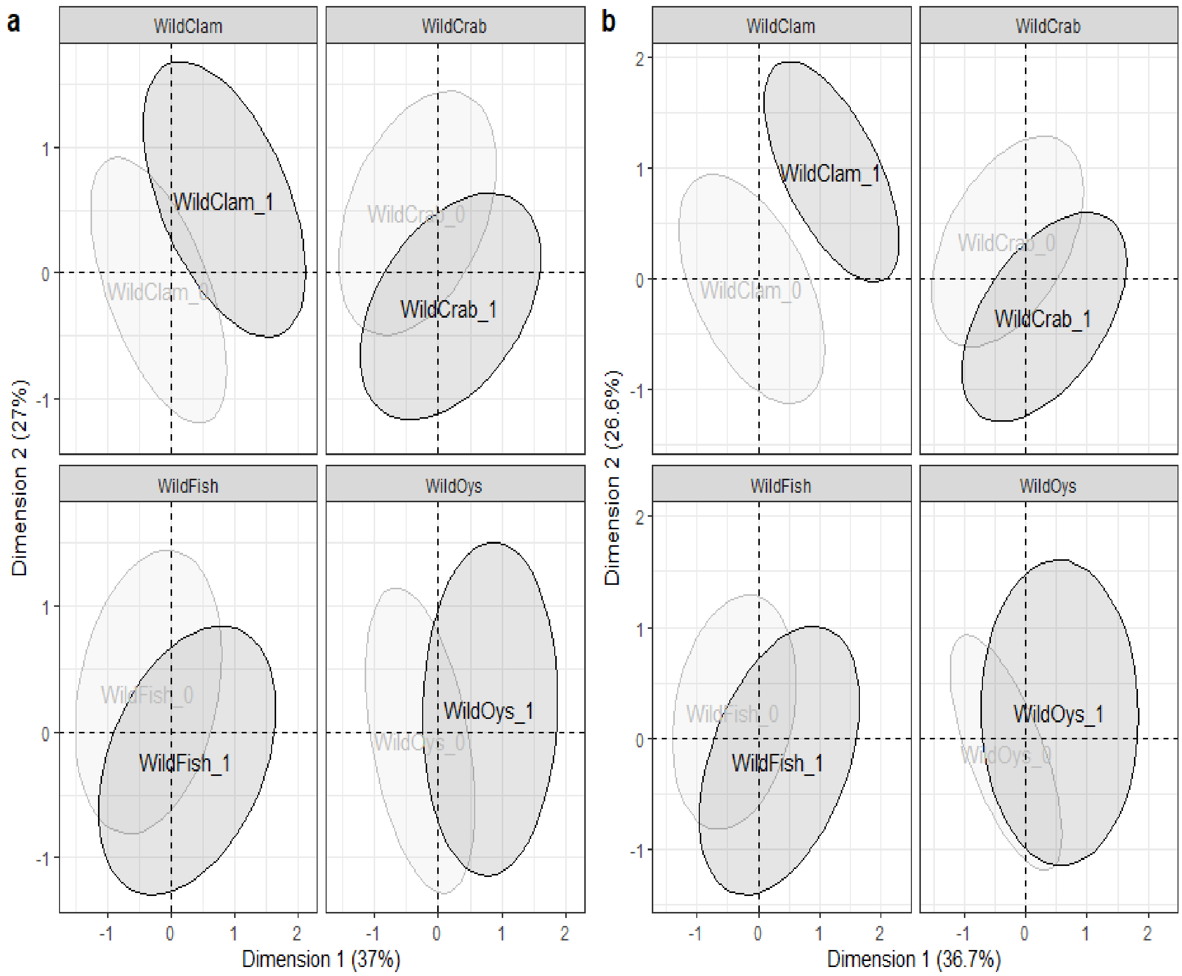

Figure 1.2. Multiple correspondence analysis (MCA) for participation in wild harvest fisheries for clam (upper left), crab (upper right), finfish (lower left), and oyster (lower right) for 1994-2006 (a) and 2007-2018 (b). A "1" represents that a license or permit was held in a wild species fishery for the time period and a "0" represents no license or permit was held. Ellipses include 95% of the population with overlap of ellipses (between fisheries and/or time periods) indicating similar participation characteristics. Units are in Euclidean distances.

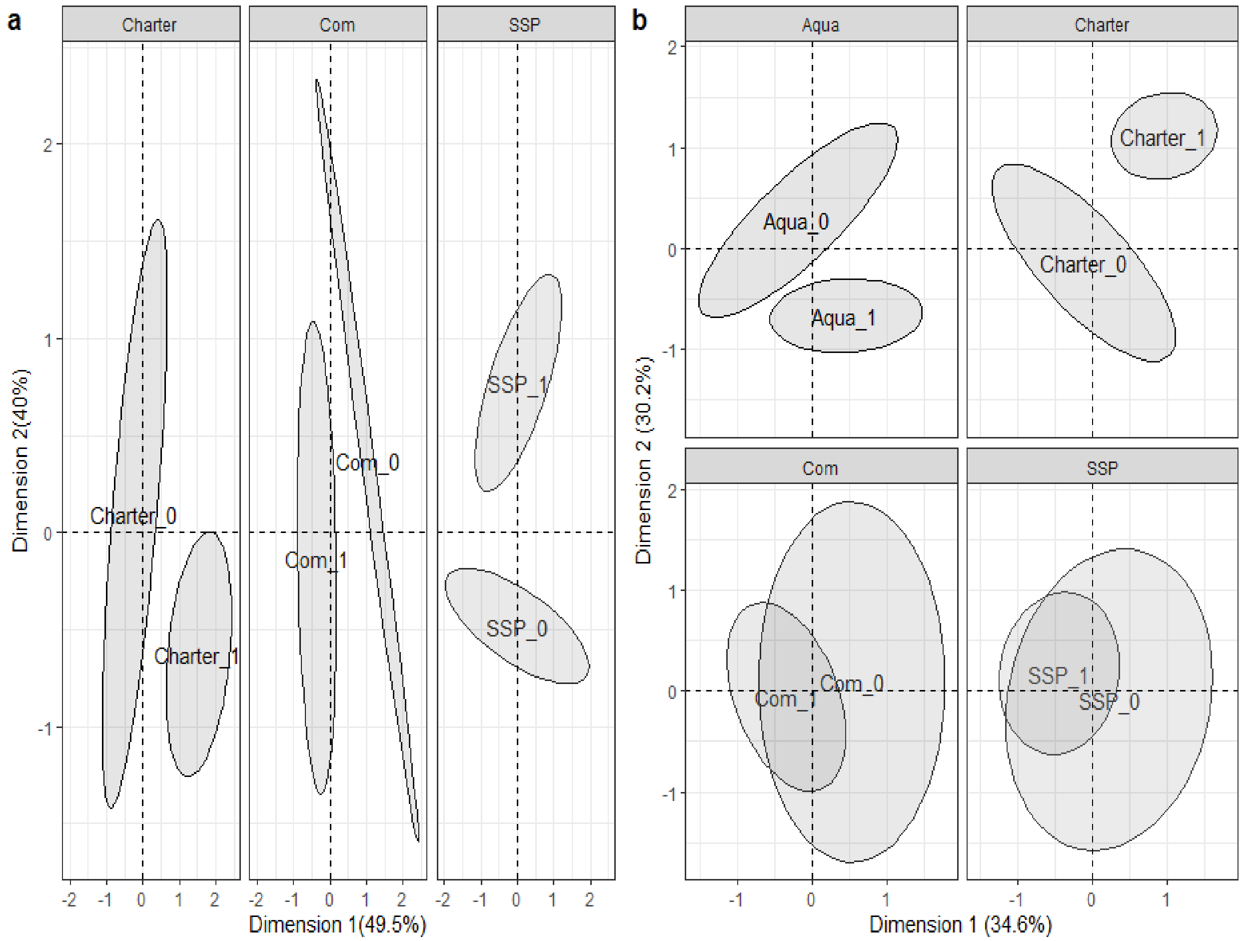

Figure 1.3. Multiple correspondence analysis (MCA) for participation in marine-related industries for chartering (left), commercial fishing (middle), and seafood sales and processing (SSP) (right) for 1994-2006 (a) and for aquaculture (upper left), chartering (upper right), commercial fishing (lower left), and SSP (lower right) for 2007-2018 (b). A "1" represents that a license or permit was held in a marine-related industry for the time period and a "0" represents no license or permit was held. Ellipses include 95% of the population with overlap of ellipses (between sectors and/or across time periods) indicating similar participation characteristics. Units are in Euclidean distances.

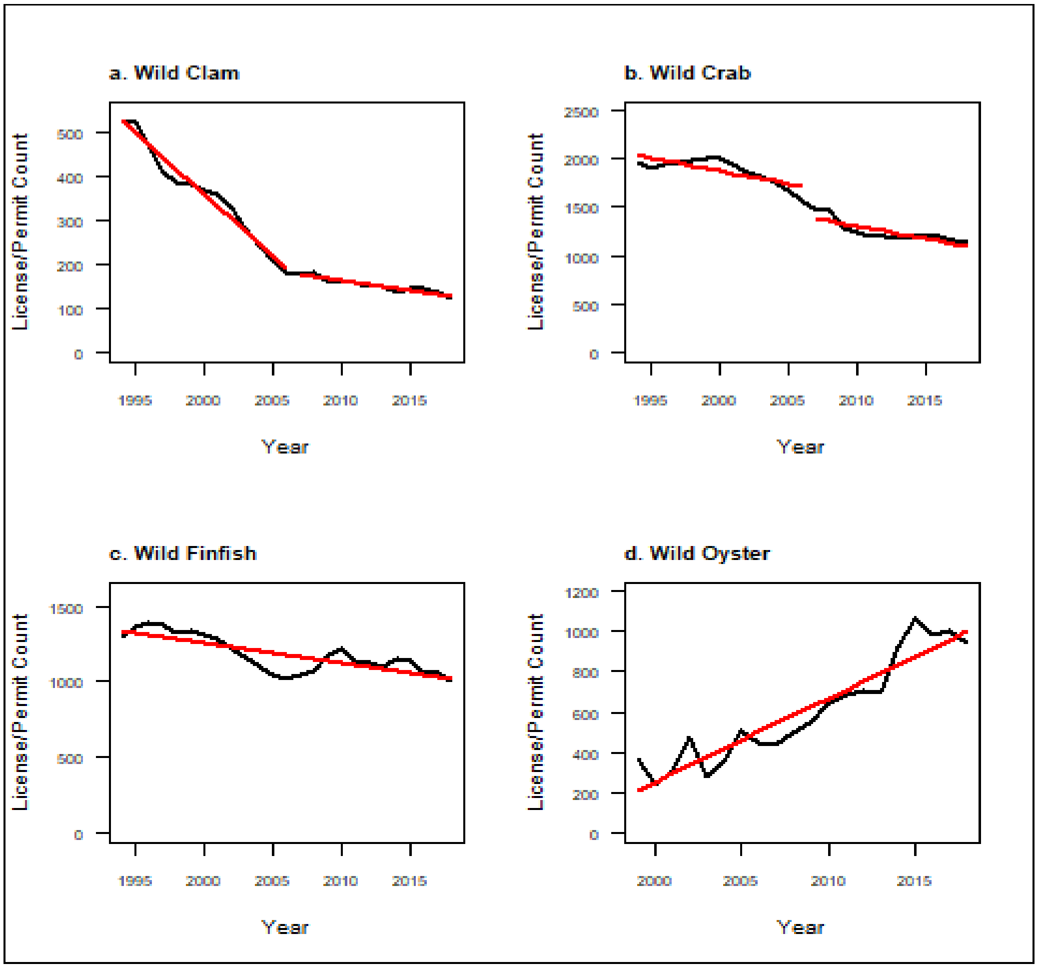

Figure 1.4. Participation levels in wild harvest fisheries for clam (a), crab (b), finfish (c), and oyster (d) with trend lines (red).

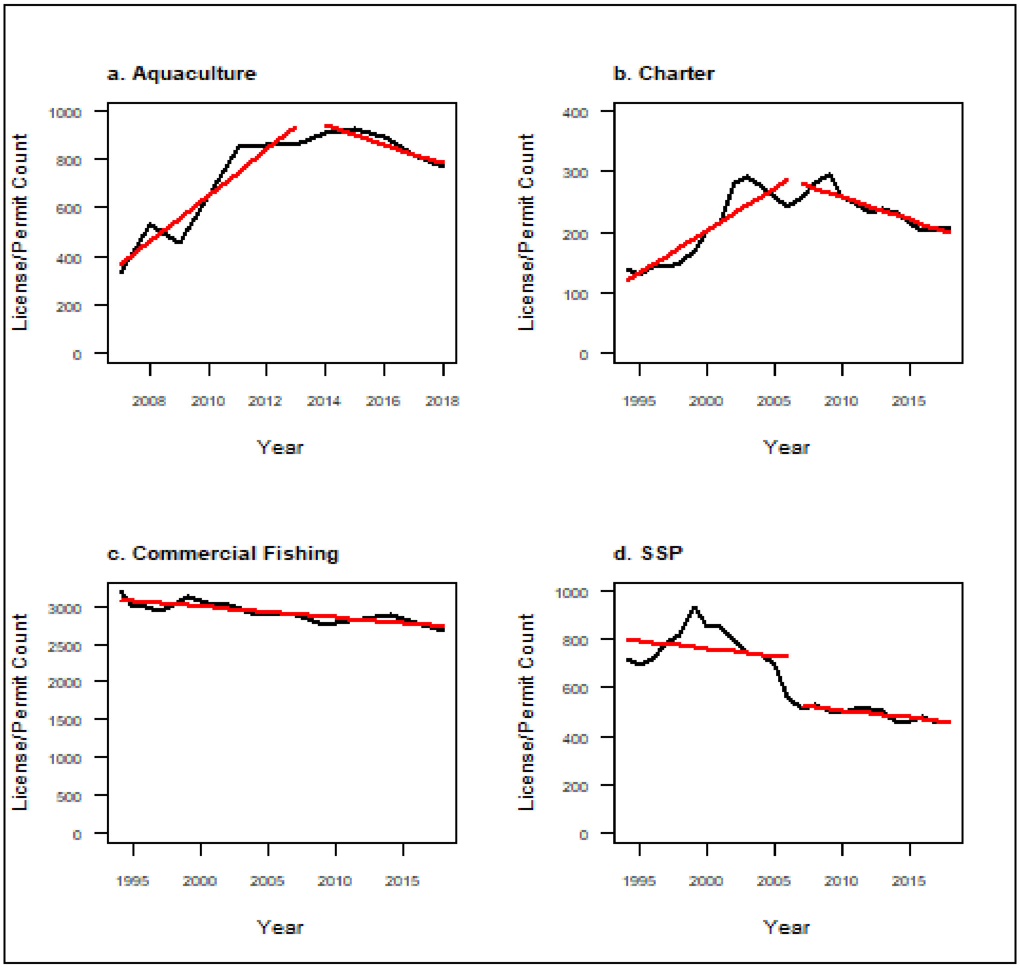

Figure 1.5. Participation levels of commercial fishermen in marine-related industries for aquaculture (a), chartering (b), seafood sales and processing (SSP) (c), and commercial fishing (d) with trend lines (red).

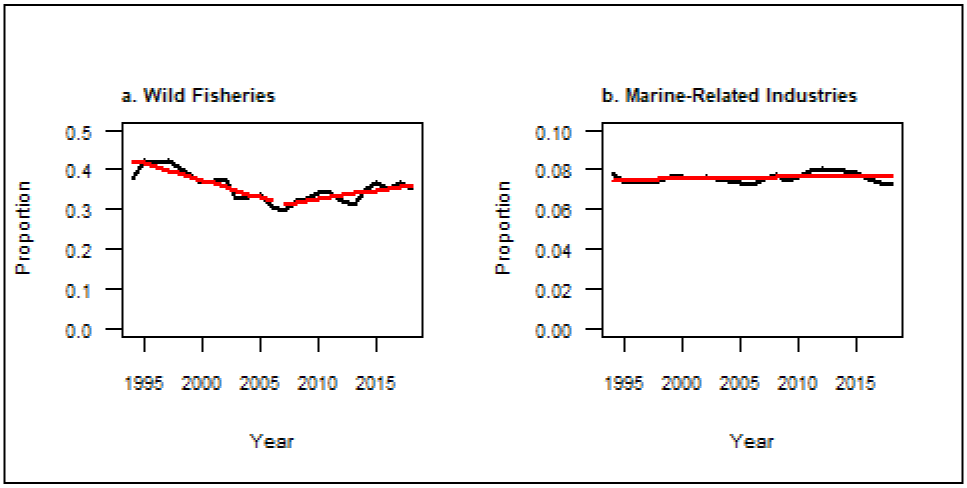

Figure 1.6. Proportion of commercial fishermen participating in more than one fishery category (a) and proportion of all individuals participating in more than one marine-related industry (b) with trend lines (red).

Table 1.1. Total number of individuals with a license/permit in each wild fishery (Column 1) and marine-related industry (Column 2) between 1994-2018, as well as the percentage of individuals diversified in wild fisheries and marine-related industries (Column 3). Acronym SSP represents "seafood sales and processing."

	Wild Fisheries				Marine-Related Industries				Diversification	
	Clam	**Crab**	**Finfish**	**Oyster**	**Aquaculture**	**SSP**	**Charter**	**Commercial Fishing**	**Wild Species**	**Marine-Related Industries**
1994	523	1,958	1,300	352	-	722	137	3,198	0.375	0.078
1995	530	1,906	1,371	343	-	695	130	2,989	0.421	0.073
1996	475	1,950	1388	268	-	722	141	2,993	0.419	0.073
1997	409	1,963	1,375	281	-	783	142	2,948	0.423	0.073
1998	386	1,991	1,329	348	-	816	147	3,026	0.407	0.074
1999	382	2,016	1,333	370	-	934	170	3,122	0.386	0.076
2000	367	2,002	1,312	241	-	854	201	3,067	0.369	0.076
2001	358	1,944	1,283	305	-	852	214	3,026	0.371	0.076
2002	329	1,867	1,224	474	-	794	283	3,029	0.375	0.077
2003	283	1,820	1,165	275	-	749	290	2,961	0.326	0.075
2004	240	1,751	1,102	352	-	736	274	2,894	0.331	0.074
2005	210	1,683	1,047	509	-	693	257	2,900	0.339	0.073
2006	181	1,578	1,020	446	-	563	243	2,909	0.306	0.072
2007	179	1,465	1,044	432	329	509	257	2,901	0.295	0.075
2008	183	1,468	1,068	491	530	528	281	2,839	0.320	0.078
2009	157	1,276	1,175	548	456	508	294	2,769	0.325	0.074
2010	161	1,240	1,220	645	656	498	257	2,773	0.344	0.077
2011	160	1,201	1,136	685	856	516	247	2,804	0.340	0.080
2012	149	1,192	1,123	700	865	513	232	2,841	0.321	0.080
2013	151	1,180	1,093	690	861	503	238	2,858	0.314	0.080
2014	136	1,192	1,157	922	908	457	233	2,877	0.349	0.080
2015	145	1,193	1,136	1,066	932	460	215	2,842	0.368	0.078
2016	143	1,189	1,054	983	893	477	203	2,788	0.352	0.076
2017	137	1,157	1,056	1,008	819	458	205	2,731	0.366	0.074
2018	123	1,131	1,009	949	766	463	205	2,683	0.353	0.072

Table 1.2. Average proportion of licensed individuals participating in marine-related industries across all years calculated using the sum of individuals holding a license or permit in both the column and row categories over all license or permit holders for each row of marine-related industries. Each percentage is the total number of individuals in the column sector over the total number of individuals in the row sector. For example, 12.9% of commercial fishermen have an aquaculture license or permit and 48.6% of individuals with an aquaculture license or permit also have a commercial license or permit.

	Commercial	**Aquaculture**	**Seafood Sales & Processing**	**Chartering**
Commercial	100 %	12.9 %	15.4 %	1.4 %
Aquaculture	48.6 %	100 %	12 %	1.1 %
Seafood Sales & Processing	71.6 %	18.4 %	100 %	1.1 %
Chartering	18.6 %	3.4 %	3.5 %	100 %

Table 1.3. Average proportion of licensed fishermen participating in wild species fisheries across all years calculated using the sum of individuals holding a license or permit in both the column and row categories over all license or permit holders for each row of wild species fisheries. Each percentage is the total number of individuals in the column sector over the total number of individuals in the row sector. For example, 7.9% of fishermen with a wild crab permit also have a wild clam license or permit and 49.1% of individuals with a wild clam license or permit also have a wild crab license or permit.

	Wild Clam	**Wild Crab**	**Wild Finfish**	**Wild Oyster**
Wild Clam	100 %	49.1 %	49.4 %	53.3 %
Wild Crab	7.9 %	100 %	45.4 %	22.3 %
Wild Finfish	7.4 %	45.4 %	100 %	16.2%
Wild Oyster	25.1 %	61.0 %	45.6 %	100 %

Table A1.1. Licenses and permits considered commercial fishing, chartering, seafood sales or processing, or aquaculture (N = 20).

Category	VMRC License or Permit Description
COMMERCIAL FISHING	COMM REGISTRATION-SENIOR CITIZ
	COMMERCIAL REGISTRATION
CHARTERING	CHARTER/HEAD BOAT-6 & UNDER
	CHARTER/HEAD BOAT-MORE THAN 6
SEAFOOD SALES & PROCESSING	BUYERS BUSINESS PLACE
	CRAB SHED TANK-20 OR LESS
	CRAB SHED TANK-OVER 20
	SEAFOOD BUYER'S TRUCK
	SHUCKING HOUSE-UNDER 1000
	SHUCKING HOUSE-TO 10,000
	SHUCKING HOUSE-TO 25,000
	SHUCKING HOUSE-TO 100,000
	SHUCKING HOUSE-TO 200,000
	SHUCKING HOUSE-OVER 200,000
AQUACULTURE	CLAM AQUACULT HARVESTER PERMIT
	CLAM AQUACULT PROD OWNER PERMIT
	CLAM AQUACULTURE
	OYS AQUACULT HARVESTER PERMIT
	OYS AQUACULT PROD OWNER PERMIT
	OYSTER AQUACULTURE

Table A1.2. Licenses and permits considered for wild species fisheries (N = 33).

Category	VMRC License or Permit Description
OYSTER	OYSTER BY HAND OYSTER DREDGE PUBLIC GROUND OYSTER PATENT TONGS-DOUBLE OYSTER PATENT TONGS-SINGLE OYSTER BY HAND SCRAPE OYSTER BY HAND TONGS
CLAM	CLAM BY HAND/RAKE CLAM DREDGE-HAND CLAM DREDGE-POWER CLAM PATENT TONGS-DOUBLE CLAM PATENT TONGS-SINGLE
CRAB	CRAB-ORDINARY TROT LINE CRAB-PATENT TROT LINE CRAB DIP NET CRAB HAND SCRAPE-DOUBLE CRAB HAND SCRAPE-SINGLE CRAB PEELER POT-210 OR LESS CRAB POT-85 OR LESS CRAB POT-170 TO 255 CRAB POT-256 TO 425 CRAB POWER DREDGE CRAB TRAP
FINFISH	COMMERCIAL CAST/THROW NET COMMERCIAL FISH DIP NET COMMERCIAL HOOK & LINE FISH TROT LINE FYKE NET GILL NETS-1200 OR LESS GILL NETS-600 OR LESS HAUL SEINE-500 YDS &OVER HAUL SEINE-UNDER 500 YDS POUND NET STAKED GILL NET

Table A1.3. Results from Chow test (F-statistic and associated p value) in column "Chow Test." If a significant structural change was indicated, then the results for both time period[8] regressions are presented. If a structural change was not identified, then the linear regression for 1994-2018 is presented.

	Chow Test		Time Period 1			Time Period 2			1994-2018		
	F-statistic	p	β_0	β_1	p	β_0	β_1	p	β_0	β_1	p
Wild Fisheries											
Clam (Fig. 4a)	92.661	***	527.86	-28.07	***	234.67	-4.47	***	-	-	-
Crab (Fig. 4b)	13.135	***	2042.01	-27.14	**	1716.16	-25.72	***			
Finfish (Fig. 4c)	6.3848		-	-	-	-	-	-	1341.7	-13.41	***
Oyster (Fig. 4d)	3.039								209.6	41.57	***
Marine-Related Industries											
Aquaculture (Fig. 5a)	17.972	**	364.79	95.21	**	1220.90	-39.70	*	-	-	-
Chartering (Fig. 5b)	42.768	***	117.74	14.08	***	377.28	-7.48	***	-	-	-
Commercial Fishing (Fig. 5c)	0.481		-	-	-	-	-	-	3088.3	-14.78	***
Seafood Sales & Processing (Fig. 5d)	15.736	***	780.00	-6.24		602.74	-6.05	***	-	-	-
Diversification											
Wild Species (Fig. 6a)	7.828	**	0.424	-0.008	***	0.247	0.005	**	-	-	-
Marine-Related Industries (Fig. 6b)	0.116		-	-	-	-	-	-	0.007	0.00009	

Significance codes : '*' <0.001 '**' <0.01 '*' <0.05 'blank' >0.05**

[8] Time Period 1 represents 1994-2006 for all wild fisheries and marine-related sectors (with the exception of aquaculture, which is 2007-2013 and oyster, which is 1999-2008). Time Period 2 represents 2007-2018 for all wild fisheries and marine-related sectors (with the exception of aquaculture, which is 2014-2018 and oyster, which is 2009-2018).

Table A1.4. Multiple correspondence analysis (MCA) dimension coordinates for wild species fisheries, including oyster (WildOys_0, WildOys_1), crab (WildCrab_0, WildCrab_1), clam (WildClam_0, WildClam_1), and finfish (WildFish_0, Wildfish_1) between 1994-2006 and 2007-2018.

		Dimension 1	**Dimension 2**	**Dimension 3**	**Dimension 4**
1994-2006	**WildOys_0**	-0.4726	-0.1073	-0.0882	-0.3272
	WildOys_1	1.351	0.3068	0.2521	0.9356
	WildCrab_0	-0.5083	0.9208	-0.7512	0.2730
	WildCrab_1	0.2913	-0.5277	0.4305	-0.1564
	WildClam_0	-0.3551	-0.2500	-0.0124	0.2447
	WildClam_1	1.4270	1.0647	0.0526	-1.0422
	WildFish_0	-0.4863	0.5806	-0.7965	0.0336
	WildFish_1	0.4021	-0.4802	-0.6587	-0.0278
2007- 2018	**WildOys_0**	-0.5383	-0.2389	-0.2345	0.4201
	WildOys_1	0.9308	0.4131	0.4055	-0.7264
	WildCrab_0	-0.4601	0.6492	-0.4773	-0.2609
	WildCrab_1	0.4953	-0.6688	0.5138	0.2807
	WildClam_0	-0.1910	-0.1717	0.0281	-0.1658
	WildClam_1	2.0264	1.8213	-0.2986	1.7591
	WildFish_0	-0.5954	0.4311	0.6891	0.1286
	WildFish_1	0.5771	-0.4178	-0.6679	-0.1246

Table A1.5. Multiple correspondence analysis (MCA) dimension coordinates for marine-related industries, including aquaculture (Aqua_0, Aqua_1), chartering (Charter_0, Charter_1), commercial fishing (Com_0, Com_1), and seafood sales and processing (SSP_0, SSP_1) between 1994-2006 and 2007-2018. There are only three dimensions included for the 1994-2006 MCA, as aquaculture licensing/permitting did not exist until the second half of the time series.

		Dimension 1	Dimension 2	Dimension 3	Dimension 4
1994-2006	**Aqua_0**	-	-	-	-
	Aqua_1	-	-	-	-
	Charter_0	-0.3337	0.1513	-0.1365	-
	Charter_1	2.1830	-0.9898	0.8928	-
	Com_0	1.4579	0.5864	-0.5902	-
	Com_1	-0.5174	-0.2081	0.2095	-
	SSP_0	-0.0220	-0.7617	-0.2118	-
	SSP_1	0.0352	1.2177	0.3386	-
2007-2018	**Aqua_0**	-0.3232	0.5077	-0.1031	-0.2128
	Aqua_1	0.7729	-1.2142	0.2465	0.5089
	Charter_0	-0.2054	-0.2573	0.0638	-0.1196
	Charter_1	1.6202	2.0292	-0.5031	0.9426
	Com_0	0.9045	0.1633	0.7508	-0.3898
	Com_1	-0.5796	-0.1047	-0.4811	0.2498
	SSP_0	0.3672	-0.1572	-0.5423	-0.1743
	SSP_1	-0.7587	0.3246	1.1203	0.3600

CHAPTER II

ASSESSING DIVERSIFICATION BEHAVIOR OF VIRGINIA'S SMALL-SCALE FISHERMEN

Introduction

Commercial fishing is an inherently risky occupation, both financially and physically (Eckert et al. 2018; Lucas and Case 2018). Fishermen face volatile markets, fluctuations in resource abundance, unpredictable weather conditions, and abrupt regulatory changes that influence participation on varying temporal and spatial scales, forcing fishermen to make decisions based on uncertainty. Individual decision-making on where and how to fish, what to fish for, and whether or not to fish is influenced by a number of ecological, social and economic constraints (Yletyinen et al. 2018). Traditional fisheries management tends to focus on the effects of fishing on quantitative resource measures rather than how ecological and exogenous factors (e.g., markets, regulation, culture) influence the decision-making processes of fishermen. Understanding factors influencing participation dynamics can be used to estimate impacts of adverse events to fishing communities and enhance resiliency. Individual decision-making is likely heterogenous among fishing communities (Camerer 2000; Smith and Wilen 2005) and a one size fits all approach to fisheries management can increase the prevalence of unintended consequences that arise from management actions and lessen the ability of individuals and fishing communities to adapt to perturbations (Fulton et al. 2010). While more complex, an enhanced understanding of the relationships that exist between small-scale fishermen and the environment is more holistic and imperative for ecosystem-based management approaches.

Small-scale fisheries are considered particularly vulnerable to perturbations due to the inherent riskiness of fishing, limited access to financial capital, and rising social challenges, including competition with other user groups (e.g., coastal developers, recreational fisheries, conservation groups), perceived injustices (e.g., socio-political underrepresentation), and increased government intervention (Flint and Luloff 2005; Bavinck et al. 2018). While broadly defined, small-scale fisheries account for a substantial portion of the global commercial fishing population and are characterized as diverse and dynamic, often with strong social and economic dependence on fishing as a livelihood (Teh and Sumaila 2013; Basurto et al. 2017). Virginia's small-scale coastal fisheries harbor similar characteristics with historical ties to nearshore and inshore species, such as blue crab (*Callinectes sapidus*), eastern oyster (*Crassostrea* *virginica*), hard clam (*Mercenaria mercenaria*), striped bass (*Morone saxatilis*), Atlantic croaker (*Micropogonias undulates*) and other finfish that continue to serve as a livelihood for colloquially termed "watermen" and contribute to the development of the state's coastal communities (Kirkley 1997; McGoodwin 2001; Paolisso 2007). In the past two decades, however, the number of commercial fishing licenses sold in Virginia has declined more than 15% while the number of senior licenses (≥65 years) has nearly doubled (White and Scheld 2021). These trends may indicate broad societal impacts, including a "graying of the fleet" that coincides with shifts in participation and resource dependence (Donkersloot and Carothers 2016; Cramer et al. 2018; Johnson and Mazur 2018). Furthermore, the lack of younger individuals entering the industry threatens the long-term resiliency of Virginia's coastal commercial fisheries and fishing communities.

Sustainable livelihood strategies to increase resiliency and reduce vulnerability in small-scale fisheries have been studied around the world (Panayotou 1985; Allison and Ellis 2001; Finkbeiner 2015; Selgrath et al. 2018). These strategies rely on an understanding of what motivates fishermen to enter or exit various fisheries or sectors (e.g., marine-related or otherwise). Reasons for entry (exit) have been noted in fisheries of varying scale with factors including residency, revenues, market conditions, historical productivity, resource abundance, and knowledge of the industry (Pálsson and Durrenberger 1982; Ward and Sutinen 1994; Pradhan and Leung 2004; Slater et al. 2013; Bucaram and Hearn 2014). The socio-cultural components of fishing (e.g., cultural significance, family and community support, job satisfaction, and occupational identity) can also influence decision-making, although they are often intangible and difficult to quantify. In some instances, socio-cultural factors can affect fishing decisions to a greater extent than economics or regulation and prevent fishermen from exiting the industry even when there is no economic rationale to continue fishing (Marshall et al. 2007; Crosson 2015; Holland et al. 2020). In rural areas where individuals have a strong place attachment and fishing is viewed as a way of life rather than an occupation, social and economic dependence can strongly influence participation and decision-making (Marshall et al. 2007; Pollnac and Poggie 2008; Khakzad and Griffith 2016; Jurjonas and Seekamp 2018; Naranjo-Helven and van Putten 2019).

Small-scale fishermen may diversify between fisheries or other employment (e.g., marine-related or otherwise) as a strategy to stabilize income, reduce vulnerability, and enhance long-term resiliency (Allison and Ellis 2001; Kasperski and Holland 2013; Sethi et al. 2014; Cline et al. 2017; Fuller et al. 2017). Fishermen can diversify within the commercial fishing industry by alternating fishing locations, seasons, gear types, or target species. Diversification within the industry can enable fishermen to fish year-round rather than being restricted to specific times, areas, or seasons. As an example, in Virginia, diversified fishermen can target blue crab during the spring and summer seasons and continue fishing throughout the fall and winter by targeting eastern oyster. Diversification can be considered a necessity due to environmental changes which force fishermen to switch between locations and species (Pinsky and Fogarty 2012; Papaioannou et al. 2021). Fishermen with employment outside of commercial fishing can choose to fish when conditions (e.g., resource abundance, ex-vessel price, etc.) are optimal and may recover more quickly following a disturbance (Beaudreau et al. 2019). Smith and Wilen (2005), however, noted that part-time fishermen in the California sea urchin fishery engage in physically riskier behavior due to limited fishing opportunities that may not be reflective of optimal conditions. Otherwise it is noted that fishermen are generally risk adverse (Bockstael and Opaluch 1983; Smith and Wilen 2005), suggesting that diversification outside of the commercial fishing industry and its influence on decision-making should be further investigated as it may be location or fishery-specific (Holland and Sutinen 2000; Smith and Wilen 2005; Eggert and Lokina 2007).

Despite the well-studied benefits of diversification, less than half of Virginia's commercial fishermen diversify between fisheries in a given year and less than one-third are diversified into other marine-related industries (e.g., aquaculture, chartering, or seafood sales and processing; White and Scheld 2021). This is similar to findings in Alaskan fisheries where consolidation of individual fishing portfolios (i.e., specialization), is becoming more frequent (Kasperski and Holland 2013; Beaudreau et al. 2019). The ability to diversify can be constrained by lack of knowledge, management (e.g., limited entry, individual fishing quotas), financial and social capital, and individual desire (Frawley et al. 2019). The size and condition of the fishery may also be noteworthy, as in the case of Baltic Sea fisheries where diversification decisions between small- and large-scale commercial fisheries differed in response to changes in stock status, market price, and management, with large-scale fishermen becoming less diversified and small-scale fishermen more diversified over time (Hentati-Sundberg et al. 2015; Yletyinen et al. 2018). Bockstael and Opaluch (1983) also noted that despite more profitable alternatives, fishermen may continue in certain fisheries due to familiarity or risk aversion. The decision to specialize can be related to high investment or dependence on a fishery, as well as the condition of the fishery (i.e., high resource abundances and market prices may promote specialization; Allison and Ellis 2001; Kasperski and Holland 2013; Finkbeiner 2015). Nonetheless, specialization may constrain the capabilities of small-scale fishermen and fishing communities to adapt during adverse events.

The individual decision-making processes related to participation and diversification in Virginia's small-scale coastal fisheries are not well understood and represent a management need for local and state government. Although the drivers of entry (exit) decisions have been studied in more depth, a better understanding of how Virginia's small-scale fishermen are choosing to diversify (within and outside commercial fishing) on varying temporal scales would help reduce unintended consequences from management actions, including disruption of social and cultural norms, access issues, and non-compliance, as well as allowing for adaptation to changing environmental conditions (Degnbol and McCay 2007; Bennett and Dearden 2014; Stoll et al. 2016; Chambers and Carothers 2017). Diversification behavior in Virginia's small-scale coastal fisheries is explored through 1) assessing levels of individual and fleet diversification using Herfindahl-Hirschman Indices (HHI) and 2) examining factors related to individual diversification decision-making. While focused on Virginia, this research also contributes to a broader understanding of factors influencing participation and diversification decisions with implications to other small-scale commercial fishing communities of similar attributes.

Methods

Data

The Virginia Marine Resources Commission (VMRC) oversees commercial landings, as well state licensing and permitting for commercial harvest, processing (i.e., shucking houses, crab shedding), fish dealers, charters operating in state waters, and aquaculture. In Virginia, a commercial registration license is required for all wild harvest, while additional licenses or permits are needed to participate in specific fisheries or sectors (e.g., aquaculture, chartering, seafood sales and processing). Permits are no-cost and provide additional eligibility to harvest species such as summer flounder (*Paralichthys dentatus*) after obtaining a license for gear. Two datasets – one for VMRC licenses and permits and another for commercially licensed landings – were merged to explore individual participation and diversification of small-scale commercial fishermen in Virginia.

The license and permit dataset included a unique individual license number and identified which licenses or permits each individual held annually between 1993-2018. The initial year was omitted from analyses, as many license and permit types only existed in this year and were recategorized. Licenses and permits used for administrative purposes were not included in analyses (e.g., replacement licenses, refunded licenses, etc.) nor were permits that provided extra eligibility for wild harvest in restricted areas. Licenses and permits identified as "transferred" were included, as transferring licenses and permits across individuals is common in Virginia and allows equivalent participation to holding a non-transferred license or permit. Licenses and permits were grouped into two categories, marine-related businesses and wild species fisheries, based on descriptions from the VMRC (http://www.mrc.virginia.gov/). Marine-related businesses included licenses and permits related to commercial fishing, chartering, aquaculture, and seafood sales and processing (Table 2A.1; N =30 licenses and permits). Wild species fisheries that require additional licenses or permits for harvest were grouped into species categories based on gear type when available. A total of 84 licenses and permits were considered for wild species fisheries (Table 2A.2). Finfish was considered an aggregate category, as there are multiple species of finfish that can be harvested with a single gear type (e.g., gill net, fyke net, pound net) and do not require species-specific licenses or permits such as spotted seatrout (*Cynoscion nebulosus*) or Atlantic croaker (*Micropogonias undulatus*). Licenses and permits that did not include specific gear types were categorized by species (e.g., spiny dogfish, summer flounder). The resulting license and permit dataset included the individual license number, year license or permit was held, as well as the sector (i.e., marine-related business) and species categories treated as binary variables with "1" representing that a license or permit was held for a given year and "0" indicating that the individual did not have the license or permit.

The commercial landings dataset contained a unique individual license number, year of licensure, and for each year, indicated all landings by species, market grade and gear, in terms of pounds and value. The dataset contained landings from 1993-2018, with the first year reflecting the onset of electronic record-keeping by VMRC. The first year (1993) was omitted from analyses for consistency with the license and permit dataset. Landings associated solely with aquaculture and landings from privately leased grounds were removed. Commercially landed species were aggregated based on market grade or similar species characteristics when market grades were unavailable (Table 2A.3). For example, various market grades (e.g., small, medium, large) of bluefish (*Pomatomus saltatrix*) were grouped into one aggregate category, while alewife (*Alosa pseudoharengus*) and blueback herring (*A. aestivalis*) were grouped into a broader category for shads and herrings.[9] Species with <100 landings observations in the dataset, cumulative across all market grades, were omitted as they are not considered a viable diversification option for small-scale commercial fishermen.

The license and permit dataset was merged with the landings dataset so that each observation corresponded with an individual license number, year of licensure, a binary indicator of participation (holding a license or permit) for selected wild species and marine-related business sectors, and the pounds and value of each species or species-aggregate landed. Only commercial fishermen present in both datasets were merged, as these individuals are the focus of this research. The merged license and landings dataset was restricted to remove individuals with no landings and no commercial registration (n=17), as well as individuals with a commercial registration but no landings throughout the time series (n=2,233)[10] and

[9] The aggregate whelk category includes two species of whelk colloquially referred to as "conch" in Virginia fisheries (A. Galván, VMRC, e-mail to author, May 11, 2022).

[10] This includes individuals that only had landings in 1993 and were subsequently removed, as well as individuals that retain licenses or permits with no intention to use them.

individuals with landings but no commercial registration (n=197). These individuals would bias estimates of diversification decisions and represent an aspect of the population where decision-making cannot be interpreted with available data (i.e., retaining licenses or permits with no intention to use them, missing licenses or permits). The merged dataset contained a total of 70,022 observations for 4,890 licensed commercial fishermen between 1994 and 2018 (Table 2A.4).

Herfindahl-Hirschman Indices (HHI)

Total pounds and revenue across species were summed for each individual and year in the merged license and landings dataset. Individual species revenue and annual incomes were adjusted for inflation using the Gross Domestic Product Implicit Price Deflator (USBEA 2022) and rescaled to thousands of dollars in 2018. The number of licenses or permits an individual held for participation in wild fisheries was also calculated. Aggregate license and permit categories (Table 2A.2) were used to calculate the total number of licenses or permits held by each individual in every year. For example, if an individual held a license or permit for crab, oyster, and summer flounder in a particular year, then the individual would have a license or permit count of three. Aggregate species categories (Table 2A.3) were used to determine the total number of fisheries an individual participated in for a given year based on whether an individual had landings for that species. For example, if an individual had landings for any fishery considered "oyster" and any fishery considered "shad and herring" then the individual would have a species count of two (Table 2A.3). Pearson correlation tests were used to evaluate the relationship between the number of licenses or permits an individual held and entry year, as well as the total number of years an individual was present in the dataset. It is thought that individuals who enter the commercial fishing industry earlier and remain in the industry longer are more diversified as a result of enhanced knowledge and capital.

The Herfindahl-Hirschman Index (HHI), a measure of industry concentration commonly applied to fishing portfolio diversification, was calculated for each individual in every year using total income across all species landed in a given year (Miller 1982; Crosson 2011; Kasperski and Holland 2013; Finkbeiner 2015; Anderson et al. 2017). HHI values are defined as:

Equation 2. $HHI_{it} = \sum_{j=1}^{N} s_{ijt}^2$

where N is the total number of fisheries individual i could derive income from and s_{ijt} is the share of individual i's total income from fishery j in year t. HHI values range from 0 to 1, with higher values indicating that an individual is less diversified (i.e., more specialized participation), and lower values indicating that an individual is more diversified. HHI values were calculated as the sum of squared shares of total income for all species landed and analyzed across the fleet for all years. To evaluate differences across species and marine-related sectors, average HHI values for individuals with species-specific or marine-related business licenses or permits were calculated. Spearman correlations were used to evaluate the relationship between HHI income values, annual income, and income variability (i.e., coefficient of variation). Based on prior studies, it is expected that more diversified individuals will have higher annual incomes with less annual variability (Finkbeiner 2015; Sethi et al. 2014)

Diversification Model Development

Generalized linear mixed models (GLMMs) were used to examine factors influencing individual decisions to increase or decrease diversification. Decisions to increase or decrease diversification were modeled separately as the motivations for each may differ between individuals. For instance, individuals may be more likely to enter a fishery if the expected returns are high, but less likely to exit the same fishery when returns are low (Ward and Sutinen 1994). Diversification decisions were treated as binary and evaluated by a change in the number of licenses or permits held between years. For example, when the response variable was the decision to increase diversification, a "1" represented an increase in the number of held licenses or permits and a "0" indicated that the individual had no change. Conversely, when the decision to decrease diversification was assessed, a "1" represented a decrease in the number of held licenses or permits and a "0" indicated no change. Individual diversification decisions were modeled based on factors in the previous year (e.g., annual income, average market price) to reduce the potential of endogeneity and understand the effect of these variables on decision-making. For example, if an individual decreased the number of licenses or permits held from 2006 to 2007, this decision would be based on factors that occurred in 2006. The first and last year an individual held a commercial fishing license was used to calculate the total number of years an individual had participated in commercial fishing. If an individual was not present for the duration of the time series, the last year an individual was in the dataset was extended by one year (Abbott et al. 2022).

Prior studies have found diversification to be related to the total number of years an individual has participated in commercial fishing, market conditions, individual landings revenues, regulation, as well as a number of ecological and socio-economic factors (Ward and Sutinen 1994; Bucaram and Hearn 2014; Hentati-Sundberg et al. 2015; Stoll et al. 2017; Abbott et al. 2022). Model covariates tested to evaluate the influence on decisions to increase or decrease diversification in a given year included: year of licensure, annual income, volume of landings, HHI income values, holding licenses or permits in marine-related businesses (in addition to commercial fishing), participation in niche (e.g., conch, eel, horseshoe crab) or limited entry fisheries, years of participation in the commercial fishing industry, entry year, number of licenses or permits held, holding a senior commercial fishing registration, and average market price received across all species (see Table 2A.5 for descriptive statistics of included variables). Limited entry fisheries were considered as limited the year following the initial regulation. For example, spiny dogfish became a limited entry fishery in November 2009, but this restriction was considered to begin in 2010 when all individuals would be required to obtain a license or permit. Individual license numbers (i.e., individual fishermen) were included as random effects in both models to control for unobserved heterogeneity in decision making. Variance Inflation Factors (VIF) were used to determine multicollinearity between covariates and VIF values of ≥ 5 were avoided (O'Brien 2007). The final increasing and decreasing diversification models were selected based on Akaike's Information Criterion model comparison. All continuous covariates were standardized using z-score transformations. GLMMs were modeled as binomial regressions using a logit link and fit in the glmmTMB package for R Studio (Brooks et al. 2017). Odds ratios were calculated by exponentiating significant coefficient estimates for both models. The change in odds was calculated by subtracting 1 from the exponentiated coefficient and multiplying by 100 to get a percentage.

Results

The average number of years a commercial fisherman was active in the dataset was 17.53 ± 7.16 years. Fishermen held 1.55 (±1.25) licenses or permits and landed 1.73 (±2.60) species on average across all years between 1994-2018 (Table 2A.6). The proportion of fishermen, on average, that changed the number of licenses or permits held from one year to the next across the time series was 41.2%, while the average annual change in species landed from one year to the next was 63.3%. The average inter-annual change in the number of licenses or permits held and species landed across all individuals and years was slightly negative, although the standard deviations were large (Δ -0.003 ± 0.79 for licenses or permits held and Δ -0.046 ± 0.37 for species landed. Despite the slightly negative trend in the number of licenses or permits held, fishermen are continuing to diversify between fisheries, though to a limited extent given the average of 1.55 licenses or permits per person. The length of time an individual was present in the dataset was positively correlated with the total number of licenses and permits held (0.314, p value <0.001). The number of permits an individual held, however, was negatively correlated with the year an individual entered the dataset, suggesting that individuals entering later are less diversified (-0.087, p value <0.001).

Herfindahl-Hirschman Indices (HHI)

The average HHI income value across all years and individuals was 0.82 (±0.24), indicating that most fishermen are highly specialized when all landed species, regardless of whether a species-specific license or permit is required, are included (Table 2A.3; Table 2A.7). Average HHI income values vary when considering only individuals with particular species-specific licenses or permits across years. HHI income values for species-specific licenses or permits are typically below the average HHI income value across all individuals (Figure 2.1; Figure 2.2). This is likely driven by blue crab being the dominant fishery in Virginia and individuals holding a license or permit for crab being least diversified with average HHI income values of 0.84 (Figure 2.2B). Individuals holding a license or permit for summer flounder (Figure 1D) or clam (Figure 2.2A) also tend to be less diversified with average HHI income values of 0.88 and 0.79, respectively. Individuals with an aggregate finfish license or permit had an average HHI value of 0.73 for all years between 1994-2018 (Figure 2.1A). However, when licenses and permits for finfish are considered at the species level, HHI values are lower than those for the aggregate finfish category with the exception of summer flounder (Figure 2.1A-2.1C). These results indicate that individuals with a license or permit in the aggregate finfish category tend to be less diversified into other fisheries (e.g., clam, crab, oyster), but more diversified between finfish species within the aggregate category. Individuals in niche fisheries (e.g., horseshoe crab, eel, and conch) tend to demonstrate higher levels of diversification with HHI income values between 0.66 and 0.76 (Figures 2.1B, 2.1E, and 2.1F). Individuals with a license or permit for dogfish were the most diversified with average HHI income values of 0.57 (Figure 2.1D). Individuals with a license or permit for oyster had average HHI income values of 0.78 (Figure 2.2G). The level of diversification varies between individuals holding species-specific licenses or permits; however, the majority of commercial fishermen only hold licenses or permits for one species, which results in higher average HHI income values across the fleet (0.82).

There was a significant, positive correlation between the average individual HHI values for income and the average coefficient of variation, or income variability, for an individual across years in the time series (0.145, p value <0.001). This indicates that less diversified fishermen tend to have increased variability in annual income, as expected. Similarly, the correlation between the average individual HHI score for income and average total income for each individual across years in the time series was negative and significant (-0.235, p value <0.001), indicating that more diversified individuals tend to have higher annual incomes on average.

Diversification Models

Covariates in both the final increasing and decreasing diversification models included the total number of years an individual was present in the dataset, annual income, total number of licenses or permits held, amount of landings, holding licenses or permits in marine-related businesses or limited entry fisheries, holding a senior commercial fishing registration, and average market price received across all species landed (see Table 2A.5 for descriptive statistics).

Increasing Diversification Models

The GLMM for individual decision-making to increase diversification included 58,452 observations of 4,890 commercial fishermen (Table 2A.8). Individual license numbers (i.e., individual fishermen) were included as a random effect and suggested a high degree of variability between individuals and their decision to increase diversification (0.72 ± 0.85). Odds ratios were calculated for each significant covariate (Table 2.1).

The total years an individual was in the dataset (i.e., held a commercial fishing license) had a negative impact on the decision to increase diversification in the following year (p value <0.001). The odds of increasing diversification decreased 3% with a one standard deviation change of participation (±7.16) years in the commercial fishing industry (odds ratio, OR=0.97). Annual income derived from commercial fishing had a positive impact on the decision to increase diversification, meaning individuals with higher incomes were more likely to diversify in the next year (p value <0.001). While significant, the odds of an individual increasing diversification based on annual income in the prior year are considerably low, indicating that other factors may have greater role in determining participation or the change in income needs to be much higher for an individual to increase diversification (OR = 1.000004). The impact of whether an individual had any landings across all species on increasing diversification was negative (p value <0.001) with the odds of obtaining an additional license or permit decreasing by 20% if an individual had no landings in the previous year (OR=0.80). The decision to not land, especially in consecutive years, is likely reflective of exit from a particular fishery or the industry altogether. Similarly, holding a senior commercial fishing registration had a negative, significant impact on the decision to increase diversification (p value <0.001). The odds of an individual increasing diversification if holding a senior commercial fishing registration declined by 41% the following year (OR=0.59). When total licenses or permits for wild harvest are considered, there is a negative impact on increasing diversification in the next year (p value <0.001) and the odds of increasing diversification decline by 31% with a change in one standard deviation of permits held (SD=±1.25, OR=0.69). Average market price was not significant in the increasing diversification model. It is important to note however that the correlation between the average market price received and average annual income across all years is negative (-0.080, p value <0.001), suggesting that higher average market values are associated with lower annual incomes. The impact of holding a license or permit for a marine-related business such as chartering, aquaculture, or seafood sales and processing and the decision to increase diversification was positive and significant. The odds that an individual would increase diversification in the following year increased 26% if an individual held a license or permit for a marine-related business. Similarly, if an individual held a license or permit for a limited entry fishery, the odds of increasing diversification in the following year increased 12% (OR=1.12).

Decreasing Diversification Models

The GLMM for individual decision-making to decrease diversification included 60,474 observations of 4,890 commercial fishermen (Table 2A.9). The final covariates included in the decreasing diversification model were the total years an individual held a commercial fishing license or permit, annual income, whether an individual had landings in the prior year, whether an individual held a senior commercial registration, average market price received for catch across all species, total permit count, and whether the individual held a license or permit for a limited entry fishery. Individual license numbers (i.e., individual fishermen) were included as a random effect in the model and demonstrated high heterogeneity between individuals and the decision to decrease diversification (0.54 ± 0.73). Year was included as an interaction term on participation (i.e., held a license or permit) in a limited entry fishery. Odds ratios, presented as the change in odds, were calculated for all significant covariates (Table 2.2).

The total number of years an individual held a commercial fishing license negatively impacted the decision to decrease diversification (p value <0.001). For each one standard deviation in the years of participation in the commercial fishing industry (±7.16), the odds of an individual decreasing diversification decreased 3%. Annual income also had negative impact on the decision to decrease diversification the following year (p value <0.001), however, the odds of an individual decreasing diversification with higher incomes is negligible (OR=1.00). When an individual had no landings across any species in the previous year, an individual was more likely to decrease diversification in the following year (p value <0.001). The odds of decreasing diversification if an individual had no landings increased by 94%, suggesting that an individual would reduce the number of licenses or permits held if they had no landings in the previous year, all else equal (OR=1.94). Individuals holding a license or permit for a limited entry fishery were more likely to decrease diversification in the following year (p value <0.001), however, when year is included as an interaction term on participation in limited entry fishery, the impact on decreasing diversification is negative (p value <0.001). This suggests that individuals holding a license or permit for a limited entry fishery are likely to decrease diversification initially, but across time this effect is dampened (OR= 0.98; p value <0.001). Participation in marine-related businesses had a negative impact on decreasing diversification (p value <0.001), meaning that individuals holding a license or permit in a marine-related business (in addition to commercial fishing) are less likely to decrease diversification. The odds of decreasing diversification decline by 35% when an individual participates in a marine-related business (OR=0.65). The number of licenses or permits held had a positive impact on the decision to decrease diversification (p value <0.001). The odds of an individual decreasing diversification with each one standard deviation change in the number of licenses or permits held (±1.25) are 163% (OR=2.63). Individuals with more licenses or permits may be unable to further diversify as they have already capitalized on available fisheries and therefore, the only option is to maintain these licenses or permits or decrease diversification. Individuals holding senior commercial fishing registration (≥65 years) had a positive impact on the decision to decrease diversification (p value <0.001). The odds of an individual decreasing diversification with a senior commercial fishing license increase by 33.8% (OR= 1.34). The effect of average market price on the decision to decrease diversification is positive (p value <0.001) with a one standard deviation increase in market price (±$1.94) resulting in a 4% increase in the odds that an individual will remove licenses or permits in the following year (OR=1.04).

Synthesis and Predictions

Based on the differences in variances explained by individual random effects in both models, there is evidence that it is important to control for individual heterogeneity in behavior models and that individual heterogeneity is more important in influencing the decision to increase diversification, rather than decrease diversification. There were similar negative effects on increasing and decreasing diversification decisions based on the number of years an individual participated in commercial fishing. The more years an individual is in the industry, the more likely one is to remain unchanged in the number of licenses or permits held. Individuals that have been in the commercial fishing industry for more years are less likely to increase or decrease diversification and thus, years of participation may serve as a barrier to diversification and promote stability in decision-making. Alternatively, other factors seem to promote changes in fishing behavior with opposite effects on the decision to increase or decrease diversification such as annual income, whether an individual had any landings in the previous year, holding a senior commercial fishing registration, holding a license or permit for a marine-related business, and the total number of licenses and permits held. While individuals holding a license or permit for a limited entry fishery were less likely to decrease diversification across years, there was no significant effect of holding a limited entry permit across years on the decision to increase diversification. Average market price had a similar positive effect on the decision to decrease diversification, suggesting that increases in average market price may stimulate changes in fishing behavior through decreasing the number of licenses or permits held.

Individual predictions for both diversification models indicate that in a given year, the average probability of an individual increasing diversification is 15.7% (±0.09), while the average probability of decreasing diversification is 18.7% (±0.15) (Figure 2.3). These predictions are similar to the observed changes in diversification (whether increasing or decreasing), with an average of 41.2% change in the number of licenses and permits held across all individuals and years.

Discussion

Despite the suggested benefits of diversification (Kasperski and Holland 2013; Anderson et al. 2017; Holland et al. 2017), Virginia's small-scale fishermen have largely specialized since the mid-1990's. Average indices of diversification for income and landings across all individuals and years suggest that a significant portion of Virginia's fishermen are deriving income and landings from a single species. This corroborates the findings of White and Scheld (2021), which indicate less than half of commercial fishermen are diversified between species. These levels are likely affected by the dominant blue crab fishery in Virginia as individuals with a license or permit for blue crab tend to be less diversified. Nonetheless, this is similar to findings of US West Coast and Alaskan fisheries where specialization is becoming increasingly common (Holland and Kasperski 2016; Ward et al. 2018; Beaudreau et al. 2019). While the relationship between increased diversification and decreased income variability in Virginia's small-scale fisheries is similar to other US fisheries (Kasperski and Holland 2013; Anderson et al. 2017; Sethi et al. 2014), evidence indicates that specialization may be an important adaptive strategy of fishermen to increase income during favorable conditions (e.g., increased market price, high species abundance) (Finkbeiner 2015; Anderson et al. 2017; Ward et al. 2018). Although this study supports the notion that higher average market prices promote specialization, it does not find that higher annual income has similar impacts. In contrast, diversification is negatively correlated with annual incomes, meaning that more diversified individuals tend to have higher annual incomes. While speculative, the relationship between increased diversification and higher incomes could be the result of increases in seafood value and market price within the last few decades or it could be indicative of individuals increasing diversification to target species with higher market values. It is probable that fishermen with higher annual incomes hope to derive additional economic benefits from increasing levels of participation, while lower annual incomes and decreasing diversification decisions may be tied to exit from the industry or indicate participation in outside employment that serves as the primary source of income. Ward and Sutinen (1994) noted that fishermen are more likely to enter a fishery when profits are higher than exit when profits are low. While this study does not capture differences in the rate of increasing or decreasing diversification relative to annual income, it is plausible that similar behaviors are occurring in Virginia's small-scale fisheries. The odds of increasing or decreasing diversification with changes in annual income were negligible, indicating that large changes in annual income were needed for individuals to increase or decrease diversification. This is likely driven by a few individuals with high annual incomes (>$200,000) holding nearly double the average number of licenses or permits compared to the entire commercial fishing population.

Due to the financial cost and difficulty of obtaining licenses and permits to enter many commercial fisheries in Virginia, particularly licenses and permits for limited entry or quota-managed fisheries, it is possible that individuals may appear to increase diversification by adding licenses or permits with no intent to utilize them other than retaining them for potential opportunities. These individuals remain specialized in certain fisheries despite expanding their license portfolio. Individuals with higher annual incomes may also be more resource dependent on commercial fishing (i.e., full-time fishermen) and ultimately, have an enhanced ability or need to expand their fishing portfolio. Fishery scientists and managers should consider the potential impacts of specialization during adverse events as this fishing strategy could create unintended socio-ecological consequences and promote unsustainable fishing pressure on other species (Addicott et al. 2019).

Levels of diversification within the commercial fishing industry can vary based on license or permit holdings. In Virginia, the probability that an individual will choose to decrease diversification is significantly impacted when an individual holds a senior commercial registration. This "graying of the fleet" phenomenon corresponds with shifts in resource dependence, as older fishermen reduce participation (or exit in some cases) the industry and there is limited new entry (Donkersloot and Carothers 2016; Cramer et al. 2018; Johnson and Mazur 2018). The graying of the fleet threatens the resiliency of the commercial fishing industry by inhibiting generational knowledge transfer and social memory (Folke 2006; Johnson and Mazur 2018). Furthermore, the length of time an individual is present in the dataset is positively correlated with the number of licenses or permits held (i.e., more diversified). These correlations are unsurprising as individuals that remain in the industry longer may have the knowledge, financial capital, and ability to diversify more readily than a newcomer (Ward and Sutinen 1994; Holland and Kasperski 2016). However, similar to findings of Abbott et al. (2022), as the cumulative years of participation increases, an individual is less likely to continue diversifying. This may be due to the fact that the fisherman already holds a desired number of permits, or it is not feasible to enter another permitted fishery. Cumulative years of participation also had a negative effect impact on the decision to decrease diversification. These findings suggest that the longer a fisherman remains in the commercial fishing industry, the less likely they are to alter their participation behavior (e.g., increase or decrease diversification). There is evidence that Virginia's commercial fishermen might retain licenses or permits even if they are not being used as a strategy to increase future selling price. This is particularly true for fisheries that are managed through privatization such as limited entry or quota-based fisheries.

Differences in diversification levels based on licenses and permit holdings for specific species are also apparent. On average, individuals with a license or permit for blue crab are less diversified and individuals holding a license or permit for spiny dogfish are more diversified. The reasoning for specialization in the Virginia blue crab fishery is unclear, although it could be due to the demands of obtaining a limited entry license for the fishery, the amount of capital investment for gear (e.g., crab pots, pot puller), or the potential for high market values (and thus, revenues) in a given year. Higher levels of diversification for individuals with licenses or permits for various finfish species and spiny dogfish is not unexpected, as gears used in these fisheries can be used to target a wide variety of commercially profitable species (e.g., gill nets, pound nets). Nonetheless, the ability to diversify using less selective gear types remains limited by the scope of the licenses or permits that a fisherman holds. If a fisherman catches black drum and spiny dogfish in a single trip using a gill net, but only holds permit for spiny dogfish, then the ability to diversify is constrained.

As more fisheries require additional licenses or permits and management trends towards private property regimes, the ability to diversify may become increasingly constrained (Stoll et al. 2016; Holland and Kasperski 2016; Silver and Stoll 2019). Limited entry and individual fishing quotas (IFQs) have been found to negatively impact revenues and job security of individuals without sufficient quota in the US West Coast (Carothers 2013; Holland and Kasperski 2016). Furthermore, these management regimes can promote specialization as individuals with larger quotas can attribute more time and effort to the fishery

(Carothers 2013; Holland and Kasperski 2016). In Virginia, many fisheries are regulated through a combination of limited entry and/or quota regimes, including (but not limited to) black drum, black sea bass, blue crab, spiny dogfish, and striped bass. As a requirement for participation in Virginia's limited entry fisheries, fishermen must provide landings in order to maintain participation and therefore, may be more likely to specialize in these fisheries. In addition to the impacts on established fishermen, the cost of limited entry or quota fisheries may prevent new fishermen from participating, especially younger individuals (Chambers and Carothers 2017). Recently advertised licenses and permits for the limited entry blue crab fishery in Virginia are listed for as high as $30,000 (VMRC; https://mrc.virginia.gov/othrlics.shtm), which could arguably be considered a financial burden for fishermen involved in small-scale fisheries where access to financial capital is limited. The cost, as well as requirements of maintaining a limited license or quota share, reduce the adaptive capacity of fishermen to alternate between periods of diversification and specialization. Crosson (2011) suggests that these management strategies overlook the socio-cultural aspects (i.e., generational ties, community structure) of commercial fishing, although these aspects can influence management preferences. Fishermen that have historically switched between species, gears, and locations to compensate for environmental and economic changes (e.g., low species abundance, low market price) may be displaced under limited entry and quota programs. This study finds that fishermen holding a license or permit in a limited entry fishery had a 2% reduction in the odds of decreasing diversification in the following year, although it is possible that fishermen are retaining licenses and permits as a "just in case" risk management strategy. Similarly, abrupt management decisions can influence the decision to increase or decrease diversification in a given year. In 2008, there was a moratorium on the Virginia blue crab dredge, forcing fishermen participating in the fishery to either diversify (if they had not already) or exit the industry. There was nearly a 13% decline in wild blue crab fishery participation in the following year that is likely related to this fishery closure.

In addition to the economic and social influences on diversification decisions, ongoing environmental changes have the ability to further constrain or enhance diversification opportunities. Fishermen may be able to adapt to these environmental changes by following the northward shift in species distributions (Lucey and Nye 2010; Pinsky and Fogarty 2012) or diversifying into other established or emerging fisheries. Birkenbach et al. (2022) and Papaioannou et al. (2021) indicate that fishermen tend to be habitual in their fishing locations, however, and there is likely individual heterogeneity in the decision to switch between fishing locations. If fishermen choose to follow distributional shifts, it is probable that increased travel time and cost, as well as infrastructure and management will become constraining factors. Nonetheless, fishermen are often acutely aware of changes within fisheries and can utilize traditional knowledge and experiences to adapt to shifts in various ways (Papaioannou et al. 2021), including the exploitation of emerging or invasive species. In Virginia, opportunities to capitalize on emerging and invasive species fisheries are presented with the expansion of the invasive blue catfish (*Ictalurus furcatus*) and probable climate-induced range shift of white shrimp (*Litopenaeus setiferus)*. These opportunities can enhance economic opportunities for small-scale fishermen, although they may be met with varying management and social responses (Dubik et al. 2018).

Diversification decisions are not limited to within the commercial fishing industry and the ability to diversify between commercial fishing and a subset of marine-related industries can also be influenced by economic, environmental, and social factors. Fishermen who hold licenses or permits for marine-related businesses, in addition to commercial fishing, are still vulnerable to abrupt environmental and economic changes as each income source pulls from similar sources of marine productivity (Hanh and Boonstra 2018). For example, the seafood sales and processing sector is closely intertwined with the commercial fishing industry and thus, both can be negatively impacted by management changes such as fishery closures or declines in species abundance. In this analysis, there was no statistical difference between income diversification between individuals with a license or permit for seafood sales and processing, chartering, or aquaculture, however, holding a license or permit for marine-related business had a positive impact on the decision to increase diversification and a negative impact on the decision to decrease diversification. This indicates that individuals with additional ties to the commercial fishing industry are less likely to decrease diversification. Each marine-related business considered in these analyses has had notable shifts in participation since the mid-1990's. Participation in aquaculture has increased since the inception of a formal license in 2007 and with the rapid growth of the intensive oyster aquaculture sector that has slightly declined in recent years, while seafood sales and processing participation has continuously declined with the consolidation of fish houses and processing plants. While there is limited diversification into marine-related businesses by individuals holding a commercial fishing license, employment outside of the fishing industry, whether marine-related or otherwise, is a viable option for many fishermen (White and Scheld 2021).

This research captures levels of diversification within the commercial fishing industry of Virginia, however, it is possible that additional factors, including vessel size and ownership, have an effect on the ability to diversify (Abbott et al. 2022). Social and cultural factors were not accounted for in these analyses, but likely play a significant role in decision-making (Marshall et al. 2007). The use of individual random effects in both diversification models control for these additional factors, but do not provide any insight as to how they may drive decision-making. Likewise, levels of diversification outside of commercial fishing are likely greater than noted as this study was limited to participation in aquaculture, chartering, and seafood sales and processing. Fishermen may also derive income from other sources (marine-related or otherwise) to counteract variability in commercial fishing. Fishermen that participate in fewer fisheries or are limited to fishing in a particular season may hold other occupations to supplement income. Another caveat in this study is that harvest from private leases (aquaculture) was removed from analyses, although this is a considerable option of diversification for many fishermen and likely contributes to annual income. Participation in federal fisheries (e.g., some shark and tuna species, swordfish) is also not accounted for as VMRC only provides commercial fishing licenses or permits within Virginia and therefore, this data was not available for analyses. Participation in federal fisheries is another viable option for diversification that likely exists among fishermen with the available financial and social capital in this dataset, although the extent of contribution is uncertain.

An enhanced understanding of the factors that influence participation and diversification can help managers assess, and potentially lessen, the impacts of adverse events on fishermen and fishing communities. The findings of this study indicate that there are opportunities to increase the resilience of fishermen and fishing communities through an understanding of various factors that determine whether the decision to diversify or specialize is optimal in reducing financial vulnerability. Furthermore, levels of diversification can have varying impacts on fishery resources and result in unintended socio-ecological consequences if not well-understood. Predicting diversification decisions based on specific license and permit holdings can be used to counter the graying of the fleet through an understanding of resource dependence and participation characteristics. As a socio-cultural norm, it is common for older fishermen to continue commercial fishing past what is considered retirement age, although in limited capacity. As the average age of fishermen continues to increase, the need to promote new entry into the commercial industry as a means of continual workforce development is imminent, especially in terms of transferring generational knowledge. Understanding the effect of holding specific licenses and permits can also be used to evaluate the impact of creating fisheries under private property regimes and the potential to promote specialization.

Individual diversification decisions of small-scale commercial fishermen in Virginia are influenced by a number of variables, some of which cannot be quantitatively captured. The decision to diversify within and outside of the commercial fishing industry is likely heterogenous and based on imperfect information of economic and environmental conditions. These broad, annual decisions are likely the cumulation of daily, or even shorter temporal scale, decision-making. While this study analyzed decision-making of commercial fishermen in terms of license and permit holdings in Virginia, it is probable that similar variables may impact decision-making in other fishing communities with comparable characteristics. There is the potential for future research to investigate the socio-cultural aspects of decision-making, including the decision to enter (or exit) the certain fisheries or the commercial fishing industry.

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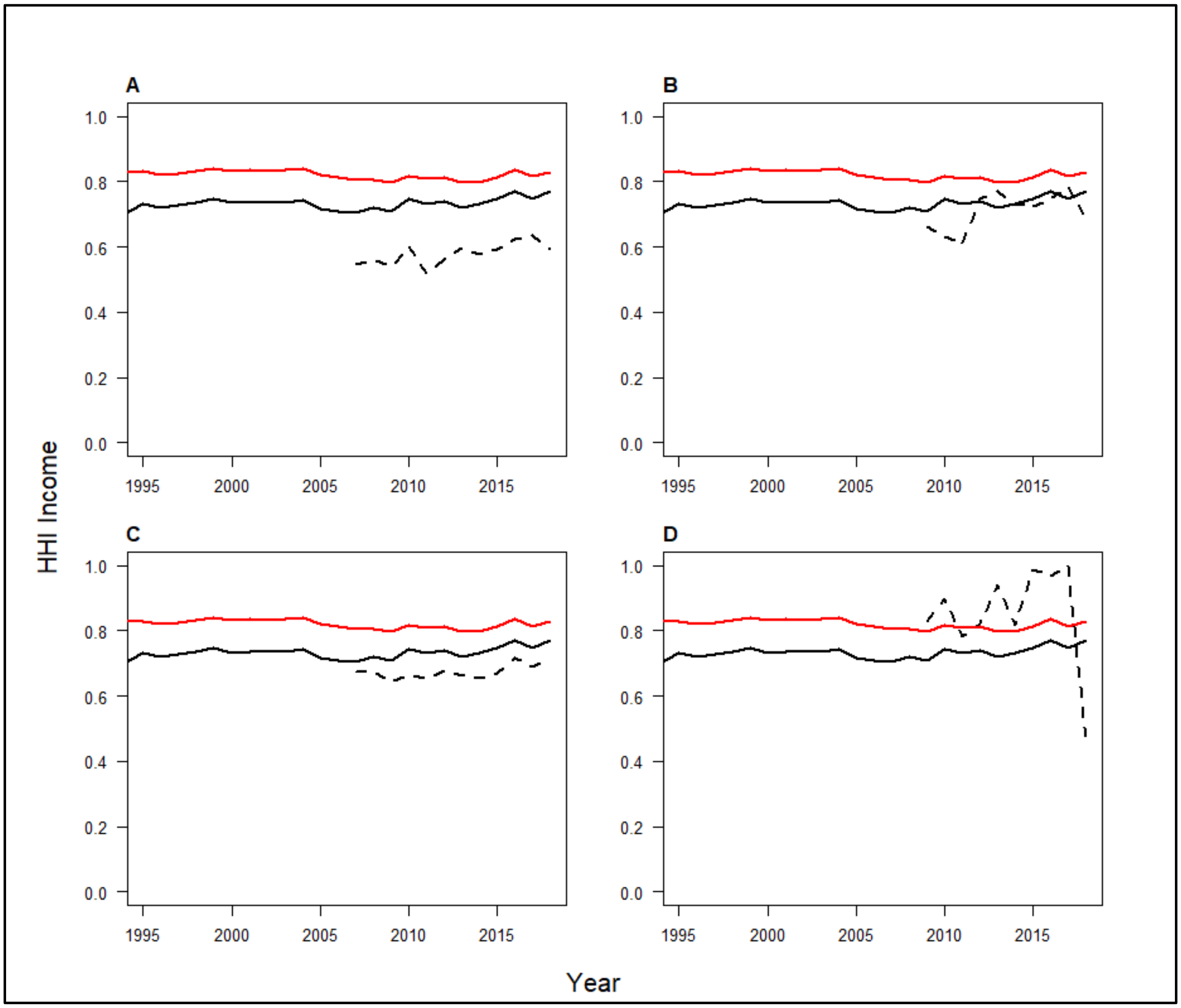

Figure 2.1. Average Herfindahl-Hirschman Index (HHI) values across individuals holding a license or permit in an aggregate wild finfish fishery (solid black line) or species-specific finfish fisheries (dashed black line) compared to the average HHI income values across all individuals in the commercial fishing industry, including fisheries where species-specific licenses or permits are not required (red line) between 1994-2018. Top row, left to right: (A) black drum, (B) black sea bass, (C) striped bass, and (D) summer flounder.

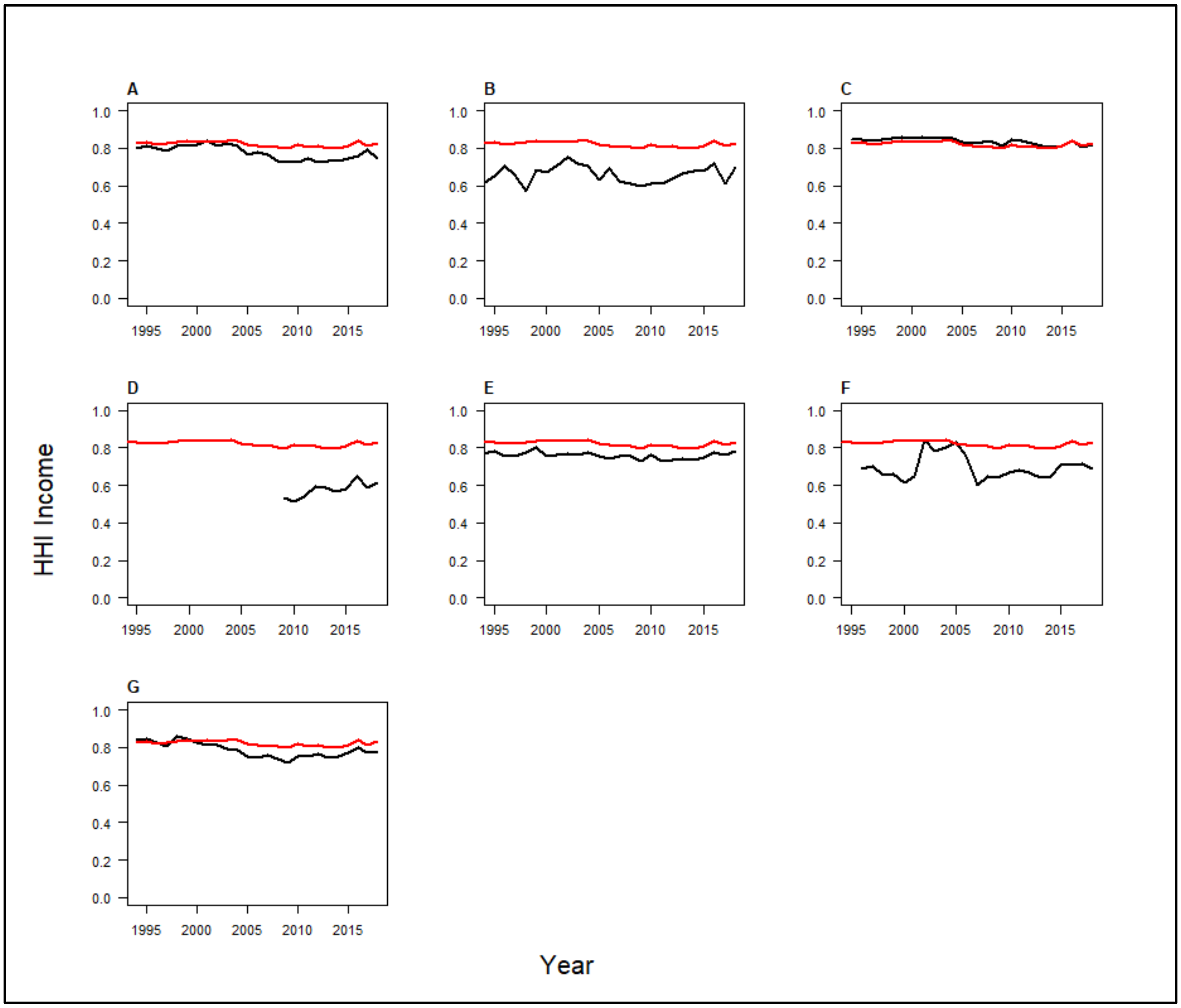

Figure 2.2. Average Herfindahl-Hirschman Index (HHI) values across individuals holding a license or permit in species-specific fisheries (black line) and the average HHI income values across all individuals in the commercial fishing industry, including fisheries where species-specific licenses or permits are not required (red line) between 1994-2018. Top row, left to right: (A) clam, (B) conch, (C) crab, (D) dogfish, (E) eel, (F) horseshoe crab, and (G) oyster.

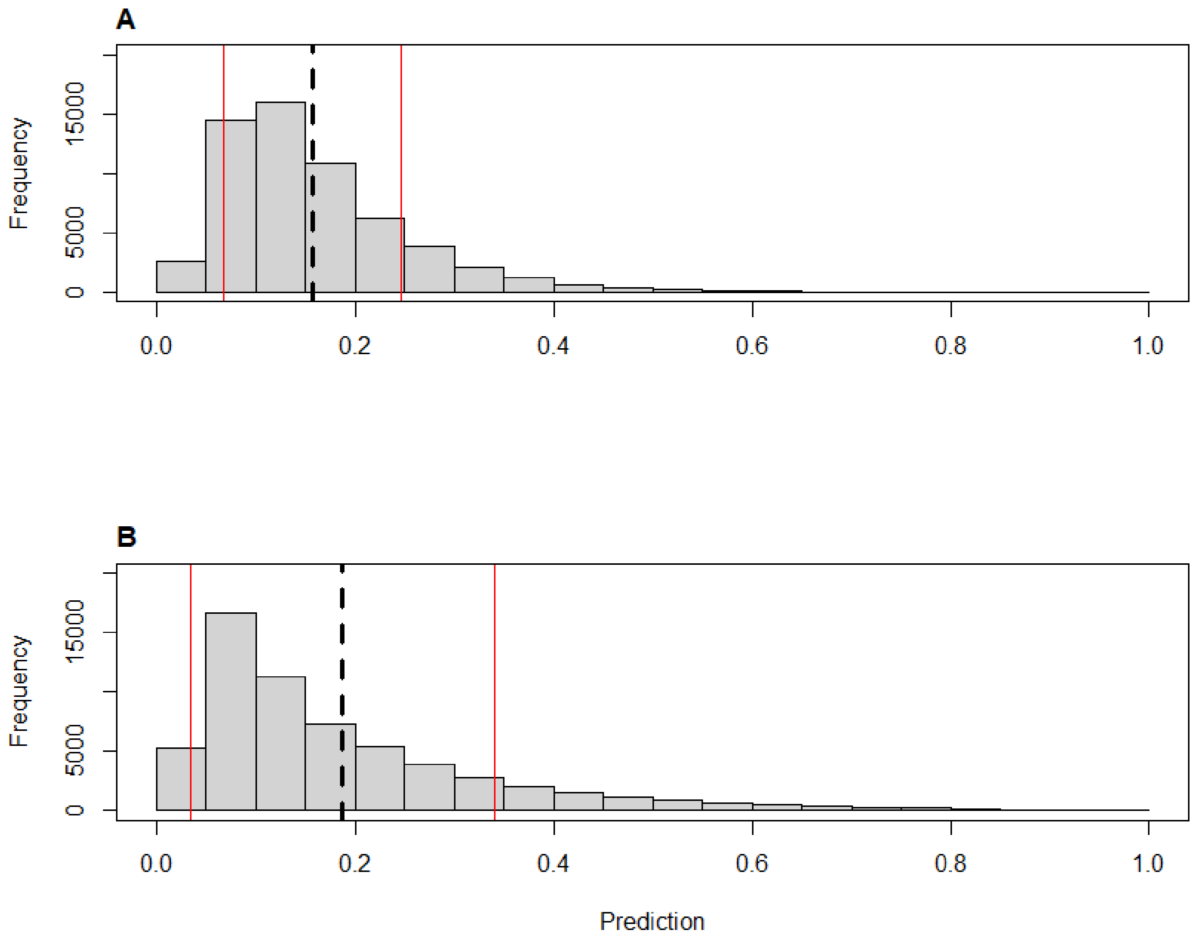

Figure 2.3. Probability of individuals increasing diversification (A) or decreasing diversification (B) in a given year, including the averages across all individuals and years (dashed, black line) and standard deviation (red lines).

Table 2.1. Odds ratios and probabilities calculated from model estimates, standard errors, and associated *p* values of covariates on the decision to increase diversification.

Increasing Diversification

Predictors	***Odds Ratios***	***Std. Error***	***p***	
Total Years	0.97	0.00	<0.001	***
Annual Income	1.00[11]	0.00	<0.001	***
No Landings	0.80	0.03	<0.001	***
Marine Business	1.26	0.05	<0.001	***
Senior Registration	0.59	0.03	<0.001	***
Permit Count	0.69	0.01	<0.001	***
Average Market Price	1.01	0.01	0.48	
Limited Entry	1.12	0.05	<0.009	**
Year	1.00	0.00	0.22	
Limited Entry*Year	1.00	0.00	0.45	
Random Effects				
σ^2	3.29			
τ_{00}	0.72			
ICC	0.18			
$N_{VMRC.ID}$	4,890			
Observations	58,452			
Marginal R^2 / Conditional R^2	0.057 / 0.225			

Significance Codes: '*' <0.001 '**' <0.01 '*' <0.05 'blank' > 0.05**

[11] The odds ratio for "Annual Income" is rounded to the nearest hundredth for consistency, although it is significant (p value <0.001) at 1.000004.

Table 2.2. Odds ratios and probabilities calculated from model estimates, standard errors, and associated p values of covariates on the decision to decrease diversification.

Decreasing Diversification

Predictors	***Odds Ratios***	***Std. Error***	***p***	
Total Years	0.97	0.00	<0.001	***
Annual Income	1.00	0.00	<0.001	***
No Landings	1.94	0.07	<0.001	***
Marine Business	0.65	0.02	<0.001	***
Senior Registration	1.34	0.06	<0.001	***
Permit Count	2.63	0.04	<0.001	***
Average Market Price	1.04	0.01	<0.001	***
Limited Entry	1.51	0.06	<0.001	***
Year	0.99	0.00	0.01	*
Limited Entry*Year	0.98	0.00	<0.001	***

Random Effects

σ^2	3.29
τ_{00}	0.54
ICC	0.14
$N_{VMRC.ID}$	4,890
Observations	60,474
Marginal R^2 / Conditional R^2	0.227 / 0.336

Significance Codes: '*' <0.001 '**' <0.01 '*' <0.05 'blank' > 0.05**

Table 2A.1. Licenses and permits considered commercial fishing, chartering, seafood sales or processing, or aquaculture (N = 30).

Category	VMRC License or Permit Description
COMMERCIAL FISHING	COMM REG TRANSFD FROM DELAYED
	COMM REGISTRATION-SENIOR CITIZ
	COMMERCIAL REGISTRATION
	DELAYED ENTRY ADJ FOR 2006 INC
	DELAYED ENTRY SR ADJ FOR 2006
	DELAYED ENTRY-COMM REG.
	DELAYED ENTRY-SENIOR CITIZEN
	TRANSFERRED COMM REG CARD
	TRANSFERRED COMM REG CARD DE
	TRANSFERRED COMM REG CARD SR
CHARTERING	CHARTER/HEAD BOAT-6 & UNDER
	CHARTER/HEAD BOAT-MORE THAN 6
	SEAFOOD LANDING LICENSE
SEAFOOD SALES & PROCESSING	BUYERS BUSINESS PLACE
	CRAB SHED TANK-20 OR LESS
	CRAB SHED TANK-OVER 20
	SEAFOOD BUYER'S TRUCK
	SHEDDER-COMMERCIAL REGISTRATION
	SHUCKING HOUSE- > 200,000
	SHUCKING HOUSE-TO 10,000
	SHUCKING HOUSE-TO 100,000
	SHUCKING HOUSE-TO 200,000
	SHUCKING HOUSE-TO 25,000
	SHUCKING HOUSE-UNDER 1000
AQUACULTURE	CLAM AQUACULT HARVESTER PERMIT
	CLAM AQUACULT PROD OWNER PERMIT
	CLAM AQUACULTURE
	OYS AQUACULT HARVESTER PERMIT
	OYS AQUACULT PROD OWNER PERMIT
	OYSTER AQUACULTURE

Table 2A.2. Licenses and permits considered for wild species fisheries (N = 87).

VMRC License or Permit Description		
BLACK DRUM	BLACK DRUM HARVEST PERMIT	
BLACK SEA BASS	BLK SEA BASS DIRECT PERMIT	BLK SEA BASS TRANSFER PERMIT
HARD CLAM	CLAM BY HAND/RAKE CLAM DREDGE-HAND CLAM DREDGE-POWER	CLAM PATENT TONGS-DOUBLE CLAM PATENT TONGS-SINGLE
CONCH	CHANNELED WHELK POT CONCH-DREDGE	TRANSFERRED CHANNELED WHELK
BLUE CRAB	CRAB-ORDINARY TROT LINE CRAB-PATENT TROT LINE CRAB DIP NET CRAB HAND SCRAPE-DOUBLE CRAB HAND SCRAPE-SINGLE CRAB PEELER POT-210 OR LESS CRAB POT-85 OR LESS CRAB POT-86 TO 127 CRAB POT-170 TO 255 CRAB POT-256 TO 425 CRAB POT-OVER 500 CRAB POWER DREDGE CRAB TRAP	TRANSFERRED CRAB POT 200 TRANSFERRED CRAB DIP NET TRANSFERRED CRAB ORDINARY TROT TRANSFERRED CRAB PATENT TROT LINE TRANSFERRED CRAB POT 100 TRANSFERRED CRAB POT 150 TRANSFERRED CRAB POT 300 TRANSFERRED CRAB POT 500 TRANSFERRED CRAB SCRAPE-DOUBLE TRANSFERRED CRAB SCRAPE-SINGLE TRASNFERRED CRAB TRAP TRANSFERRED PEELER POT
SPINY DOGFISH	SPINY DOGFISH LIMIT ENTRY PERMIT	
EEL	EEL POT-OVER 300 EEL POT-100 OR LESS EEL POT-300 OR LESS	FISH/EEL POT-100 OR LESS FISH/EEL POT-300 OR LESS FISH/EEL POT-OVER 300
FINFISH	COMMERCIAL CAST/THROW NET COMMERCIAL FISH DIP NET COMMERCIAL HOOK & LINE FISH TROT LINE FISH/EEL POT -100 OR LESS FISH/EEL POT- 300 OR LESS FISH/EEL POT – OVER 300 FYKE NET GILL NETS-1200 OR LESS	GILL NETS-600 OR LESS HAUL SEINE-500 YDS &OVER HAUL SEINE-UNDER 500 YDS POUND NET STAKED GILL NET TRANS CLASS A GILL NET TRANS POUND NET TRANSFERRED HOOK & LINE TRANSFERRED STAKED GILL NET
HORSESHOE CRAB	HORSESHOE CRAB HAND HARVESTER HSC CLASS A DREDGE PERMIT HSC CLASS B DREDGE PERMIT HSC GENERAL PERMIT	HSC HAND HARVEST PERMIT HSC POUND NET PERMIT HSC RESTRICTED ENDORSEMENT HSC TRAWL PERMIT HSC UNRESTRICTED ENDORSEMENT
EASTERN OYSTER	OYSTER BY HAND OYSTER DREDGE PUBLIC GROUND OYSTER PATENT TONGS-DOUBLE	OYSTER PATENT TONGS-SINGLE OYSTER BY HAND SCRAPE OYSTER BY HAND TONGS
STRIPED BASS	COMM HOOK & LINE STRIPED BASS SB BAY PERMIT SB BAY TAG TRANSFER SB FYKE NET PERMIT SB GILL NET PERMIT	SB HOOK & LINE PERMIT SB OCEAN PERMIT SB OCEAN TAG TRANSFER SB POUND NET PERMIT
SUMMER FLOUNDER	RESTRICT SUMMER FLOUNDER EDMNT	SUMMER FLOUNDER ENDORSEMENT

Table 2A.3. Species and market grades included in each aggregate species category (N=18) for commercial landings data. Aggregated species categories include all market grades for a particular species or multiple species with similar fishery characteristics. If no market grade is noted, then it is "unclassified." Some species have no associated market grade and are the only species within the species category (e.g., black drum, menhaden).

Species Category	**Species** **Market Grade**
BLACK DRUM (*Pogonias cromis*)	
BLACK SEA BASS (*Centropristis striata*)	Jumbo, Large, Medium, Small, Unclassified
BLUE CRAB (*Callinectes sapidus*)	BLUE CRAB SOFT Hotel Prime, Prime, Jumbo, Whale, Jimmy, Medium, Soft BLUE CRAB HARD Hard, Jimmy, Sook PEELER
BLUEFISH (*Pomatomus saltatrix*)	Gutted, Large Round, Medium Round, Small Round, Unclassified Round
CATFISH (Ictalurids)	BLUE CATFISH (*Ictalurus furcatus*) CATFISH (Unknown spp.)
WHELK (Melongenids)	Channeled Whelk, Large, Knobbed Whelk, Small, Unclassified
DRUM (Sciaenids)	RED DRUM (*Sciaenops ocellatus*)
EEL (*Anguilla rostrataii*)	Large, Small, Unclassified
HARD CLAM (*Mercenaria mercenaria*)	Button, Cherrystone, Chowder, Inshore Unclassified, Large, Littleneck, Small, Top
HORSESHOE CRAB (*Limulus polyphemus*)	Female, Male, Unclassified
MACKERELS (Scombrids)	ATLANTIC MACKEREL (*Scomber scombrus*) Large, Medium, Small, Unclassified KING MACKEREL (*Scomberomorus cavalla*) SPANISH MACKEREL (*Scomberomorus maculatus*) Jumbo, Large, Medium, Small, Jumbo, Unclassified
MENHADEN (*Brevoortia tyrannus)*	
MISCELLANEOUS FINFISH (Miscellaneous spp.)	ANGLER (Unknown spp.) Livers, Tails Large, Tails Only, Unclassified Round ATLANTIC HERRING (*Clupea harengus*) BAIT (Unknown spp.) BLOOD ARK CLAM (*Anadara ovalis*) BUTTERFISH (*Peprilus triacanthus*) Jumbo, Medium, Large, Large/Mix, Small, Unclassified

	CARP AND MINNOWS (Cyprinids) COBIA (*Rachycentron canadum*) CREVALLE (*Caranx caninus*) FISH, OTHER FOOD (Unknown spp.) GARFISH (*Lepisosteus osseus*) HARVESTFISH (*Peprilus paru*) KING WHITING (*Menticirrhus spp.*) MULLET (*Mugil spp.*) NORTHERN PUFFER (*Sphoeroides maculatus*) Spawn Roe, Tails, Unclassified OYSTER TOADFISH (*Opsanus tau*) PIGFISH (*Orthopristis chrysoptera*) POMPANO (Carangids) RED HAKE (*Urophycis chuss*) RIBBONFISHES (Trachipterids) Round, Unclassified SCUP (*Stenotomus chrysops*) Medium, Small, Unclassified SHEEPSHEAD (*Archosargus probatocephalus*) SPADEFISH (*Chaetodipterus faber*) TAUTOG (*Tautoga onitis*) TRIGGERFISH (Balistids) TUNA, FALSE ALBACORE (*Euthynnus alletteratus*) Dressed, Round
OYSTERS (*Crassostrea virginica*)	Fall, Spring
PERCH	WHITE PERCH (*Morone americana*) YELLOW PERCH (*Perca flavescens*)
SHAD & HERRING (Clupeids)	ALEWIFE (*Alosa pseudoharengus*) AMERICAN SHAD (*Alosa sapidissima*) Buck, Roe, Unclassified BLUEBACK HERRING (*Alosa aestivalis*) GIZZARD SHAD (*Dorosoma cepedianum*) HERRING ROE (Unknown spp.) HICKORY SHAD (*Alosa mediocris*)
SHARKS	BLACKTIP SHARK (*Carcharhinus limbatus*) Fins, Unclassified Dressed, Unclassified Round DOGFISH - GENERAL Dressed, Fins, Round SANDBAR SHARK (*Carcharhinus plumbeus)* Fins, Unclassified Dressed, Unclassified Round SHARK (Unknown spp.) Fins Fresh/Frozen, Unclassified Dressed, Unclassified Round SMOOTH DOGFISH Mustelus canis) Fins, Dressed, Round THRESHER SHARK (*Alopias sp.)* Dressed Fins, Dressed Unknown, Unclassified Round
SPINY DOGFISH (*Squalus acanthias*)	Bellyflaps, Dressed, Fins, Round

SPOT (*Leiostomus xanthurus*)	
STRIPED BASS (*Morone saxatilis*)	
SUMMER FLOUNDER (*Paralichthys dentatus*)	Jumbo, Medium, Large, Small, Unclassified
TROUTS (*Cynoscion spp.*)	GREY TROUT (*Cynoscion regalis*) Medium, Large, Small, Unclassified SPOTTED SEATROUT (*Cynoscion nebulosus*) Jumbo, Medium, Large, Small, Unclassified

Table 2A.4. Total number of individuals with a license/permit in each wild fishery (Columns 1-12)[12] and marine-related industry (Column 13-16) between 1994-2018. HSC = "horseshoe crab" and SSP = "seafood sales and processing."

	Wild Fisheries												Marine-Related Industries			
	Hard Clam	Blue Crab	Finfish	Eastern Oyster	Spiny Dogfish	Conch & Whelk	Black Sea Bass	Black Drum	Eel	HSC	Striped Bass	Summer Flounder	Aquaculture	SSP	Charter	Commercial Fishing
1994	491	1,800	1,295	301	-	36	-	-	243	-	-	-	-	472	20	2,725
1995	509	1,889	1,404	317	-	20	-	-	267	-	-	-	-	456	22	2,718
1996	457	1,934	1,433	245	-	30	-	-	309	27	-	-	-	498	33	2,746
1997	399	1,965	1,448	259	-	23	-	-	323	28	-	-	-	532	35	2,750
1998	368	1,976	1,402	330	-	24	-	-	321	39	-	-	-	583	39	2,777
1999	365	2,026	1,430	347	-	50	-	-	414	20	-	-	-	721	42	2,812
2000	349	2,012	1,376	230	-	75	-	-	395	13	-	-	-	625	47	2,766
2001	343	1,956	1,351	297	-	88	-	-	374	10	-	-	-	618	51	2,744
2002	315	1,928	1,313	460	-	78	-	-	387	6	-	-	-	578	57	2,742
2003	270	1,888	1,250	266	-	60	-	-	377	14	-	-	-	535	57	2,694
2004	235	1,817	1,187	349	-	50	-	-	355	13	-	-	-	507	55	2,687
2005	204	1,734	1,130	496	-	45	-	-	336	28	-	-	-	487	56	2,666
2006	175	1,589	1,077	438	-	52	-	-	300	24	-	-	-	411	50	2,621
2007	175	1,469	1,090	423	-	53	-	61	298	43	492	-	172	366	54	2,576
2008	179	1,472	1,134	479	-	56	-	58	325	36	488	-	218	380	63	2,536
2009	155	1,298	1,224	533	93	61	19	50	355	40	488	5	219	389	63	2,467
2010	159	1,277	1,258	627	70	63	20	48	412	49	466	3	282	373	59	2,456
2011	157	1,253	1,194	662	90	64	17	52	425	56	454	5	381	378	63	2,463
2012	152	1,254	1,189	672	69	68	17	55	432	50	456	5	388	367	60	2,471
2013	147	1,237	1,165	664	89	64	15	55	426	33	445	4	430	359	63	2,480
2014	133	1,240	1,213	823	72	55	17	58	453	73	434	3	453	338	60	2,470
2015	144	1,242	1,202	954	77	66	17	57	460	71	423	4	483	343	62	3,457
2016	143	1,234	1,035	892	71	60	17	58	208	75	402	4	496	356	57	2,399
2017	135	1,202	1,021	918	63	61	18	56	206	74	392	3	440	338	55	2,332
2018	117	1,193	982	862	62	60	17	53	193	72	382	4	393	338	53	2,264

[12] Licenses or permits for striped bass between 1999-2006 were removed due to a shift in licensing software. Licenses for striped bass prior to 2007 are not comparable and considered inaccurate (J. Ramsey, VMRC, email to author, February 7, 2023).

Table 2A.5. Descriptive statistics (mean, standard deviation, median, minimum, and maximum) of continuous covariates in the full model. Discrete covariates are represented as the proportion of observations with the attribute. For example, a "1" for no landings indicates that an individual had no landings for a given year.

Covariates[13]					
	Mean	***SD***	***Median***	***Min.***	***Max.***
Total Years	17.53	7.16	19.00	1	25
Annual Income	$19,025.98	$42,802.08	$2002.03	$0.00	$1,935,364.00
Permit Count	1.55	1.25	1.00	0	10
Average Market Price	$1.24	$1.94	$0.81	$0.00	$56.40
HHI Income	0.82	0.24	1	0	1
Year	2005.6	7.10	2005	1994	2018
Entry Year	1996.8	5.18	1994	1994	2018

	Proportion
No Landings	0.38
Marine Business	0.22
Senior Registration	0.11
Limited Entry	0.54
Niche Fisheries	0.14

[13] Continuous covariates include the total number of years an individual held a commercial fishing license ("Total Years"), annual income ("Annual Income"), number of licenses or permits held ("Permit Count"), average market price received across all landings ("Average Market Price"), HHI income scores ("HHI Income"), year of licensure ("Year"), year an individual entered the dataset ("Entry Year"). Discrete covariates include whether an individual had any landings in a given year ("No Landings"), whether an individual held a senior commercial fishing registration ("Senior Registration"), held a license or permit for a marine-related business ("Marine Business"), limited entry fishery ("Limited Entry"), or niche fishery ("Niche Fisheries").

Table 2A.6. Average and standard deviation of the total licenses or permits an individual held ("Licenses or Permits") and species landed ("Species Landed")for all commercial fishermen between 1994-2018. "Changes in Licenses or Permits" indicates the average change in the number of licenses or permits held each year and standard deviation of this change while "Change in Species Landed" indicates the average annual change in the number of species landed and standard deviation of this change for all commercial fishermen between 1994-2018. The proportion of fishermen who changed the number of licenses or permits held ("% License or Permit Change") or species landed ("% Species Change") in a given year are also indicated.

	Licenses or Permits		Species Landed		Change in Licenses or Permits		Change in Species Landed		% License or Permit Change	% Species Change
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*		
1994	1.558	0.878	2.418	2.837	-	-	-	-	-	-
1995	1.548	0.977	2.072	2.764	0.057	0.821	-0.242	1.970	41.1	71.3
1996	1.522	1.029	2.045	2.775	0.009	0.788	0.021	1.814	39.9	64.2
1997	1.501	1.034	2.124	2.945	0.003	0.790	0.112	1.886	39.7	65.4
1998	1.502	1.055	2.008	2.862	0.005	0.802	-0.109	1.936	40.9	64.0
1999	1.569	1.118	1.990	2.866	0.079	0.870	-0.004	1.824	42.9	62.9
2000	1.504	1.093	1.912	2.784	-0.065	0.811	-0.078	1.854	39.6	62.7
2001	1.492	1.089	1.866	2.658	-0.017	0.768	-0.052	1.788	38.0	61.6
2002	1.526	1.130	1.759	2.605	0.024	0.802	-0.120	1.655	38.4	65.1
2003	1.412	1.096	1.579	2.488	-0.114	0.795	-0.179	1.697	41.9	69.9
2004	1.387	1.104	1.504	2.430	-0.048	0.801	-0.100	1.599	41.2	65.1
2005	1.359	1.131	1.488	2.344	-0.024	0.834	-0.013	1.476	42.7	66.0
2006	1.270	1.120	1.492	2.475	-0.099	0.808	-0.008	1.557	46.6	69.3
2007	1.453	1.320	1.514	2.613	0.157	0.882	-0.008	1.535	56.3	74.8
2008	1.492	1.343	1.573	2.603	0.031	0.848	0.052	1.562	47.9	70.2
2009	1.557	1.430	1.718	2.652	0.044	0.903	0.122	1.663	53.5	66.9
2010	1.655	1.490	1.608	2.559	0.062	0.885	-0.150	1.630	47.1	68.7
2011	1.684	1.515	1.599	2.438	-0.004	0.861	-0.041	1.557	45.0	65.8
2012	1.673	1.488	1.573	2.446	-0.001	0.873	-0.017	1.481	43.7	63.1
2013	1.659	1.485	1.630	2.491	-0.024	0.836	0.046	1.559	44.1	66.0
2014	1.740	1.455	1.708	2.546	0.067	0.881	0.062	1.501	47.0	67.1
2015	1.819	1.491	1.538	2.290	0.057	0.828	-0.193	1.575	38.5	66.2
2016	1.651	1.389	1.393	2.156	-0.203	0.838	-0.174	1.372	43.6	64.7
2017	1.692	1.385	1.542	2.356	0.018	0.707	0.098	1.493	34.4	60.1
2018	1.679	1.387	1.421	2.161	-0.063	0.756	-0.168	1.496	35.0	62.0
Average	**1.556**	**1.241**	**1.723**	**2.566**	**-0.003**	**0.792**	**-0.046**	**1.579**	**41.2**	**63.3**

Table 2A.7. Mean, standard deviation, and median of Herfindahl-Hirschman Index (HHI) income values across all commercial fishermen in a given year.

HHI INCOME			
YEAR	*Mean*	*SD*	*Median*
1994	0.827	0.252	1.000
1995	0.830	0.244	0.998
1996	0.820	0.253	1.000
1997	0.826	0.248	0.999
1998	0.832	0.242	1.000
1999	0.839	0.239	1.000
2000	0.834	0.242	1.000
2001	0.836	0.241	1.000
2002	0.834	0.242	1.000
2003	0.837	0.237	1.000
2004	0.840	0.231	1.000
2005	0.821	0.239	1.000
2006	0.815	0.246	1.000
2007	0.807	0.258	1.000
2008	0.807	0.247	0.983
2009	0.799	0.253	0.993
2010	0.818	0.242	1.000
2011	0.808	0.243	0.988
2012	0.812	0.240	0.998
2013	0.798	0.247	0.976
2014	0.798	0.243	0.954
2015	0.812	0.235	0.985
2016	0.838	0.221	0.999
2017	0.815	0.236	0.993
2018	0.830	0.227	1.000
AVERAGE	**0.821**	**0.242**	**0.995**

Table 2A.8. GLMM model output for increasing diversification.

Number of Observations: 58,452 VMRC.ID: 4,890

	Estimate	Standard Error	Z Value	p	
Intercept	1.559e+00	3.623e-02	-43.02	0.345	***
Total Years	-3.078e-02	3.399e-03	-9.057	< 2e-16	***
Annual Income	3.691e-06	3.667e-07	10.067	< 2e-16	***
No Landings	-2.226e-01	3.983e-02	-5.589	2.29e-08	***
Marine Business	2.348e-01	3.591e-02	6.540	6.16e-11	***
Senior Registration	-5.232e-01	5.636e-02	-9.283	< 2e-16	***
Permit Count	-3.648e-01	1.815e-02	-20.106	< 2e-16	***
Average Market Price	5.534e-03	7.855e-03	0.704	0.481	
Limited Entry	1.160e-01	4.461e-02	2.600	0.009	**
Year	-4.012e-03	3.278e-03	-1.224	0.221	
Limited Entry*Year	-2.912e-03	3.829e-03	-0.761	0.447	

1|VMRC.ID Variance: 0.7176 Standard Deviation: 0.8471

Significance Codes: '*' <0.001 '**' <0.01 '*' <0.05 'blank' > 0.05**

Table 2A.9. GLMM model output for decreasing diversification.

Number of Observations: 60,474 VMRC.ID: 4,890

	Estimate	Standard Error	Z Value	p	
Intercept	1.933e+01	3.483e-02	-55.50	< 2e-16	***
Total Years	-2.165e-02	3.268e-03	-6.620	3.51e-11	***
Annual Income	-6.402e-06	4.028e-07	-15.94	< 2e-16	***
No Landings	6.632e-01	3.570e-02	18.58	< 2e-16	***
Marine Business	-4.382e-01	3.442e-02	-12.73	< 2e-16	***
Senior Registration	2.910e-01	4.405e-02	6.610	3.95e-11	***
Permit Count	9.679e-01	1.586e-02	61.04	< 2e-16	***
Average Market Price	4.146e-02	7.305e-03	5.680	1.38e-08	***
Limited Entry	4.412e-01	4.147e-02	9.990	< 2e-16	***
Year	-8.329e-03	3.319e-03	-2.510	0.0121	*
Limited Entry*Year	-1.916e-02	3.691e-03	-5.190	2.10e-07	***

1\|VMRC.ID Variance: 0.5397 Standard Deviation: 0.7346

Significance Codes: '*' <0.001 '**' <0.01 '*' <0.05 'blank' > 0.05**

CHAPTER III

WILLINGNESS OF VIRGINIA'S SMALL-SCALE COMMERCIAL FISHERMEN TO DIVERSIFY IN AN EMERGING BLUE CATFISH (*ICTALURUS FURCATUS*) FISHERY

Introduction

The human consumption of non-native, invasive species to control abundance or inhibit expansion, also known as invasivorism, has been offered as a potential management strategy to curtail the ecological and socio-economic impacts of invasions (Mooney and Cleland 2001). In the marine environment, commercial and recreational fishing harvest is considered a potentially viable mechanism to control invasive populations. One such example is the United States National Oceanic and Atmospheric Administration's (NOAA) "Eat Lionfish" campaign with targeted fishing removals of invasive lionfish *(Pterois spp.*) for human consumption. The associated ecological (i.e., reduced predation on other valuable species) and economic incentives for fishermen and consumers alike have made this an effective campaign, as well as the extensive outreach efforts informing consumers on how to prepare invasive lionfish (Ferguson and Akins 2010; de León et al. 2013). The development of commercial fisheries has also been utilized for removals of non-native, invasive bigheaded carp (*Hypophthalmichthys spp.*) in the Mississippi River basin with efforts geared towards livestock and aquaculture feed, fish meal and oil, and exports to international markets (Bowzer et al. 2013; Bouska et al. 2020). Nonetheless, the commercialization of non-native, invasive species and invasivorism is met with criticism for its potential to produced unintended consequences, such as user group conflicts, protection of invasive populations in established areas, integration of invasive species into local culture or economies, and promotion of invasives into new areas to mimic opportunities in other localities (Nuñez et al. 2012; Dubik et al. 2018). These criticisms present challenges and the potential impacts of commercialization should be considered beforehand.

The commercialization of non-native, invasive species can provide additional fishing opportunities to commercial fishermen and support the diversification of fishing portfolios. Diversifying across species, gears, and locations within the commercial fishing industry may serve as an important livelihood strategy with the potential benefits of revenue stabilization and decreased vulnerability in fishery dependent communities (Allison and Ellis 2001; Kasperski and Holland 2013; Sethi et al. 2014; Cline et al. 2017; Holland et al. 2017; Abbott et al. 2022). It is likely that commercial fishing communities will face new diversification opportunities and challenges in response to ongoing environmental changes that are associated with shifts of endemic species distributions northward or towards deeper waters, and the emergence of non-native, invasive species (Nye et al. 2009; Lucey and Nye 2010; Finch 2021). Emerging fisheries for invasive species are likely to be managed without regulations that limit entry or harvest, as it is counterintuitive to sustain an invasive population that causes negative ecological and economic impacts. Constraints to diversification such as the cost of purchasing licenses or permits, or the difficulty of entering limited or quota-based fisheries, might be less prevalent or non-existent in emerging fisheries and provide increased opportunity to diversify (Holland and Kasperski 2016; Stoll et al. 2016). A better understanding of diversification behavior and the potential benefits of income diversification into both established and emerging fisheries help to characterize intra-industry dynamics and predict how fishermen will respond to management or exogenous factors (e.g., markets, environment) in the future, thus increasing the ability of coastal communities to adapt to evolving stressors (Allison et al. 2009; Jurjonas and Seekamp 2018).

In Virginia, there are ongoing efforts to evaluate the potential for exploitation of emerging species, including blue catfish (*Ictalurus furcatus*), an invasive species in the Chesapeake Bay. This emerging, non-native, invasive species may be particularly beneficial to Virginia's small-scale commercial fishermen as it could provide additional opportunities for diversification and economic growth. There is evidence however that diversification in Virginia's small-scale commercial fisheries is somewhat limited despite the proposed benefits (White and Scheld 2021). The exploitation of emerging species may be met with similar barriers such as lack of familiarity, personal interest, financial and social capital, or availability of species in preferred fishing locations (Pradhan, and Leung 2004; Bucaram and Hearn 2014). The extent and drivers of diversification behavior are not well understood in Virginia or throughout the Mid-Atlantic and thus, bridging this knowledge gap is essential in understanding the potential for fishermen to participate in emerging fisheries.

Blue catfish were introduced to enhance the Bay's recreational fishing industry in the 1970's and the population has since flourished with dense concentrations in fresh and estuarine waters. In a portion of the James River, a tributary of the Chesapeake Bay, Fabrizio et al. (2018) estimate abundances of blue catfish to be upwards of 544 individuals per hectare. Blue catfish are omnivorous with ontogenetic dietary shifts thought to negatively impact other valuable fishery resources, such as shad and herring (*Alosa spp.*), menhaden (*Brevoortia tyrannus*) and blue crab (*Callinectes sapidus*) (Schloesser et al. 2011; Fabrizio et al. 2021). Blue catfish have become a growing management concern due to their large size, longevity, and capability of expanding to a wide range of habitats (Nepal and Fabrizio 2019). Thus, the commercialization of blue catfish may provide both ecological and economic benefits to Chesapeake Bay and its fishing communities.

A moderately sized small commercial fishery currently exists in Virginia with landings increasing from about 100,000 pounds in 2006 to over 3.1 million pounds valued at more than $1.8 million dollars (USD) in 2021 (NOAA 2023). In comparison to the prominent blue crab fishery in 2021, blue catfish accounted for less than 10% of annual blue crab revenues ($33.5 million dollars). Common gears for catfish harvest include gill nets, fish pots (e.g., hoop nets), trot lines, and pound nets. Although the blue catfish fishery has grown within the past few decades, the resource is comparatively underexploited with opportunities to enhance commercial fishing harvest in Virginia. Barriers to expansion of the blue catfish fishery are not well understood but could be tied to regulation including gear restrictions that limit harvest (e.g., restricting gill net seasons to avoid interactions with non-target species), low market values, and limited consumer demand stemming from unfamiliarity or contaminant concerns (Luellen et al. 2018).

The Virginia Marine Resources Commission (VMRC) oversees commercial harvest within the tidal waters of Virginia and has proposed efforts to expand the commercial fishery for blue catfish as a means of managing the population (VMRC 2020). The VMRC established the use of low-frequency electrofishing (LFE) to target removals of blue catfish for commercial harvest in Virginia's tributaries, as the first application of its kind in the United States. In 2020, three licensed commercial fishermen were permitted through a lottery system to use LFE gear solely for harvest of blue catfish and another invasive, flathead catfish (*Pylodictis olivaris*), in three tributaries of the Chesapeake Bay. LFE permits allow one vessel to shock the catfish to the surface, while another "chase boat" retrieves the fish with dip nets. Harvest rates of up to 28 pounds per minute and minimal bycatch suggest that LFE gear can be an effective method to control the blue catfish population (Bodine et al. 2013; Trice 2015). However, spatial and temporal restrictions of LFE gear limit utilization and the gear is only effective under certain environmental conditions. Additionally, with only a small number of permits allowed, the gear type is inaccessible to a majority of the commercial fishing population. Thus, it is appropriate to consider the expansion of the commercial fishery for blue catfish using traditional gears in conjunction with LFE. Likewise, the development and use of LFE has been met with criticism from the recreational fishing sector and commercial fishermen utilizing traditional gears for blue catfish harvest, as well as stakeholders who perceive LFE to have negative impacts on other wildlife and marine species. Trice (2017) found that interactions between LFE and hoop nets were negligible on catch rates and suggested conflicts can be resolved through seasonal and spatial management. Nonetheless, stakeholder perceptions and social acceptance of LFE can impact the efficacy of this gear as a management tool and commercial fishing practice, and it is important to mitigate concerns across user groups for continued growth in the blue catfish commercial fishery, regardless of gear type.

This research aims to evaluate fishing behavior and preferences of small-scale commercial fishermen in Virginia and evaluate changes in fishing behavior in response to ex-vessel price, both in the context of blue catfish. This research identifies factors influencing sustainable development of an emerging small-scale commercial fishery for blue catfish using a survey instrument distributed to licensed commercial fishermen in Virginia. Participation and diversification decisions in small-scale commercial fisheries are not well understood, especially in the context of emerging fisheries. This research will address a knowledge gap in Virginia's small-scale commercial fisheries with findings that can be extended to other fishing communities with similar characteristics throughout the United States. Understanding the willingness of commercial fishermen to participate in emerging fisheries is timely, as environmentally-driven shifts in species distributions will likely alter fishing behavior to some extent in the future. While the emergence of a blue catfish fishery in Virginia is not dependent on geographical species shifts in existing fisheries, this research will help to provide an understanding of the opportunities for diversification under conditions where shifts occur and help managers better understand how fishermen will adapt to ongoing environmental changes (Bennett and Dearden 2014; Stoll et al. 2016; Chambers and Carothers 2017;

Degnbol and McCay 2017). For example, fishermen may continue to target species with geographic distribution shifts by altering fishing locations or exert fishing pressure on more abundant species that have not previously been targeted. Furthermore, evaluating barriers to participation in emerging fisheries can encourage managers and commercial fishing-related sectors to seek innovative solutions that encourage participation and promote sustainable harvest.

Methods

Survey Development

A stated preference survey was developed in collaboration with commercial fishermen, state fishery managers at the VMRC, extension and outreach agents at the Virginia Institute of Marine Science (VIMS), the Virginia Marine Products Board (VMPB) and researchers working closely with the blue catfish industry. The survey instrument contained questions regarding estimates of average annual income from commercial fishing, variable costs at the trip level (e.g., average trip expenditures on fuel/oil, bait, and groceries), seasonal fixed costs (e.g., licenses/permits, fishing gear, and maintenance), perspectives and concerns on the expansion of the blue catfish fishery and the commercial fishing industry, willingness to participate in the blue catfish fishery, past participation in the blue catfish fishery, changes in fishing behavior, participation in various fisheries, and socio-demographics (e.g., family ties to fishing, age, education). In lieu of holding focus groups during the COVID-19 pandemic, a subset of ten individuals (including participants and non-participants in the blue catfish fishery) were emailed a copy of the survey to address any concerns with wording, structure, and comprehension. Following reviewer feedback, the survey was further refined and distributed via postal mail in the spring of 2022.

The final survey included 36-40 questions, depending on responses to questions within the survey. In addition, respondents were offered two opportunities to provide additional comments on the blue catfish fishery and their individual participation in the commercial fishing industry. Three questions of particular interest to this research were based on hypothetical contingent behavior scenarios (Englin and Cameron 1996), where an individual was presented a particular range for ex-vessel blue catfish price and asked how many days they would target the species under those market conditions. In 2021, the average ex-vessel price of blue catfish was $0.58 per pound, although input during survey development noted ranges of $0.25 to $0.85 (NOAA 2023). Anecdotal evidence suggests that low ex-vessel price serves as a barrier to participation in the blue catfish fishery and thus, hypothetical contingent behavior questions were used to test that hypothesis. The experimental design included three ex-vessel price levels (low =$0.50; medium =$1.00; high =$2.00) with two levels of variability (low ±$0.10, high ±$0.40), where respondents were presented hypothetical prices as a range, e.g., [$0.30, $0.70] for a low mean price and high variability. Each individual was asked three hypothetical contingent behavior questions, producing 20 possible price range combinations. From this set, combinations that presented the same hypothetical price ranges in different order were removed, as were any combinations that did not include both a low and high average price level and low and high price variability. These restrictions produced an experimental design of 10 combinations, from which five were randomly selected and associated with a unique survey version (A-E).

Survey Implementation

Mailing addresses obtained from the VMRC were requested based on three groups of fishing participation. The first group included individuals that had participated in the blue catfish fishery (≥100 pounds of non-cumulative blue catfish landings across years) between 2017-2021 (n= 224); the second group included individuals that did not participate in the blue catfish fishery (<100 pounds of non-cumulative blue catfish landings across years), but had ≥1,000 pounds of other species landings *and* licenses or permits for gears that could be used to harvest blue catfish (e.g., fyke net, gill net, hook-and-line, hoop net or fish pot, low-frequency electrofishing, pound net, and trot line) between 2017-2021 (n= 806); and the third group included individuals that did not participate in the blue catfish fishery (<100 pounds of non-cumulative blue catfish landings across years) *and* did not have licenses or permits for gears that could be used to target it but had ≥1,000 pounds of other species landings between 2017-2021 (n=680). The survey frame included a total of 1,710 active (i.e., at least one day of recorded participation in a given year) Virginia licensed commercial fishermen with permanent in-state residences from 2017-2021. Individuals with undeliverable addresses or non-Virginia residences were removed.

Using the stratified survey frame, a total of 800 fishermen were sampled across the three groups. Based on the research objective to understand the potential for expanding the blue catfish fishery in Virginia and the small sample size, all individuals that had previously landed blue catfish in the previous five years (≥100 pounds) were sampled (n=224). The remaining individuals were divided equally using a random selection of 288 individuals that did not participate in the blue catfish fishery but had licenses or permits for gears to do so and 288 individuals that did not participate in the blue catfish fishery and did not have the licenses or permits for gears to do so. Individuals within each of the three groups were randomly assigned a version of the survey, so that there was equal representation of survey versions within and across groups. The occurrence of survey versions across ZIP codes were also evaluated to ensure representation across areas. Blue catfish are not locally available in all areas and it is therefore important to understand how this might affect participation in the fishery. All survey materials were approved by William & Mary's Protection of Human Subject Committee (Protocol No. PHSC-2022-02-03-15429-amscheld; see Appendix for survey materials).

Survey distribution followed a Dillman et al. (2009) approach, where individuals received up to four mailings between April and July of 2022. Individuals in the sample received an initial invitation postcard to highlight the purpose of the survey and indicate that a survey packet would arrive in the next two weeks; a survey packet, including a cover letter that indicated consent, the survey, and a return envelope with postage; a follow-up postcard, thanking individuals for their participation and asking that they return the survey if they had not done so; and a second survey packet to those who had not responded. To raise awareness of the survey within the commercial fishing industry, the Virginia Waterman's Association, the predominant industry group in the state, highlighted the research on social media following the initial postcard but prior to the survey mailing.

Survey Analyses

Descriptive Statistics and Models

All surveys were coded, entered into a database and checked for accuracy prior to analysis. A majority of questions were analyzed as the average or mode of responses, which helps to characterize patterns across respondents and the broader small-scale commercial fishing industry in Virginia. Individuals who did not respond to certain questions were removed when calculating proportions. Differences across response groups to key questions were used to assess potential response bias. Comparisons between fishermen who had landed blue catfish and those who had not (regardless of holding licenses or permits for certain gear) were evaluated using Kruskal-Wallis tests (Hecke 2012), as the purpose of this research was to understand differences between individuals landing blue catfish and those who are not, regardless of gear.

Responses to Likert scale questions were considered non-parametric and a Kruskal-Wallis test was used to assess differences between fishermen that landed blue catfish and fishermen that did not (Hecke 2012). Potential responses to Likert scale questions ranged from “none” to “high” or “strongly disagree” to “strongly agree” with an additional “not sure” option. The “not sure” option was excluded in analyses and each scale was centered on “neutral.” Likert scale questions related to concerns regarding the ecological and fishery impacts of blue catfish and expansion of the commercial fishery were coded on a 0-5 scale. The Likert scale question associated with perspectives on LFE was coded on a 1-5 scale.

Statistical models were developed to assess responses to the three hypothetical contingent behavior questions included in each survey. Based on feedback received during survey development, it was hypothesized that an individual’s willingness to increase fishing effort (or number of fishing days) for blue catfish might be influenced by ex-vessel price, availability of buyers, presence of blue catfish in fishing areas, current fishing behavior, as well as socio-demographics. In general, diversification decisions have been tied to a suite of factors including the total years an individual has participated in the commercial fishing industry, regulation, resource dependence, and revenues (Bucaram and Hearn 2014; Hentati-Sundberg et al. 2015; Stoll et al. 2017; Abbott et al. 2022). It is probable that these factors also influence an individual’s decision to participate in emerging fisheries and thus, model development considered the willingness to participate as a function of ex-vessel price and price variability as well as other potentially relevant factors. The hypothetical increase in fishing days was represented as bins in the survey. The mean of each bin was used as a continuous response variable in the model. Model covariates tested included ex-vessel price, treated as a continuous variable and the level of price variability, considered as a binary factor, as well as additional variables created from responses to survey questions such as age, annual revenues, whether an individual landed blue catfish in the past five years, total number of years fished, changes in species targeted or gears used during fishing career, whether an individual obtained income from outside employment, anticipated fishing behavior in the next ten years, and total number of species targeted, gears used, and areas fished in 2021. Additional models were fitted including individual license numbers (i.e., individual fishermen) as either fixed or random effects to control for unobserved heterogeneity and to provide comparisons with models including individual explanatory covariates. Variance Inflation Factors (VIF) were used to assess multicollinearity between covariates and values of ≥ 5 were avoided in model development (O'Brien 2007).

A total of three models were developed, including two linear models and a single, two-step hurdle model, each controlling for individual effects in different ways. The first linear model was used to assess the impact of individual factors on willingness to participate in the blue catfish fishery. Model selection was based on Akaike's Information Criterion and structured as:

Equation 3. $$Yij = \beta_0 + \beta_{price} * Price_{ij} + \beta_{var} * Var_{ij} + \boldsymbol{Individual_{ij}} * \boldsymbol{\beta_{individ}} + \varepsilon_{ij},$$

where Y is the number of fishing days for blue catfish given ex-vessel price ($\beta_{price} * Price_{ij}$), variability of ex-vessel price ($\beta_{var} * Var_{ij}$), and sociodemographic characteristics included in the individual matrix of covariates (bold), and ε_{ij} is the associated error term. The second linear model included individual fixed effects to control for individual heterogeneity in assessing the effect of market price and price variability on willingness to participate. Fixed effects of individual VMRC.ID. The hurdle model was composed of two parts: a generalized linear mixed model (GLMM) binomial regression with a logit link to evaluate differences between zero and non-zero hypothetical fishing effort responses and a GLMM with a gamma regression and log link to assess factors influencing non-zero effort responses. Covariates included ex-vessel price, ex-vessel price variability, and individual identification numbers as a random effect. GLMMs were fit in the glmmTMB package for R Studio (Brooks et al. 2017). Residual plots were used as robustness checks for each of the models.

Qualitative Analysis of Open-Ended Responses

Each survey offered two opportunities for open-ended responses related to the blue catfish commercial fishery and individual participation in Virginia's commercial fishing industry. Survey responses were coded in QSR International NVivo using a modified grounded theory approach (Glaser and Strauss 1967). There was extensive overlap between topics mentioned and, therefore, responses were combined for coding. Responses were coded based on positive or negative sentiment and then multiple iterations of coding were conducted to detect emergent themes or concepts.

Results

Survey Responses

Data Cleaning Procedures

Due to a printing malfunction in the second survey mailing, some of the return envelopes did not have an assigned identification number (n=39, or 22.5% of respondents) and were subsequently recategorized based on responses to various questions. Individuals that self-reported targeting blue catfish in 2021 were assigned to the group with blue catfish landings. Individuals that stated they did not target blue catfish in 2021 were either assigned to the group that had no blue catfish landings but had licenses or permits for gears that could be used for harvest or the group that had no blue catfish landings nor licenses or permits for gears to do so based on responses to questions regarding species targeted and gears used. Five survey questions had similar instances where individuals either selected more than one option or exceeded the suggested number of choices. Fishermen were asked to select an option that best described their fishing behavior in terms of species targeted and gears used over time. Respondents who selected that their fishing behavior was different since they began fishing and also indicated that number of species targeted or gear used had increased or decreased, were recategorized as the option that indicated changes in behavior regardless of how it had changed. One respondent had conflicting selections and thus, the response was excluded. Similarly, fishermen often selected more than one option when asked if they anticipated fishing in ten years. If respondents indicated that this decision was dependent on regulations and market, then the response was coded to the option that indicated uncertainty. Fishermen were also asked to select three choices that best described the reason for ending participation in any fishery and challenges to the success of an individual's commercial fishing business. Respondents often selected more than three options and thus, forced rankings could not be assumed. All responses were coded, despite exceeding the suggested number of options, as these provide useful insight into barriers or challenges that exist within Virginia's small-scale commercial fishing industry.

Virginia's Small-Scale Commercial Fisheries

A total of 173 surveys were returned (22.4% return rate, excluding individuals with undeliverable addresses, n=26). Return rates (excluding undeliverable addresses), were highest among fishermen that had landed blue catfish within the last five years (34%) and lowest for individuals that had not targeted blue catfish and did not hold licenses or permits for gears that could be used for harvest (15.2%). Fishermen who did not have landings for blue catfish but had licenses or permits for gears that could be used for harvest had an intermediate response rate (19.9%). The average age of respondents was 60.9 (SD ± 14.6) years old and a majority of individuals indicated a high school diploma as their highest degree of education. Most fishermen had been a commercial waterman for 20 or more years (n=107) and more than 70% of respondents have immediate or extended family members that work, or have previously worked, in commercial fishing or seafood industries. Likewise, a majority of individuals were second generation watermen (n=64), although a number of fishermen reported having five or more generations of watermen in their family (n=18). There was considerable variability in the number of days fished and revenues in

2021. However, on average, fishermen reported fishing between 101-150 days with average incomes between \$15,001 - \$30,000. Fishermen reported having an average of 1.1 ± 1.5 crew members on their vessel. Differences in these factors across sample groups were not significant, with the exception of age (p value <0.10).

To evaluate levels of diversification within and outside of Virginia's small-scale fisheries, fishermen were asked to indicate which species were targeted, what gears were used, and what areas were fished in 2021. More than half of respondents (67.6%) targeted more than one species and used more than one gear type (57.2%). There were significant differences in the number of gears used and species targeted between fishermen who had landed blue catfish in the last five years and fishermen who had not landed blue catfish, regardless of holding licenses or permits for gears that could be used for harvest (p value <0.001). Individuals that landed blue catfish were more diversified across gears and species than individuals without blue catfish landings. Fishing locations were based on VMRC's waterbody codes used for self-reporting harvest with some locations combined. Less than half of fishermen indicated fishing in more than one location (48.6%). A majority of fishermen (59.5%) reported targeting blue crab (*Callinectes sapidus*) and using pots or traps (58.4%) in 2021. Gill nets were the second most commonly mentioned gear type (51.4%). Despite evidence of diversification between species and gears, only 31% of fishermen reported holding a license or permit for commercial harvest outside of Virginia state waters, including jurisdictions of the Potomac River Fisheries Commission. Fishermen most commonly sold their catch to a processor (i.e., fish house) or seafood markets and wholesalers, and half of individuals sold to more than one buyer type (50.4%). There were significant differences in the number of ways in which fishermen sold their catch between groups (p value <0.01) with individuals who had landed blue catfish utilizing more methods of selling catch than individuals who did not land blue catfish. When asked to compare an individual's current fishing behavior in terms of species targeted and gears used to when an individual began fishing, the most common response indicated no change across years. Interestingly, when comparing whether there was an increase or decrease in species targeted or gears used, more respondents had decreased participation in both capacities. At the group level, individuals who had landed blue catfish noted using more gear types, rather than decreasing the number of gears used. On average, fishermen derived approximately 47.4% of their income from fishing and 45.1% of respondents indicated having at least one additional source of income outside of commercial fishing. Fishermen were asked to list other income sources and of these responses, approximately 26% of individuals noted retirement, pension, or social security. Other responses were predominately non-marine related, although some individuals identified additional marine-related income through employment hanging net for other fishermen, working at marinas, seafood processing or aquaculture facilities, or marine construction.

Fishermen were asked to indicate if they had ever stopped targeting a particular species and what drove this change. The top responses were related to the availability of species (n=56) and price received for species (n=52); however, the third highest response were fishermen who indicated they had not stopped targeting any species (n=48). To better understand challenges to participation in Virginia's small-scale commercial fishing industry, fishermen were asked which factors presented the greatest challenges to success. The top three responses included availability of species in fishing areas or seasons (n=72), price received for landings (n=71), and management or regulation (n=69).

Responses to Blue Catfish Questions

Individuals who landed blue catfish in the previous five years (≥100 pounds of non-cumulative landings between 2017-2021) targeted blue catfish an average of 55.4 ± 66.5 days and received an average ex-vessel price of $0.53 per pound in 2021. The most common gear type used by fishermen targeting blue catfish were gill nets (n=52), although respondents often indicated using multiple gears in addition to gill nets, such as hoop nets (fish pots) and trot lines. More than half (61.8%) of all respondents indicated that they had caught blue catfish as bycatch while targeting other species within the last five years and, of those individuals, 70.1% reported selling blue catfish caught as bycatch. The majority of individuals who did not actively target blue catfish indicated a lack of interest (n=40), followed by a lack of appropriate gear (n=29) or availability of blue catfish in fishing areas (n=21).

Average responses to Likert scale questions were evaluated across all respondents (excluding "not sure" responses) and responses were compared between groups to evaluate differences between fishermen that landed blue catfish and those who did not (Figures 3.1-3.3). Concerns regarding the ecological and fishery impacts associated with expansion of the blue catfish in Virginia ranged from "no concern" to "high concern" (coded on 0 to 5 scale) and on average, individuals were less concerned about the impact of blue catfish occurring as bycatch in other fisheries (2.7 ±1.9) and more concerned with other ecological impacts, such as predation on other species (4.2 ±1.5) or expansion of blue catfish to other areas (4.0 ±1.6). Ecological impacts of habitat use and competition with other species had average responses of 3.7 (±1.7) and 3.9 (±1.6), respectively. A higher proportion of individuals across both groups (individuals that landed blue catfish and individuals that did not) indicated concerns greater than the midpoint (>3) regarding ecological and fishery impacts of blue catfish in Virginia with the exception of bycatch in other fisheries. Individuals that did not land blue catfish were less concerned about bycatch (48%) compared to individuals that did land blue catfish (29%) with significant differences between groups (p value <0.05). Significant differences existed between groups for habitat use and competition with other species (p value <0.05), and expansion of blue catfish to other areas (p value <0.001) with fishermen who had landed blue catfish having higher concerns. Concerns related to predation on other species by blue catfish were also significantly different between groups, although to a lesser extent (p value <0.01). Fishermen who had landed blue catfish had higher concerns regarding predation on other species.

Respondents rated concerns on different factors related to expansion of the blue catfish commercial fishery in Virginia on a scale of "no concern" to "high concern" (coded on 0 to 5 scale). Average concerns regarding the expansion of the blue catfish commercial fishery in terms of the availability of buyers (2.7 ±1.9), conflicts with other commercial gears or species (1.9 ±1.8) or the recreational fishing sector (1.5 ±1.7), and consumer perceptions of blue catfish (1.8 ±1.6) were considered low (<2.9). On average, the ex-vessel price of blue catfish was more of a concern in regard to expanding the commercial fishery for blue catfish in Virginia (3.3 ±1.8). Individuals who landed blue catfish were more concerned with ex-vessel price than individuals who did not (p value <0.001). In addition to ex-vessel price, significant differences existed between groups regarding concerns about the availability of buyers, conflicts with the recreational fishing sector, and consumer perceptions (p value <0.05), as well as conflicts with other commercial gears or species (p value <0.01). In all instances, fishermen who had landed blue catfish in the previous five years had higher concerns that those who did not. Fishermen were asked to rate their level of agreement with statements regarding the use of LFE for blue catfish harvest. Responses ranged from "strongly disagree" to "strongly agree" (coded on 1 to 5 scale) and, on average, individuals considered LFE to be an effective method for controlling the blue catfish population (3.4 ±1.8). Individuals disagreed slightly that LFE gears did not impact other marine wildlife and habitats (2.5 ±1.7), other commercial fishing gears (2.7 ±1.8), or the recreational fishing sector (2.8 ±1.8). On average, fishermen agreed that expanding the blue catfish commercial fishery using traditional gears (e.g., gill net, hoop net, trot line) should be prioritized (3.7 ±1.6). A higher proportion of individuals that had landed blue catfish agreed with statements regarding the use of LFE compared to individuals who did not land blue catfish. There was a significant difference between groups related to the impact of LFE on the recreational fishing sector (p value <0.05), and a higher proportion of fishermen who had landed blue catfish strongly agreed that LFE does not impact the recreational fishing sector compared to fishermen who had not landed blue catfish.

Models

A linear model was constructed to determine the willingness of fishermen to target blue catfish. Correlations between observed and expected residuals (0.964) were utilized to ensure robustness, as well as QQ and residual plots. The linear model, determined by AIC model selection, was used to predict the number of fishing days as a function of ex-vessel price, variability in ex-vessel price, previous landings of blue catfish, total number of years an individual had been a commercial fisherman, total number of gears used in a given year, total revenue in a given year, having an additional source of income, and whether an individual had more than one generation of commercial fishermen in their family (Table 3.1; Table 3A.1). Ex-vessel price was included as an interaction term on whether individuals had landed blue catfish in the previous five years (≥100 pounds of non-cumulative landings). The ex-vessel price received for blue catfish was significant and positive (p value <0.001), indicating that the average individual who had previously landed blue catfish would target it 71.6 more days with a one dollar increase in price (Figure 3.4). The effect of an individual landing blue catfish in the previous five years was insignificant as an intercept shifter. However, when price was included as an interaction term with whether individuals had landed blue catfish or not, the interaction was negative and significant (p value <0.01). Individuals that had not previously landed blue catfish were likely to increase fishing days with an increase in ex-vessel price, although to a lesser extent than individuals who already targeted blue catfish (35.7 fishing days for a one dollar increase in price; Figure 3.4). The variability of ex-vessel price, however, was not significant and suggests that fishermen are more responsive to increases in price regardless of how variable the price is. The total number of gears used was also significant and positive (p value <0.001), indicating that for each additional gear used, the average fishermen would increase the number of fishing days for blue catfish by 19.6 days, independent of price. Similarly, whether an individual had more than one generation of commercial fishermen in their family had a positive impact on the willingness to target blue catfish (p value <0.10) with an increase of 20.2 days for each additional generation. The adjusted coefficient of determination (R^2) for the linear model including individual covariates was 0.271, suggesting a high level of variance that is not accounted for in the model.

A second linear model was constructed to determine the effect of ex-vessel price and variability of ex-vessel price on the willingness to increase fishing days, controlling for individual factors (Table 3.2). Model covariates included ex-vessel price and variability in ex-vessel price, as well as individual identification numbers (i.e., individual fishermen) as a fixed effect. Ex-vessel price had a significant and positive impact on the number of hypothetical fishing days for blue catfish (p value <0.001) with an increase of 49.4 fishing days per one dollar increase in ex-vessel price. The variability of ex-vessel price was not significant in the model. The adjusted R^2 for the fixed effect linear model was 0.855, indicating that individual fixed effects explain considerably more variation compared to the prior model that included individual covariates but did not control for all sources of individual heterogeneity.

A two-step GLMM hurdle model was constructed to evaluate robustness of findings from linear models (Table 3A.2). Covariates included in the hurdle model were ex-vessel price, variability of ex-vessel price, and individual license numbers as a random effect. The first step of the model used a binomial regression with a logit link and whether individuals had landed blue catfish in the last five years (>100 pounds of non-cumulative landings) or not was considered binary variable. A "0" represented individuals who had not landed blue catfish in the last five years regardless of whether or not they had the gear to do so and a "1" represented individuals who had landed blue catfish. In the binomial model, there was a significant and positive effect of price on the willingness to target at least one fishing day for blue catfish (p value <0.001). Coefficients in the first step of the hurdle model are the log odds of the predictor values and interpreted as predicted probabilities obtained by exponentiating the intercept coefficient and odds ratio. The second part of the two-step GLMM hurdle model used a gamma regression with a log link to evaluate the effect of covariates on individuals who had targeted blue catfish within the last five years. Coefficients in the second part of the hurdle model are interpreted as the impact on number of fishing days given a change in the covariate obtained by multiplying the exponentiated intercept and coefficient. This model indicates the effect of ex-vessel price on the willingness to increase fishing days is positive and significant (p value <0.001) with fishermen increasing fishing effort by 75.5 days with a one dollar increase in ex-vessel price.

Qualitative Responses

A total of 33 individuals provided additional comments related to individual participation in commercial fishing and 58 individuals provided comments regarding the commercial fishery for blue catfish. There were more instances of negative sentiment than positive sentiment.

Iterations of coding revealed high levels of concern regarding the presence of blue catfish and declining species populations, especially blue crab (*Callinectes sapidus*). The impact of blue catfish on other species was mentioned more than 75% of the time by individuals who harvested blue catfish within the previous years. The impacts of blue catfish were noted as "severe" with the ability to outcompete or “take the place of native species.” Other negative statements were focused on broader concerns within the commercial fishing industry including the decline in participation and limited ability of younger individuals to enter the industry. Positive sentiments were related to encouraging participation and removals of blue catfish, the effectiveness of electrofishing, and individual fishing behavior. The majority of positive sentiments were from individuals who had harvested blue catfish (42.8%). One individual noted that blue catfish were bad for the rivers but “it has given us valuable income in the months we don’t crab,” suggesting that blue catfish served as a diversification opportunity, while others expressed interest in obtaining LFE permits in the future for harvest. There were multiple instances of fishermen noting the need to adapt and diversify between species and gears with evidence that some individuals considered themselves diversified into blue catfish. Individuals that provided statements that were considered neither positive nor negative sentiments were often those who were not interested in participating in the blue catfish commercial fishery or were not aware of blue catfish in their area. Fishermen commonly cited the Eastern Shore as an area where blue catfish have not yet expanded.

Discussion

The motivation of this research was to assess the willingness of Virginia’s small-scale commercial fishermen to participate in the existing, but relatively small, blue catfish fishery and to identify potential barriers to expansion. In response to the growing management concern regarding blue catfish, the Chesapeake Bay Program established the Invasive Catfish Workgroup, comprised of various industry members, state and federal management agencies, and researchers. As part of the Workgroup’s strategic plan to curtail population growth and inhibit expansion of blue catfish in Virginia, commercialization of the species is thought to provide ecological and socioeconomic benefits to fishermen and fishing communities (Chesapeake Bay Program 2020). It is evident in the findings of this study, that commercial fishermen are aware of the ecological impacts of blue catfish in the Chesapeake Bay regardless of whether individuals have landed blue catfish or not. One such impact is the effect of blue catfish predation on other economically valuable species, such shad and herring and blue crab (Schloesser et al. 2011; Fabrizio et al.

2021). A majority of survey respondents indicated participation in the blue crab pot fishery and thus, it is unsurprising that predation on other species was of higher concern for both fishermen that had landed blue catfish and individuals who had not. Although the impacts (e.g., predation, competition, habitat use) of blue catfish on other species in Chesapeake Bay are not well understood, there are likely widespread ecological and economic implications to other commercially (and recreationally) valuable species that warrant investigation.

Removals of blue catfish could reduce predation rates on other species, however, the effect on population abundance is uncertain and necessitates continued observation on large, temporal scales. In the Illinois River, bigheaded carp (*Hypophthalmichthys spp.*) invasions are correlated with declines in the abundance and body condition of gizzard shad (*Dorosoma cepedianum*). Targeted removals of bigheaded carp were associated with higher abundances of large gizzard shad, however, the effect on smaller gizzard shad during the study period was negligible (Love et al. 2018). It is probable that similar responses could exist between removals and ecological responses for blue catfish and thus, the effects of predation might not be recognized until much later. It is important for managers and stakeholders to consider these delayed responses when establishing goals and anticipated impacts of removals as there may be tradeoffs between present and future benefits, as well as unintended socioeconomic impacts (Nuñez et al. 2012; Jacobs 2016; Quintana et al. 2023). It is also important to consider biological impacts of emerging species, particularly the removal of invasives, as reduced density-dependent effects could result in higher productivity and have the unintended consequence of increasing population through enhanced reproductive effort (Conover and Baumann 2009).

There is less concern about various aspects of expanding the commercial fishery for blue catfish compared to the ecological impacts and managers could leverage ecological concerns to encourage participation and removals in the fishery. Based on the perceptions of fishermen, the most concerning aspects of expanding the commercial fishery for blue catfish are the availability of buyers and more notably, ex-vessel price. There is evidence that ex-vessel price is a prominent factor in the decision to increase fishing effort for blue catfish in Virginia's small-scale commercial fishing industry. In 2021, fishermen reported an average ex-vessel price of $0.53 per pound for blue catfish, which was slightly above the lowest average value included in contingent behavior questions ($0.50 per pound) and less than the average $0.58 per pound value indicated by NOAA (2023). An increase in ex-vessel price for blue catfish might result in increased fishing effort for individuals who actively target blue catfish and incentivize those who do not target blue catfish to enter the fishery. Interestingly, when fishermen were asked why they did not target blue catfish, more individuals noted a lack of interest, lack of appropriate gear, or availability of blue catfish in fishing areas, rather than ex-vessel price. For individuals who did not harvest blue catfish in the previous five years, regardless of license or permit holdings for gear, there was an effect of ex-vessel price on the willingness to increase fishing days. It is likely that fishermen without the appropriate gears to harvest blue catfish would require higher ex-vessel prices to compensate for investment in gear, time spent to outfit their vessel, and opportunity cost of participating in other fisheries or employment outside of commercial fishing. Likewise, higher ex-vessel prices may be needed to compensate for traveling further distances to fishing areas where blue catfish are present.

Likert scale questions suggest that the availability of processors to buy blue catfish was also a concern in regard to expansion, although the extent of this issue is not well documented and should be further explored. It has been suggested that the processing requirements for blue catfish contribute to low harvest and inhibit expansion due to a lack of ex-vessel buyers that stabilize market prices at lower levels. Per the 2008 and 2014 Farm Bills, inspections by the Food Safety and Inspection Service (FSIS) through the United States Department of Agriculture (USDA) were mandated for processing of Siluriformes, including blue catfish and all other catfish species (USDA 2017). Low and inconsistent harvest levels of blue catfish in Virginia have deterred some processors from investing in and outfitting facilities to meet these USDA requirements, thus creating a negative feedback loop and constraining the market for blue catfish. Future research could build on recent legislation to further develop processing (SB 897; https://lis.virginia.gov) through a grant program. Evaluating barriers and bottlenecks within the seafood sales and processing sector could be used to better understand the feasibility of expanding the commercial fishery for blue catfish and seek solutions that promote invasivorism and enhance market demand in order to encourage higher ex-vessel prices.

Marketing strategies are already underway to alleviate public concerns and promote consumption of blue catfish in Virginia with branding that includes “Virginia wild caught” and NOAA’s slogan, “invasive and delicious” (Fisher 2020; NOAA 2020). Although there are underlying apprehensions with blue catfish consumption stemming from historical management, including contaminant concerns, public acceptance of blue catfish will likely rely on continued exposure, association of positive attributes (in the case of blue catfish, ecological or health benefits) and sufficient advertisement (Shepherd and Raats 2006). In the Maryland portion of the Chesapeake Bay, two seafood processors were contracted to provide blue catfish products to state institutions such as prisons, public schools, hospitals, and universities as a means of reducing population size and strengthening local economies (Chesapeake Bay Magazine 2018). It is possible that Virginia could implement similar programs that encourage removals and provide the commercial fishing industry with access to additional markets.

In addition to ex-vessel price, there are other barriers to participation or diversification in emerging species fisheries that are worth noting. In Virginia’s small-scale commercial fishing industry, levels of diversification are limited despite the suggested benefits of revenue stabilization and increased resiliency to sudden shocks (Kasperski and Holland 2013; Sethi et al. 2014; Abbott et al. 2022). Since the mid-1990s, less than half of licensed commercial fishermen have diversified across fisheries (White and Scheld 2021). In this study, however, survey respondents were more diversified on average with over half of fishermen indicating that they targeted more than one species or used more than one gear type. There are a number of factors that might influence diversification decisions, including age, years of participation, license and permit holdings, and resource dependence, although it is not well understood as to what drives decision-making in Virginia (White and Scheld 2021). Fishermen with higher resource dependence on commercial fishing may be more likely to diversify between species, gears, or seasons as a means of fishing year-round, while less resource dependent fishermen may have other sources of income to supplement commercial fishing. On average, respondents derived less than half of their income from commercial fishing and a number of fishermen reported having another occupation in addition to fishing. Diversification into emerging fisheries may be constrained if individuals hold outside employment (in addition to commercial fishing) and can only participate during certain times of the day or during particular seasons. It could be that emerging fisheries, such as blue catfish, provide additional fishing opportunities that allow fishermen with additional employment to increase participation in commercial fishing rather than derive income from other sources. Aside from ex-vessel price, it is also important to recognize that lack of personal interest or knowledge, age, and residency (i.e., species does not exist in preferred fishing area) can be constraining factors to diversification (Ward and Sutinen 1994; Pradhan and Leung 2004; Naranjo-Madrigal and van Putten 2019). Some fishermen noted that retirement or age-related benefits (e.g., social security) accounted for a portion of their income and thus, were less resource dependent on fishing. It is possible that these individuals might have limited interest in participating in the blue catfish fishery regardless of increases in ex-vessel price.

Despite the barriers to diversification, expanding the commercial fishery for blue catfish offers additional economic and sociocultural benefits to fishermen and fishing communities. In Virginia, a majority of fisheries are regulated as limited entry and/or quota-based and require substantial financial capital for entry. Blue catfish offers a more flexible opportunity for entry into the commercial fishing industry as conservation is not a management concern, although interactions with other species should be considered. Furthermore, diversification into the blue catfish fishery can serve to increase the resiliency and adaptive capacity of fishermen and fishing communities. There also appears to be an interest in diversification into emerging fisheries in Virginia, including the LFE fishery for blue catfish and the experimental trawl fishery for harvest of white shrimp. While both of these fisheries are currently limited in participation, understanding interest and participation effort can help managers to predict future behavior and harvest levels in conjunction with resource and market conditions. Optimal market conditions for emerging species could incite fishermen to participate more heavily in these fisheries and reduce pressure on less abundant species.

As environmental conditions continue to change, the prevalence of emerging species is likely to increase. Non-native species may utilize different habitats and negatively impact ecosystems, while native species might shift their geographic range northward or to deeper waters (Lucey and Nye 2010; Pinsky and Fogarty 2012; Dubik et al. 2018; Finch et al. 2021). Contemporaneous with management to control invasives, fishing harvest could provide novel fishing opportunities to target emerging species. Managers should understand potential shifts in diversification and resource dependence associated with exploitation Understanding human responses to changing conditions is essential and fisheries management should be adaptable in responses to environmental changes that will undoubtedly cause managed resources to become increasingly dynamic. Nonetheless, it is unlikely that blue catfish populations will be reduced significantly in the near future and thus present available diversification opportunities that can help Virginia's commercial fishing industry to become more resilient to potential stressors, as well as potentially reduce ecological impacts to other commercially valuable species

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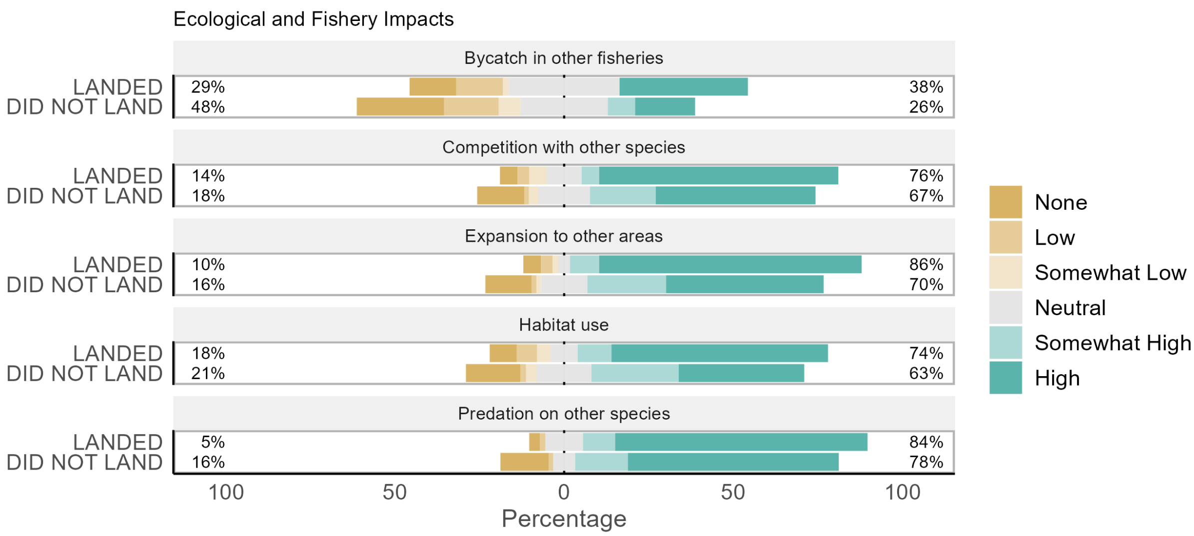

Figure 3.1. Respondents were asked to rate concerns regarding the ecological and fishery impacts of blue catfish in Chesapeake Bay.

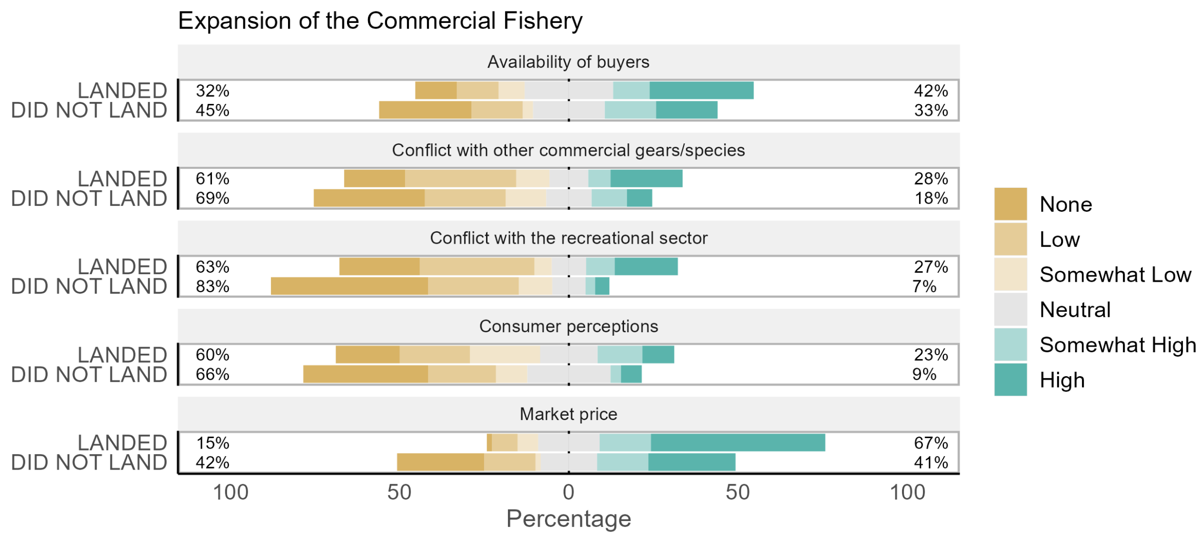

Figure 3.2. Respondents were asked to rate concerns regarding expansion of the commercial fishery for blue catfish in Chesapeake Bay.

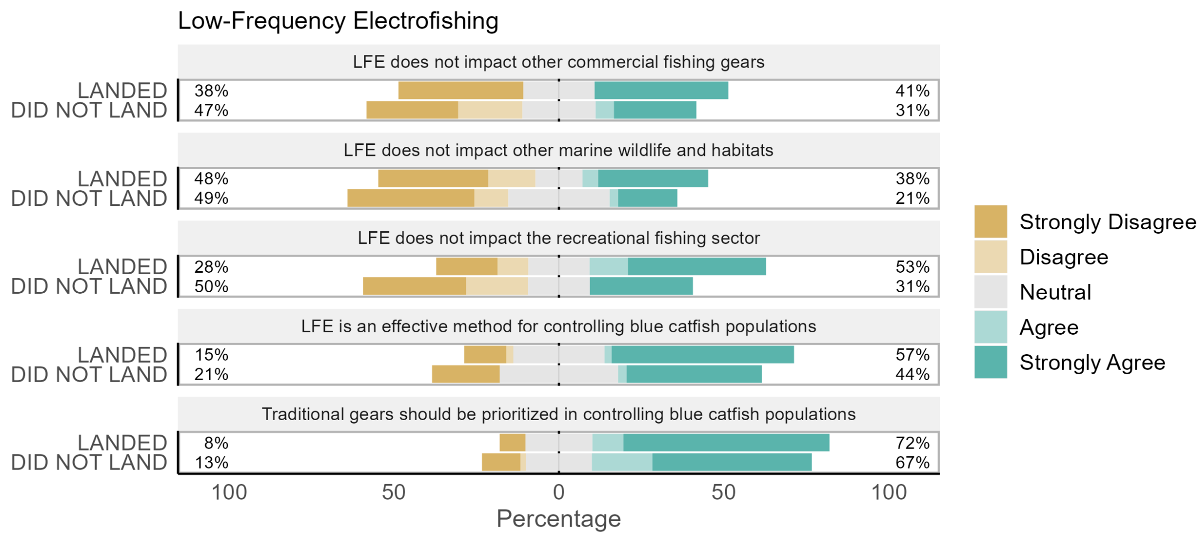

Figure 3.3. Respondents were asked to indicate the level of agreement with statements about using low-frequency electrofishing (LFE) for commercial blue catfish harvest in Virginia's tidal waters.

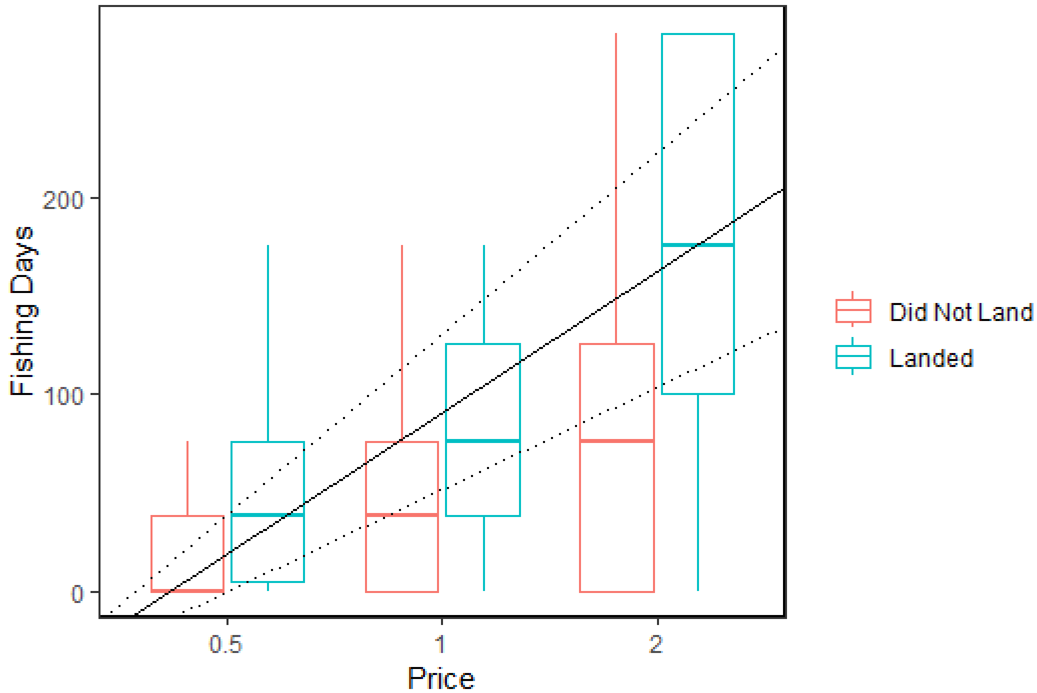

Figure 3.4. Boxplots depicting the number of fishing days in response to changes in market price for fishermen who had not landed blue catfish in the past five years, regardless of holding licenses or permits for gears that could be used for harvest (red), and fishermen who had landed blue catfish in the past five years (blue). Linear model predictions indicated by regression line (solid black line) and 95% confidence intervals (dotted black lines).

Table 3.1. Linear model for blue catfish targeting days as a function of ex-vessel price, price variability, and individual covariates.

Number of Observations: 354

	Estimate	Standard Error	t Value	p	
Intercept	-5.16e+01	2.42e+01	-2.13	0.03	*
Ex-Vessel Price	7.16e+01	1.02e+01	7.06	<0.001	***
High Variability	9.74e+00	8.79e+00	1.11	0.27	
Total Gears Used	1.96e+01	4.10e+00	4.78	< 0.001	***
More than One Generation	2.02e+01	9.18e+00	2.20	0.03	*
No Blue Catfish Landings	7.11e+00	1.83e+01	0.39	0.70	
No Blue Catfish Landings*Ex-Vessel Price	-3.59e+01	1.36e+01	-2.63	0.01	**
Annual Revenue	-9.92e-05	1.60e-04	-0.62	0.54	
Years Fished	1.42e+00	9.31e-01	1.52	0.13	
Additional Income	-1.12e-01	6.44e+00	-0.17	0.86	

Multiple R-squared: 0.2903 Adjusted R-squared: 0.2717

F-statistic: 15.63 on 9 and 344 DF p value <2.2e-16

Significance Codes: '*' <0.001 '**' <0.01 '*' <0.05 '.' 0.1 'blank' > 0.05**

Table 3.2. Linear model for blue catfish targeting days as a function of ex-vessel price, variability in ex-vessel price, and individual fishermen as a fixed effect (excluded from table).

Number of Observations: 475

	Estimate	Standard Error	t Value	p	
Survey ID (Fixed Effect)	---	---	---	---	
Ex-Vessel Price	4.94e+01	3.56e+00	13.90	<2e-16	***
High Variability	1.60e+00	4.84e+00	0.33	0.74	

Multiple R-squared: 0.9043 | Adjusted R-squared: 0.8548

F-statistic: 18.27 on 162 and 313 DF | p value <2.2e-16

Significance Codes: '*' <0.001 '**' <0.01 '*' <0.05 '.' 0.1 'blank' > 0.05**

Figure A3.1. Example of survey instrument distributed to fishermen in Virginia.

VIRGINIA WATERMEN BLUE CATFISH SURVEY

SECTION ONE – THE BLUE CATFISH FISHERY

The following questions (1-17) reference blue catfish (*Ictalurus furcatus*), a non-native species found in fresh and estuarine waters of the Chesapeake Bay (see image below). There is currently a small commercial fishery for blue catfish using gears such as hoop nets, gill nets, and trot lines. Recently, the Virginia Marine Resources Commission (VMRC) issued three commercial permits for the use of low-frequency electrofishing (LFE) for blue catfish harvest in three tidal rivers. LFE permits allow for one vessel to stun blue catfish to the surface, while additional vessels retrieve the fish with dip nets.

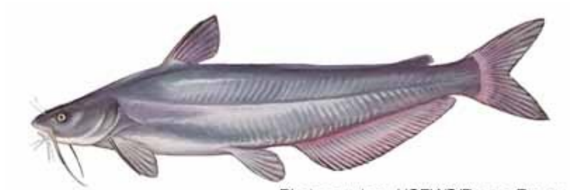
Photo courtesy USFWS/Duane Raver

1. Have you caught blue catfish as bycatch while targeting other commercial species during the last five years?
   ☐ Yes ☐ No

2. Have you sold blue catfish caught as bycatch while targeting other commercial species during the last five years?
   ☐ Yes ☐ No

3. Have you ever commercially targeted and sold blue catfish? ☐ Yes ☐ No

4. In 2021, approximately how many days did you commercially target and sell blue catfish? __________

5. If you have targeted blue catfish while commercial fishing, which gears did you use? **Select all that apply.**
   ☐ Fyke net
   ☐ Gill net
   ☐ Hook-and-line
   ☐ Hoop net (fish pot)
   ☐ Low-frequency electrofishing (LFE) (including catch boats)
   ☐ Pound net
   ☐ Trot line
   ☐ Other (please describe) ____________________________________
   ☐ I have never targeted blue catfish

6. If you have never targeted blue catfish, what prevents you from doing so? **Select all that apply.**

□ Availability of blue catfish in the area that I fish
□ Availability of processor/fish house demand
□ Handling/transporting of catch
□ I do not have the gear to target blue catfish
□ Limited experience with blue catfish
□ Price received for catch
□ Not interested
□ Other (please describe) ______________________________________

7. If you harvested and sold blue catfish (target or bycatch) in 2021, what was the approximate average price you received for your catch? $______/lb blue catfish

8. Please rate your concerns regarding <u>ecological and fishery impacts</u> of blue catfish in the Chesapeake Bay.

		Low		Moderate		High	
Bycatch in other fisheries	□ None	□ 1	□ 2	□ 3	□ 4	□ 5	□ Not sure
Competition with other species	□ None	□ 1	□ 2	□ 3	□ 4	□ 5	□ Not sure
Expansion to other areas	□ None	□ 1	□ 2	□ 3	□ 4	□ 5	□ Not sure
Habitat use	□ None	□ 1	□ 2	□ 3	□ 4	□ 5	□ Not sure
Predation on other species	□ None	□ 1	□ 2	□ 3	□ 4	□ 5	□ Not sure

9. Please rate your concerns regarding <u>expansion of the commercial fishery</u> for blue catfish in the Chesapeake Bay.

		Low		Moderate		High	
Availability of buyers	□ None	□ 1	□ 2	□ 3	□ 4	□ 5	□ Not sure
Conflict with other commercial gears/species	□ None	□ 1	□ 2	□ 3	□ 4	□ 5	□ Not sure
Conflict with the recreational sector	□ None	□ 1	□ 2	□ 3	□ 4	□ 5	□ Not sure
Consumer perceptions	□ None	□ 1	□ 2	□ 3	□ 4	□ 5	□ Not sure
Market price	□ None	□ 1	□ 2	□ 3	□ 4	□ 5	□ Not sure

Please indicate the level to which you agree with the following statements using the scale below:
1 = Strongly disagree, 3= Neutral, 5 = Strongly agree

10. Low-frequency electrofishing is an effective method for controlling blue catfish populations.
□ 1 □ 2 □ 3 □ 4 □ 5 □ Not sure

11. Low-frequency electrofishing for blue catfish in Virginia's tidal waters does not impact <u>other marine wildlife and habitats</u>.
□ 1 □ 2 □ 3 □ 4 □ 5 □ Not sure

12. Low-frequency electrofishing for blue catfish in Virginia's tidal waters does not impact <u>other commercial fishing gears.</u>
□ 1 □ 2 □ 3 □ 4 □ 5 □ Not sure

13. Low-frequency electrofishing for blue catfish in Virginia's tidal waters does not impact the recreational fishing sector.
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ Not sure

14. Expanding the commercial fishery for blue catfish using traditional gears (e.g., gill net, hoop net, trot line) should be prioritized in controlling blue catfish populations.
☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ Not sure

Questions 15-17 refer to hypothetical blue catfish market scenarios. Even if you have never targeted blue catfish or did not target blue catfish in 2021, please answer the following questions as accurately as possible.

15. How many days per year would you be willing to actively target blue catfish if the price you received were between $0.30-$0.70/lb and blue catfish were available in the areas you typically fish?
☐ Less than 10 days ☐ 11-25 days ☐ 26-50 days ☐ 51-100 days ☐ 101-150 days
☐ 151-200 days ☐ More than 200 days ☐ None/I would not target

16. How many days per year would you be willing to actively target blue catfish if the price you received were between $0.80-$1.20/lb and blue catfish were available in the areas you typically fish?
☐ Less than 10 days ☐ 11-25 days ☐ 26-50 days ☐ 51-100 days ☐ 101-150 days
☐ 151-200 days ☐ More than 200 days ☐ None/I would not target

17. How many days per year would you be willing to actively target blue catfish if the price you received were between $1.95-$2.05/lb and blue catfish were available in the areas you typically fish?
☐ Less than 10 days ☐ 11-25 days ☐ 26-50 days ☐ 51-100 days ☐ 101-150 days
☐ 151-200 days ☐ More than 200 days ☐ None/I would not target

Please use the space below to provide any additional comments you may have regarding the blue catfish commercial fishery:

SECTION TWO – YOUR PARTICIPATION IN COMMERCIAL FISHING

18. In 2021, approximately how many days did you commercially fish?
    - ☐ 50 days or less
    - ☐ 51-100 days
    - ☐ 101-150 days
    - ☐ 151-200 days
    - ☐ 201-250 days
    - ☐ 251- 300 days
    - ☐ More than 301 days
    - ☐ I did not commercial fish in 2021

19. In 2021, which species did you target when commercial fishing in Virginia state waters? **Select all that apply.**

☐ Black sea bass	☐ Menhaden
☐ Blue catfish	☐ Spiny dogfish
☐ Blue crab (hard)	☐ Spot
☐ Blue crab (peeler)	☐ Spotted seatrout
☐ Croaker	☐ Striped bass
☐ Eastern oyster	☐ Summer flounder
☐ Eel	☐ White Perch
☐ Hard clam	☐ Other (please describe) ___________________________

20. In 2021, what gears did you use for commercial fishing in Virginia state waters? **Select all that apply.**
    - ☐ Dredge
    - ☐ Fyke net
    - ☐ Gig
    - ☐ Gill net
    - ☐ Hand gear for shellfish (rakes, hand harvest, tongs, etc.)
    - ☐ Hook-and-line
    - ☐ Hoop net (fish pot)
    - ☐ Pots/traps
    - ☐ Pound net
    - ☐ Seines
    - ☐ Trawl
    - ☐ Trot line
    - ☐ Other (please describe) ____________________________________

21. In 2021, when commercial fishing in Virginia state waters, which areas did you fish most frequently? **Select all that apply.**

- ☐ Atlantic Ocean (Virginia Beach, Eastern Shore)
- ☐ Back Bay or North Landing River
- ☐ Eastern Shore – Bayside (including Pocomoke and Tangier Sounds)
- ☐ Eastern Shore – Seaside Bays (including Chincoteague, Hog Island, Outlet, and other Bays)
- ☐ James River Lower (including Chuckatuck Creek, Elizabeth, Lafayette, and Nansemond Rivers)
- ☐ James River Central/Upper (including Chickahominy and Warwick Rivers)
- ☐ Mainstem Chesapeake Bay Lower (East and West) - General
- ☐ Mainstem Chesapeake Bay Upper (East and West) - General
- ☐ Potomac River Lower (including Yeocomico and Coan Rivers)
- ☐ Potomac River Central/Upper (including Machodoc, Mattox, and Potomac Creeks, Currioman River, and Nomini Bay)
- ☐ Rappahannock River Lower (including Corrotoman River)
- ☐ Rappahannock River Central/Upper
- ☐ York River Lower
- ☐ York River Central/Upper (including Pamunkey and Mattaponi Rivers)
- ☐ Other Eastern Shore Bays, Rivers, and Tributaries (please describe)___________________________
- ☐ Other Western Shore Bays, Rivers, and Tributaries (please describe)__________________________

22. In 2021, what was your approximate total revenue from commercial fishing landings? **Do not include any deductions for trip expenses, maintenance, or license/permits costs.**

- ☐ $0 / I did not go fishing in 2021
- ☐ $1-$5000
- ☐ $5,001-$15,000
- ☐ $15,001-$30,000
- ☐ $30,001-$50,000
- ☐ $50,001-$75,000
- ☐ $75,001-$100,000
- ☐ > $100,000
- ☐ Not sure
- ☐ Refuse to answer

23. In 2021, about what percentage of your household income did commercial fishing represent? _____

24. Please list each additional job you held in 2021 that contributed more than 10% of your total household income. **If none, then leave blank.**

Other Income (other than commercial fishing) – briefly name/describe.
1.
2.
3.

25. In 2021, on average how much did you spend on <u>daily trip expenses</u> when commercial fishing in Virginia state waters? (Include bait, fuel/oil, groceries, ice, and other daily expenses not related to labor)
   ☐ $1-$100 ☐ $101-$-$200 ☐ $201-$300 ☐ $301-$400 ☐ $401-$500 ☐ >$500 ☐ Not sure
   ☐ Refuse to answer

26. In 2021, approximately how much did you spend on <u>commercial registrations/permits, fishing gear and equipment, and maintenance</u> (boat, trailer, vehicle, gear) used for commercial fishing in Virginia state waters?
   ☐ $1-$5000 ☐ $5,001-$10,000 ☐ $10,001-$15,000 ☐ $15,001-$20,000 ☐ $20,001-$30,000
   ☐ $30,001-$40,000 ☐ $40,001-$50,000 ☐ > $50,000 ☐ Not sure ☐ Refuse to answer

27. In 2021, not including yourself, how many crew members did you typically have on your vessel?_______

28. In 2021, did you hold any licenses/permits for commercial harvest in areas outside of Virginia state waters? **Select all that apply.**
   ☐ Maryland state waters
   ☐ North Carolina state waters
   ☐ Federal waters
   ☐ Other (please describe) __________________

29. In 2021, how did you sell your landed catch? **Select all that apply.**
   ☐ Directly to consumers
   ☐ Processor/packers/fish house
   ☐ Seafood markets/wholesalers
   ☐ I did not commercial fish in 2021
   ☐ Other (please describe) ______________________________________

30. Please select the option that best describes your fishing behavior in 2021…
   ☐ I targeted more species than when I began commercial fishing
   ☐ I targeted fewer species than when I began commercial fishing
   ☐ I targeted different species than when I began commercial fishing
   ☐ I targeted the same amount and similar species as when I began commercial fishing
   ☐ Not sure
   ☐ 2021 was the first year that I commercial fished

31. Please select the option that best describes your fishing behavior in 2021…
   ☐ I used more gear types than when I began commercial fishing
   ☐ I used fewer gear types than when I began commercial fishing
   ☐ I used different gear types than when I began commercial fishing
   ☐ I used the same amount and similar gear types as when I began commercial fishing
   ☐ Not sure
   ☐ 2021 was the first year that I commercial fished

32. If you have ever stopped targeting a particular species, what drove this change? **Select up to three.**
- ☐ Availability of markets/processors
- ☐ Availability of species
- ☐ Competition with imported/foreign seafood products
- ☐ Costs of licenses or permits
- ☐ Difficulty of obtaining licenses or permits
- ☐ Management/regulation
- ☐ Price received for species
- ☐ I have not stopped targeting any species
- ☐ Other (please describe) ____________________________________

33. Which of the following factors present the greatest challenges to the success of your commercial fishing business? **Select up to three.**
- ☐ Availability of markets/processors
- ☐ Availability of species in areas or seasons that I fish
- ☐ Changes in environment/habitat
- ☐ Competition with imported/foreign seafood products
- ☐ Costs of licenses/permits
- ☐ Difficulty of obtaining licenses/permits
- ☐ Management/regulation
- ☐ Price received for landings
- ☐ Other (please describe) ____________________________________

34. Ten years from now, do you believe that you will continue to commercial fish?
- ☐ Yes, for similar species and using the same gears
- ☐ Yes, for different species and/or using different gears
- ☐ No, I plan to find another occupation
- ☐ No, I will retire
- ☐ Dependent on commercial fishing regulations and market
- ☐ Not sure

Please use the space below to provide any additional comments you may have regarding your participation in Virginia's commercial fishing industry:

SECTION THREE – ABOUT YOU

35. In what year were you born? ___________

36. What is the highest level of education you have completed?
    - □ Did not attend high school
    - □ Some high school, but did not graduate
    - □ High school diploma
    - □ Technical/trade/vocational training
    - □ Some college, but did not graduate
    - □ Associate’s degree
    - □ Bachelor’s degree
    - □ Graduate degree

37. How many people, including yourself, live in your household? __________

38. How many years have you been a commercial waterman?
    □ < 1 year □ 1 – 5 years □ 6-10 years □ 11 – 15 years □ 16 – 20 years □ 20+ years

39. How many generations of commercial watermen are in your family?
    □ I am the first □ 2 □ 3 □ 4 □ 5 or more

40. Do you have any immediate or extended family (e.g., siblings, cousins, aunts/uncles, in-laws) that work, or have previously worked, in the commercial fishing or seafood industries?
    □ Yes □ No

THANK YOU FOR COMPLETING THIS SURVEY!

PLEASE RETURN USING THE PREPAID ENVELOPE OR MAIL TO:

Attn: Shelby White
PO Box 1346
1370 Greate Road
Gloucester Point, VA 23062-13

Table A3.1. Descriptive statistics (mean, standard deviation, median, minimum, and maximum) of covariates in the full model. An asterisk (*) indicates binary variables.

Covariates[14]					
	Mean	***SD***	***Median***	***Min.***	***Max.***
Annual Revenue	$29,206.86	$34,027.95	$10,000.50	$0.00	>$100,000
Ex-Vessel Price	$1.14	$0.64	$1.00	$0.50	$2.00
Gear Count	1.96	1.41	2.00	0	8
Years Fished	17.89	4.87	>21	8	>21
Additional Employment	0.61	0.77	0	0	3
High Variability*	0.54	0.50	1	0	1
Did Not Land Blue Catfish*	0.57	0.49	1	0	1
More than One Generation*	0.60	0.49	1	0	1

[14] Continuous covariates include the annual revenue ("Annual Revenue"), ex-vessel price received for blue catfish ("Ex-Vessel Price"), total number of gears used ("Gear Count"), total number of years an individual held a commercial fishing license ("Years Fished"), and total number of additional incomes in addition to commercial fishing ("Additional Employment"). Discrete covariates include whether the hypothetical price range represented high variability ("High Variability"), whether an individual did not land blue catfish regardless of gear type ("Did Not Land Blue Catfish"), and whether individuals had more than one generation of commercial fishermen in their family ("More than One Generation").

Table A3.2. Two-step hurdle model to evaluate the willingness of an individual to increase fishing days for blue catfish as a function of ex-vessel price and relevant covariates.

Number of Observations: 475 SURVEY.ID: 160
1|SURVEY.ID Variance: 17754 Standard Deviation: 133.2

STEP ONE: BINOMIAL REGRESSION WITH LOGIT LINK

	Estimate	Standard Error	Z Value	p	
Intercept	-0.28	2.82	-0.10	0.92	
Ex-Vessel Price	29.44	5.08	5.08	<0.001	***
High Variability	-0.28	1.50	-0.19	0.85	***

Number of Observations: 346 SURVEY.ID: 128
1|SURVEY.ID Variance: 0.5435 Standard Deviation: 0.7372

STEP TWO: GAMMA REGRESSION WITH LOG LINK

	Estimate	Standard Error	Z Value	p	
Intercept	3.66	0.15	24.48	<2e-16	***
Ex-Vessel Price	0.67	0.06	10.56	<2e-16	***
High Variability	0.04	0.08	0.54	0.59	

Dispersion estimate for Gamma family (σ^2): 0.447

Significance Codes: '*' <0.001 '**' <0.01 '*' <0.05 '.' 0.1 'blank' > 0.05**

CHAPTER IV

WHAT THEY LIVE FOR: DIVERSIFICATION AS AN ADAPTIVE STRATEGY OF VIRGINIA'S SMALL-SCALE COMMERCIAL FISHERMEN

Introduction

Small-scale commercial fishing communities around the world are facing declining stocks (FAO 2020), altered species distributions and habitats (Lucey and Nye 2010; Deutsch et al. 2015; Poloczanska et al. 2016), increased government intervention (Bavinck et al. 2018) and competition with aquaculture and imported products (Anderson 1985; Garrity-Blake and Nash 2007). These challenges are likely to persist and may become exacerbated as these fishing communities face unprecedented adversities with ongoing environmental and social changes. Climatic driven shifts in species abundances and distributions may impact markets and individual decision-making as species either emerge or disappear, while increases in coastal user groups may limit the ability of small-scale fisheries to maintain a presence in the contested blue economy (Voyer and van Leeuwen 2019; NOAA 2021).

Small-scale commercial fishing communities often have high dependence on marine resources and strong cultural ties to the fishing livelihood (Teh and Sumaila 2013; Basurto et al. 2017; TBTI 2018). The extent of economic and social dependence, in conjunction with the inherent volatility of commercial fishing, tends to make small-scale fishermen and fishing communities more vulnerable and less able to adapt to sudden changes (Marshall et al. 2007). It is therefore important to understand how economic, ecological, and socio-cultural changes impact individuals and communities reliant on small-scale commercial fishing. Thus far, small-scale fisheries have been able to persevere despite escalating challenges, suggesting that small-scale fishermen and fishing communities are resilient and capable of adapting at some level. It is uncertain, however, whether adaptation will continue to evolve or if it will become limited as stressors become more prevalent or severe. An enhanced understanding of how individual decision-making and socio-cultural aspects have served to promote adaptability and resiliency in small-scale fishing communities is critical effective, long-term management and the persistence of small-scale commercial fishing as a source of livelihood and food security. Furthermore, understanding the extent to which these communities can continue to adapt can aid managers in developing strategies that lessen the impacts of adverse events on fishermen and fishing communities, particularly when managers are focused on a holistic, ecosystem-based management approach. This research aims to build on this understanding by assessing the impacts of varying economic, ecological and social changes on individual decision-making and resilience in a small-scale commercial fishing industry in the United States.

Shifts in social and cultural demographics have already altered the landscape of small-scale commercial fishing in the United States. An increase in the average age of commercial fishermen, referred to as a "graying of the fleet," has been noted in several US small-scale fisheries (Garrity-Blake and Nash 2007; Donkersloot and Carothers 2016; Cramer et al. 2018; Johnson and Mazur 2018; Cutler et al. 2022). Aligned with the socio-cultural norms of small-scale commercial fishing, fishermen often continue working the water well into old age. However, when coupled with a lack of new entrants, this skewed age structure becomes problematic (Coleman et al. 2019). When older fishermen cannot transfer knowledge or social memory to younger generations, the adaptive capacity of less experienced fishermen to respond to adverse events becomes limited (Adger 2006; Folke 2006; Smit and Wandel 2006). Furthermore, the longevity of the small-scale commercial fishing industry is jeopardized without continual workforce turnover, potentially impacting domestic seafood production, individual well-being, and socio-cultural norms within fishing communities. If fishing effort declines in conjunction with the commercial fishing population, it is probable that the supply of domestic, wild caught seafood will also decrease and become supplemented with imported products that have less value in local communities (Andreatta and Parlier 2010; Nash and Andreatta 2011; Nicolosi et al. 2021). Likewise, declines in the commercial fishing population can negatively impact the resilience of fishing communities where fishing is integral to sense of place and identities of individuals (Khakzad and Griffith 2016; Lyons et al. 2016).

The need to understand factors contributing to the "graying of the fleet" phenomenon has gained traction in the past decade with some evidence suggesting that management regimes (e.g., limited entry fisheries, individual transferable quotas or ITQs) have driven the consolidation of fishing fleets and increased the financial costs associated with entry (Schreiber 2001; Chambers and Carothers 2017; Cramer et al. 2018). Policy shifts towards privatization (e.g. catch shares, ITQs) are an increasingly common strategy to try to meet biological targets (Melnychuk et al. 2012), prevent fisheries collapse (Costello et al. 2008), and address social objectives with increased fishing efficiency (Kroetz et al. 2015). Nonetheless, privatization has produced inequities among the fishing industry, particularly handicapping small-scale fishermen and new entrants lacking prohibitive financial requirements for entry (Carothers 2011; Witter and Stoll 2017; Beaudreau et al. 2019). Likewise, restrictive licensing systems intended to enhance socio-ecological resilience, such as those implemented in Maine, have hindered the ability of fishermen to participate in multiple fisheries as a risk management strategy (Stoll et al. 2016; Silver and Stoll 2019). External factors also influence an individual's decision to pursue a livelihood in commercial fishing. Generational ties and exposure to the fishing industry at a young age are relevant predictors of future participation, however, these may be countered by enhanced educational and employment opportunities that result in outmigration of younger individuals from rural areas where small-scale fisheries commonly exist (Boucquey et al. 2012; Power et al. 2014; Cramer et al. 2018; Coleman et al. 2019). The lack of health insurance and other benefits (e.g., retirement plans) may also deter participation in small-scale fisheries. Despite commercial fishing being recognized as one of the most dangerous occupations (NIOSH 2021), Cutler et al. (2022) found that the percentage of New England and Mid-Atlantic fishermen without health insurance is much greater than the national rate. It is probable that some individuals forego the opportunity to fish and seek employment that provides benefits such as health insurance or retirement plans, while others may use the benefits associated with additional employment to supplement commercial fishing. Although not well-documented, there is also anecdotal evidence that 'non-traditional' fishermen, or those without generational involvement, might retire (and retain benefits) and enter the commercial fishing industry out of personal interest (Pollnac and Poggie 1988; Kirkley 1997; Rhodes et al. 2001). While these entrants stimulate new participation in the industry, they may also exacerbate an aging commercial fishing population and alter socio-cultural norms.

The volatile nature of commercial fishing itself presents a challenge for fishermen entering the industry and may motivate existing fishermen to exit. Fishermen and fishing communities reliant on small-scale commercial fishing as a livelihood are particularly vulnerable to adversities due to their level of resource dependence and socio-cultural attachment to fishing (Adger 2000; Flint and Luloff 2005; Henry and Johnson 2015). Small-scale fishermen, including those in the United States, may adopt diversification strategies to reduce vulnerability and stabilize revenues despite unfavorable conditions (Allison and Ellis 2001; Kasperski and Holland 2013; Sethi et al. 2014; Cline et al. 2017). Fishermen can diversify between (and within) fisheries or seek alternative employment (e.g. marine or non-marine related) to supplement income when fishing is less profitable (Allison and Ellis 2001; López-Martínez et al. 2021). Diversification into other sectors, where either the fisherman is diversified or members of the household hold additional employment, can influence a fisherman's willingness to exit the industry, although there is contrasting evidence as to how this drives individual fishing behavior. Slater et al. (2013) finds that fishermen with only one household occupation are more likely to exit the fishery if catch is reduced, while Cinner et al. (2008) and Daw et al. (2012) suggest that fishermen of households with a greater number of occupations are more likely to exit. This difference is likely reflective of two extremes, although varying localities and socio-economic factors could drive these deviances and should be further explored.

Despite the potential benefits, there are inherent tradeoffs associated with diversification decisions. Fishermen who diversify into non-fishing occupations (in addition to commercial fishing) may have limited ability to switch between fisheries (in terms of species, seasons, or locations) due to lack of time and capital (e.g., social and financial). This may be especially true for fisheries that require certain levels of participation to maintain harvest rights (e.g., quota-based or limited entry fisheries). Diversification within the commercial fishing industry itself can be limited in response to management (e.g., limited entry fisheries, individual transferable quotas, seasonal closures), capital investment, location, knowledge, or individual preferences (Sethi et al. 2014; Anderson et al. 2017). Furthermore, Anderson et al. (2017) found that extreme changes in increasing or decreasing diversification can promote risk and revenue variability. Less acknowledged is the potential influence of aquaculture and consumer preferences on constraining diversification, as demand plays a role in determining market price and movement within the supply chain (Tveterås et al. 2012; Witkin et al. McClenachan 2015). In addition to personal preference and socio-cultural drivers, individual decision-making related to what, where and how fishing occurs is likely tied to intricacies within the market that influence profitability (e.g., ex-vessel values, ability to transport).

Fishermen may opt to switch between levels of diversification as a means of capitalizing on favorable conditions such as high market values or species abundance. Reducing diversification (i.e., specialization) is found to be a viable strategy to amass income, although it may be at the risk of more variable returns and increased vulnerability to sudden shocks in the fishery (Finkbeiner 2015; Beaudreau et al. 2019; Kluger et al. 2019). Furthermore, specialization can be a desirable strategy when individuals have additional sources of income (aside from commercial fishing), high investment in a particular fishery, or other obligations that interfere with fishing seasons (e.g., personal health, family responsibilities) (Kasperski and Holland 2013; Finkbeiner 2015; Abbott et al. 2022). Fishermen with the ability to alternate between diversification strategies, however, are considered to be more resilient and have enhanced adaptive capacity to respond to adverse events (Finkbeiner 2015; Beaudreau et al. 2019; Abbott et al. 2022).

This research utilizes an ethnographic approach to assess the role of individual decision-making and diversification as a livelihood strategy in Virginia's small-scale commercial fisheries. It is hypothesized that fishermen are heterogenous in their response to economic, environmental, and social changes (Camerer 2000) due to differences in socio-demographic characteristics, job satisfaction, and levels of participation and diversification in commercial fishing. These diverging attributes can influence an individual's adaptive capacity and how one reacts to adverse events. It is important for fishery managers to understand how management and policy decisions influence livelihood strategies (e.g., diversification), resource dependence, and vulnerability as these constraints threaten the long-term sustainability and resiliency of commercial fishermen, the commercial fishing industry, and coastal communities dependent on commercial fishing.

Methods

Study Site

Virginia's small-scale commercial fisheries include all commercial fisheries operating in state waters with the exception of the Atlantic menhaden (*Brevoortia tyrannus*) reduction fishery for fish meal and fish oil. Situated in the Mid-Atlantic, Virginia encompasses a large portion of the Chesapeake Bay and its tributaries, and consequently has deeply embedded economic and cultural ties to the commercial fishing industry. These ties are due in part to the high biological productivity of the Bay and its historical ability to support a number of nearshore and inshore coastal fisheries. Virginia's small-scale commercial fisheries have continued to contribute to the livelihoods of thousands of individuals (both directly and through post-harvest services) and to the economies of fishing communities around the state (NMFS 2021). The state's small-scale commercial fisheries are comprised of a few thousand watermen utilizing a variety of gears and methods to target nearshore and inshore species, including blue crab (*Callinectes sapidus*), eastern oyster (*Crassostrea virginica*), striped bass (*Morone saxatilis*), Atlantic croaker (*Micropogonias undulates*), and other finfish species. Virginia's small-scale commercial fisheries retain characteristics similar to those throughout the world in that these fisheries provide employment, utilize traditional gears (e.g., nets, pots, tongs) and have ties to local communities dependent on commercial fishing (Pomeroy and Andrew 2011; TBTI 2018). Likewise, these fisheries are subject to similar pressures of other small-scale fisheries, including marginalization and reduced political power, limited access to financial capital and ability to retain economic benefits, and ongoing environmental changes affecting stock distributions.

Virginia's small-scale fisheries are managed through the Virginia Marine Resources Commission (VMRC), which also oversees licensing and permitting for aquaculture within the state, chartering, and seafood sales and processing (e.g., dealers, shucking houses, crab shedding). In the past two decades, the number of commercial fishing licenses sold in Virginia has declined more than 15 percent with historic lows of less than 2,500 licensed fishermen in recent years (White and Scheld 2021). This decline is similar to nationwide trends in commercial fishing participation (FAO 2018) and can be attributed to a number of complex and interconnected factors, including the loss of working waterfronts (Khakzad and Griffith 2016), shifts in species abundances and distributions (Poloczanska et al. 2016), increased regulations (Pradhan and Leung 2004), and privatization of fishing rights (Chambers and Carothers 2017; Cramer et al. 2018). In addition, Virginia is facing an aging fishing population with almost 20% of licensed fishermen in 2018 being ≥ 65 years old and a significant portion of fishermen nearing retirement age. Nonetheless, declines in the small-scale fishing industry are concerning for managers as they can indicate a weakening of the industry's infrastructure and result in various economic and socio-cultural consequences (Berkes et al. 2001; Chuenpagdee 2011; Crosson 2015). An ethnographic approach to evaluate changes in participation and diversification of Virginia's small-scale fishermen will contextualize potential reasons for a declining commercial fishing population.

Interviews

This research utilizes an ethnographic approach to evaluate the role of diversification as an adaptive livelihood strategy in Virginia's small-scale commercial fisheries by evaluating socio-demographics, current and past fishery participation, family involvement, job satisfaction, diversification, and future perspectives on the industry. Semi-structured interviews were conducted to better understand changes in participation and diversification as an adaptive strategy in Virginia's small-scale commercial fisheries (Longhurst 2003; Bernard 2017). Twenty-eight interviews were held via phone (n=20), video conferencing (n=4; Zoom Video Communications Inc., 2021), and in person (n=4) between 2020 and 2022. In-person interview locations were chosen by participants and held at the Virginia Institute of Marine Science (VIMS), on board a fishing vessel, and at a fish house. Interviews began with key informants identified through the Virginia Marine Resource Commission (VMRC) and VIMS researchers. Interviews continued with snowball sampling to include participation from fishermen of varying demographic, social, and economic backgrounds (Goodman 1961). Interviewees were predominantly male but varied widely in individual participation and diversification characteristics. Unlike traditional ethnographic approaches, a majority of the interviews were conducted via phone or video conferencing due to the COVID-19 pandemic and thus, shorter interview times were expected compared to in person approaches (Irvine 2011). Phone interviews, however, hold the same merit and are noted as a viable alternative in ethnographic research (Holt 2010; Cachia 2011). Three main topics were discussed in each interview: 1) socio-cultural ties to the commercial fishing industry; 2) changes in participation and resource dependence; and 3) willingness to diversify within and outside of the commercial fishing industry. Topics discussed in the interviews included individual and family involvement in commercial fishing, previous and current participation in various fisheries, diversification into other sectors (marine-related or otherwise), job satisfaction, likelihood of recommending commercial fishing to others, perceived values, and impacts of adverse events on Virginia's commercial fishing industry (see Supplementary Material for interview guide).

All interviewees were verified as holding a Virginia state issued license for commercial fishing. Interviews were recorded with permission and transcribed verbatim when possible, using QSR International's NVivo Transcription services. Equipment malfunctions in two interviews required the use of detailed notes to capture the main concepts. Interviews were concluded when no new persons were recommended and data saturation (i.e., similar responses) within the interviews occurred. Interview lengths varied between approximately 30 minutes and 2 hours. Protocols approved by the College of William and Mary's Protection of Human Subjects Committee were followed for each interview (Protocol PHSC-2021-09-15-15204-amscheld). Interview coding was performed in QSR International NVivo using a modified grounded theory approach (Glaser and Strauss 1967). Broad themes related to socio-economics, participation, and diversification were identified *a priori,* and then subsequent iterations of coding were conducted to detect emerging themes or new concepts.

Results and Discussion

The structure of Virginia's small-scale commercial fishing industry has shifted within the past few decades in response to changes in management, species abundance, and participation. These shifts have driven fishermen to implement adaptation strategies that enable continued participation in the commercial fishing industry. This research reveals the interconnection between these changes and their respective impact on social identities and cultural norms, job satisfaction, resource dependence, and the future of the commercial fishing industry in Virginia.

Social Identity

It is important to understand the socio-cultural aspects of small-scale commercial fishing in Virginia to thoroughly gauge how changes within the industry impact fishermen and fishing communities.

Interviewed fishermen often described their involvement in commercial fishing as a way of life rather than an occupation, a seemingly consistent theme within small-scale fishing communities (Miller and van Maanen 1982; Power et al. 2014; Morgan 2016). The sentiment of destined participation was particularly apparent from multi-generational fishermen who noted the decision to pursue a livelihood in commercial fishing as one rooted in family tradition and kinship. A younger fisherman (late 20's) explained the draw to commercial fishing as a natural occurrence that stemmed from being introduced to the industry as a child.

> "I'm just…I don't know, I just grew up on a boat."

Another fisherman in his late 60's who has fished since he was a child acknowledged commercial fishing as an intrinsic part of his identity.

> "Well, I guess my family's been doing it for hundreds of years, so hereditary I suppose."

The majority of individuals (n=22) identified themselves as multi-generational, often describing fishing lineages that exceeded memory. Several generational fishermen also noted that extended family members, such as uncles, cousins, maternal and paternal grandparents, and in-laws, were currently fishing or had previously been involved in the industry. Familial involvement in small-scale commercial fishing is not unusual and is an influential factor in the decision to pursue commercial fishing as a livelihood, as well as an indicator of job satisfaction (Miller and van Maanen 1982; Marshall et al. 2007; Pascoe et al. 2015). For first-generation fishermen, the fishing communities in which they resided seemed to influence their decision to pursue commercial fishing. For example, two family members became commercial fishermen despite having no familial involvement in the industry and instead described the fishing activity in the community.

> "And then the fishermen were at the country store beside my house talking fishing. And down in Browns Bay, the haul seiners, you know would come in with 100, 200 boxes of

> fish. They were picking crabs. It was just an industry down there and I was like, right in the middle of it. I loved it."

> "All the neighbors were watermen. So you know if you wanted to do some work, 'yeah, we got work.'"

Another first-generation fisherman described the contrasting effect of community influence and stated that commercial fishing was not encouraged as a viable option for a livelihood. This is particularly interesting as this individual was raised in a coastal community with extensive ties to commercial fishing, although not in Virginia.

> "Honestly, it wasn't what the school or I would say the curriculum pointed you towards at all when I was in high school. You know, it was college, this, that, and the other. They had actually just done away with the commercial fishing trade class not too many years prior to me being in high school, which is unfortunate. So I actually got a lot of negative feedback, and it probably hindered me a lot. Just because everybody looked at it as a hustle, you know, like it's summertime work. You know, you'll grow out of it kind of thing."

It is possible that a community's connection to commercial fishing provides a broader understanding of how laborious and difficult the work can be. Therefore the trade may not be encouraged as a viable option to younger individuals (Power et al. 2014). Furthermore, societal shifts in what constitutes a successful occupation has trended towards higher education and alternative sources of work outside of rural areas (Bjarnason and Thorlindsson 2006; Bernsen et al. 2022). The outmigration from rural fishing communities, as well as shifts in attitudes towards commercial fishing, are potential factors contributing to the "graying of the fleet" as younger individuals deviate from the fishing way of life (Boucquey et al. 2012; Power et al. 2014; Cramer et al. 2018; Coleman et al. 2019).

Regardless of why individuals chose to pursue a livelihood in commercial fishing, the interconnectedness of individual identity and occupation became an emergent theme throughout interviews. The value of commercial fishing in forming social identity has been referenced in various small-scale commercial fisheries, although its impact in Virginia is not well-understood (Stets and Burke 2000; Marshall et al. 2007; Urquhart et al. 2013). Social identities evolve through the development of informal and formal networks that are connected through similar behaviors, values, and norms, and consequently shape how an individual views their place within a group (Miller and van Maanen 1982; Jenkins 2014). Social identity is tied to adaptive capacity and can serve to enhance resiliency and reduce vulnerability of fishermen and fishing communities, especially as social identity can influence motivations and willingness to seek adaptive solutions to perturbations (Frank et al. 2011).

Interviewed fishermen noted inherent pride in being able to identify oneself as a colloquially termed "waterman" and some fishermen referenced their niche position as top harvesters in either past or current fisheries. Owning a commercial fishing license and deciding to pursue commercial fishing as a livelihood is not what makes a fisherman. Instead, the possession of intrinsic characteristics and skills that are woven into the social identities of fishermen. Various iterations of the phrase that fishermen are "a different breed" were noted in interviews with the idea that some individuals are simply not "cut out" for the lifestyle.

> "There's just simply not many people willing to do what it takes. And so there's, you know, a lot of pride in saying, hey, I'm a commercial fisherman and I'm a successful commercial fisherman because I am willing to do what it takes to make it and to adapt with the rules and overcome everything. And it's because I choose to, not because I have to."

Fishermen acknowledge that specific mindsets, individual characteristics, and passion are conducive to success within the commercial fishing industry. A strong work ethic was considered a necessity in order to handle the labor-intensive and demanding lifestyle of commercial fishing. This mirrors findings from

Maine's commercial fishing community where newcomers and established fishermen both cited work ethic and experience as critical skills (Gurney et al. 2022). López-Martínez and Schriewer (2021) also find similar perspectives on small-scale fishing in southeast Spain, where fishermen acknowledged that self-motivation is critical to success in the industry and that the delineation between work and leisure time is limited. Fishermen must have the drive to work and continue to work until the job is completed, which can be well after an individual is done fishing (e.g., boat and gear maintenance). A fisherman in his late 50's noted the need to focus on fishing, even on days when supplementing commercial fishing with non-marine related employment.

> "So I work on net a lot…I'd go home in the evening and work on net. So I'm always on commercial fishing gear. I'm working on the boat, net, pots, you know what I mean? Even when I'm doing other work, I try to spend so many, a few hours a day, working on fishing gear."

Several interviewees acknowledged that extended work hours are unavoidable in commercial fishing. However, this did not seem to lessen the appeal of the trade. A multi-generational fisherman who exited the industry, worked in construction, and then resumed fishing full-time spoke of the difference between occupations, noting that fishing required more hours than if one were "working for someone else." In addition to work ethic and self-motivation, some fishermen added that mental stability and the need to be adaptable were essential to a livelihood in commercial fishing. These skills were referenced in context to the volatility of the industry and the need to be able to adapt to changes in species, market, and regulation on varying temporal and spatial scales.

Job Satisfaction

Job satisfaction in the commercial fishing industry has been used as an indicator of exit decisions, participation behavior, wellbeing, and willingness to recommend commercial fishing as a livelihood

(Pollnac and Poggie 1988; Pascoe et al. 2015; Holland et al. 2020). These interviews explored the characteristics of commercial fishing that contribute to job satisfaction and the decision to stay or exit the industry and the willingness of fishermen to recommend the livelihood to the next generation.

Values

To understand the factors that contribute to job satisfaction, fishermen were asked to elaborate on what they valued about commercial fishing despite the challenges. Almost all fishermen cited similar attributes, including the opportunity to be your own boss (i.e., autonomy), working closely with nature, variability ("you never know what you're going to catch"), and the challenge associated with commercial fishing. Based on the sentiment expressed in interviews, the relationship between job satisfaction and social identity is intricately connected. Fishermen who noted the challenge of commercial fishing as a value also proclaimed to enjoy work, as well as the success that results from personal motivation and effort. The continual pursuit of knowledge is a critical component of commercial fishing that requires self-motivation and determination to learn the intricacies of different species, gears, and areas. One fisherman noted that he studies the biology and ecology of the species he is targeting, and this practice has made him more successful throughout his career. Other fishermen referenced that knowledge is a gradual process and it can take years before understanding a new fishing location or species. Therefore, it can be deduced that individuals lacking self-motivation or willingness to learn are less successful and less "cut out" for the industry (López-Martínez and Schriewer 2021). Other aspects of social identity may also serve as an indicator of job satisfaction, including whether an individual is a generational fisherman. Pollnac and Poggie (1988) found that job satisfaction of New Bedford fishermen was positively correlated to whether an individual had generational ties to commercial fishing, although this varied when different measurements of satisfaction were considered. Furthermore, the value of freedom was also noted in Pollnac and Poggie (1988) where fishermen were less satisfied when working on another fisherman's boat as the freedom to make decisions or utilize personal skills were restricted. In these interviews, physical health challenges were identified as barriers to job satisfaction with fishermen often reducing participation as a result of injury, illness, or age. Reduced participation was primarily mentioned in terms of fishing seasons (avoiding extreme temperatures) or labor-intensive gear use (e.g., haul seine). Based on the fact that physical ability is necessary for commercial fishing, it was presumed in this research that the lack of benefits, including health insurance and retirement, would negatively impact job satisfaction. Almost all fishermen had health insurance whether through personal plans, plans of their spouse or government programs such as Medicare or Medicaid, suggesting that the lack of health insurance may not be a prominent deterrent to entering the industry. One fisherman did note, however, that if he were to lose his spouse's health insurance he would give "serious consideration" to exiting the industry due to the high cost of shifting to private insurance.

Although values tend to be consistent among fishermen, there is evidence that overall job satisfaction in Virginia's small-scale commercial fisheries has declined. One fisherman stated that he no longer desired the variability that comes with commercial fishing, despite wanting to remain in the industry.

> "So, I've done…I've had 40 years of doing plenty of it. I still want to do it, I'm just saying. Yeah, at this point, that all or nothing thing, I just...there's a great opportunity here so you need to stay up 24 hours a day for the next month and drive yourself into the ground because it's going to disappear...that, I'm not fond of anymore."

Another fisherman noted that regulation and increasing management had "sort of taken a lot of the joy out of it" despite the opportunities that commercial fishing has afforded him.

> "[But] I can't imagine working another job where I would have accumulated what I've accumulated. So, you know, they always say if you enjoy what you're doing, you never work a day and that's how I was before the last two or four years."

Aligned with the challenges of increased regulation, three interviewees offered a unique outlook on how commercial fishermen were perceived in society, including within the community and by fishery managers.

It is plausible that this negative perception will persist with increased management and can influence overall job satisfaction and social identity of commercial fishermen in Virginia.

> "It's [regulation] made it very difficult to get into [the commercial fishing industry]. I mean, you almost made it feel like you're I don't know, like a bad person for doing it a lot of times."

> "No, I mean, long as you don't mind being a convict [then you can be a commercial fisherman]. That's your biggest thing like you're always going to be…you're always going to be a convict in their [management/enforcement] eyes."

The third fishermen alluded that increased regulation was a crafted method of driving individuals out of the industry as it makes it harder for individuals to make a living. This fisherman mentioned that it's not only regulations on targeted species, but also marine mammals, endangered species, and "everything you could think of."

> "I feel like God forbid none of the watermen quit the industry, the industry [in reference to management] don't want the watermen."

These perspectives mirror concerns of marginalization in small-scale commercial fishing communities where fishermen have reduced economic, social, and political power (FAO 2005) and the societal support for the fishing industry has weakened in local communities. Fishermen that feel marginalized in society are less likely to participate in management decisions, thus producing more inequities and further displacement (May 2013). Fishermen may also be less willing to collaborate with managers and provide traditional or ecological knowledge if they perceive themselves to be undervalued or marginalized (Johnson 2008).

Managers should be cognizant of the effects of marginalization on the socio-ecological relationship between fishermen and marine resources as it can result in undesirable behaviors such as non-compliance or enhanced fishing effort (Doyon 2015). An enhanced understanding of how public perceptions impact an individual's job satisfaction and well-being is useful for managers to prevent unintended societal consequences and preserve the socio-cultural norms of fishermen and fishing communities, particularly with the expansion of coastal user groups (i.e., recreational fishing, conservation organizations).

Willingness to Recommend Commercial Fishing to Next Generation Fishermen

When prompted to discuss whether individuals would recommend commercial fishing to others, most fishermen were often cautious, if not strongly opposed to doing so. They noted several reasons, including differences in motivation and personalities of upcoming generations (i.e., differing social identities and work ethic), regulations, cost, species declines, and a general lack of opportunity. Older fishermen (≥65 years old) who stated that they would not recommend commercial fishing to younger individuals were asked if they would have chosen a different career path, given the opportunity. Interestingly, most fishermen responded that they would not have been interested in changing careers, citing the enjoyment and wealth derived from commercial fishing or the general lack of interest in other choices. These findings align with Cutler et al. (2022) where most individuals in the commercial fishing industry, if given the option, would still choose to pursue the livelihood in lieu of other opportunities. Differences in the decision on whether to pursue the same career path are likely the result of various intra-industry dynamics and socio-cultural factors, including the number of years an individual has been involved in the industry (Pollnac and Poggie 1988). These decisions, however, did not seem to influence whether an individual would be willing to recommend commercial fishing, as most fishermen remained unwilling to recommend the trade, despite finding the work rewarding.

It is not a unique perspective that new entry is vital for the sustainability of the commercial fishing industry and is strongly connected to social identity, place attachment, and well-being. The lack of encouragement from established fishermen, however, can negatively impact the perceptions of younger individuals who internalize these recommendations against fishing and regard it as too risky and unworthy of consideration (Power et al. 2008). While most interviewees noted the lack of new entrants, there were unique differences between younger and older fishermen (≥50 years) and their willingness to recommend commercial fishing to the next generation. With few exceptions, older fishermen were less likely to recommend commercial fishing compared to younger fishermen and often cited regulatory changes as justification. These differences could be the result of diverging memories and perspectives as older, established fishermen have lived through more major changes (in terms of regulation and species composition) than younger fishermen. A number of older individuals stated that they began commercial fishing for species with minimal to no regulation at the time, with one individual noting that the number of regulations on one species now is equivalent to the total number of all regulations when he began fishing. A young fisherman (late 20's) provided a couple of corroborating comments on the potential impact of differing baselines when asked his perspective of how the industry had changed since he was introduced to commercial fishing as a child.

> "Yeah, see I'm pretty unjaded when it comes to regulations and the environment. I think that's because I haven't seen the days gone by where there were no limits, where you could go catch all you wanted. I never saw those days. So I don't miss those days like a lot of older fishermen do."

> "Fishing has been decent in the past 10 years, so I haven't seen the bad side. So I kind of have a fresh and new perspective compared to somebody who almost lost their house, you know, because the oyster population went away in the early 90s."

This sentiment was not expressed by all younger fishermen, as others cited regulatory changes that had, or were in the process of, impacting multiple fisheries, including eastern oyster, blue crab, and whelk[15]. The effect of age and experience on industry perceptions may be dampened in multi-generational fishing families as younger fishermen are likely more aware of what the industry used to be as a result of generational knowledge transfer and social memory (Folke 2006). However, this may not always be the case as the aforementioned quote came from a third-generation fishermen, though this individual was the only one fully dependent on commercial fishing. Discrepancies among fishermen on the willingness to recommend commercial fishing as a livelihood indicate that individual participation in various fisheries (in terms of gear use and species targeted) can influence perspectives, whether positively or negatively. For example, fishermen affected by the crab dredge moratorium in Virginia in 2008 are likely to have different views on management than a fisherman who has never experienced a significant adverse event, such as a fishery closure.[16]

It is problematic that established fishermen are hesitant to recommend commercial fishing as a livelihood, especially as the "graying of the fleet" phenomenon becomes a growing concern in the US (Donkersloot and Carothers 2016; Cramer et al. 2018; Johnson and Mazur 2018). In Virginia, the number of senior commercial fishing licenses sold (≥65 years) has increased within the past two decades, while the number of non-senior licenses has declined (White and Scheld 2021). More than half of the licensed fishermen are nearing retirement age (although this is an elusive concept in commercial fishing) and less than 9% of individuals are younger than 30 years old (P. Geer, personal communication). These declines are concerning as fishermen and fishing communities derive economic and socio-cultural value from commercial fishing and may indicate changes in resource dependence and job satisfaction (Pollnac and

[15] Whelk (*Busycotypus canaliculatus* and *Busycon carica*) is often misidentified and colloquially referred to as "conch" in Virginia (A. Galván, VMRC, e-mail to author, May 11, 2022). Instances where fishermen noted participated in the Virginia conch fishery were translated to whelk (A. Galván, VMRC, e-mail to author, May 11, 2022).

[16] It is imperative to mention that just because older fishermen often cited regulation as reasoning for not recommending commercial fishing as a livelihood, it does not mean that regulation is viewed as superfluous. There were numerous instances where both older and younger fishermen referenced the need for various regulations.

Poggie 1988; McGoodwin 2001; Poe et al. 2014). Furthermore, the lack of new entrants limits the ability of older fishermen to transfer "tried and true" knowledge to younger individuals, especially in terms of how to navigate adverse events (Folke 2006; Cutler et al. 2008; Johnson and Mazur 2018). Thus, the transfer of knowledge and social processes are critical to enhancing the resilience and adaptive capacity of fishermen and fishing communities (Folke 2006).

To corroborate the significance of knowledge transfer, multiple fishermen referenced the value of learning through 'trial and error' or from others within the fishing community. This leveraging of social capital to build knowledge was obtained through conversation, working on the boat of other fishermen, participation on various state and federal advisory committees, and/or leadership roles in fishery associations. Participation on advisory committees and within fishery associations tended to be associated with older fishermen, although younger individuals are becoming increasingly involved as issues arise (e.g., offshore wind farm development, tightening regulations). The leadership of older fishermen may be related to the logistics of serving on state committees where an individual must resign before another can take their place. One fisherman noted that he was waiting for a family member to "give up" his position before joining, indicating the potential for generational influence on the development of social capital and knowledge transfer. This is also indicative of how strengthening socio-political power in small-scale fisheries might serve as a means of reducing marginalization.

Impacts to Resource Dependence

Barriers to Entry

Interviewed fishermen were asked to elaborate on what changes were needed to make them feel confident in recommending the commercial fishing livelihood to younger individuals. Responses provided further insight on the potential barriers to entry, as well as challenges to success in the commercial fishing industry for both newcomers and established fishermen. Similar to Johnson and Mazur (2018), many responses were tied to increased regulation, financial barriers, and difficulty in obtaining licenses and permits. One older fisherman who acknowledged the need for regulation discussed the lack of boundaries between science, management, and politics.

> "I can't imagine what it is [that needs to change] you know, cause fish, fisheries are very seldom controlled by science anymore. It's almost all about politics. And that's the problem, but science I think...most watermen, and I'll go back to halfway intelligent, believe that you need regulations and stuff. But when regulations are caused by politicians and not scientists, they really cause more problems."

Another fisherman (>70 years old) expressed similar feelings towards management decisions and how increasing regulation and fishery closures have dwindled the opportunities available for younger individuals.

> "We used to catch trout and stuff down there and then they closed the trout, that's gone. Can't do that anymore. You can only have a handful of rock fish [striped bass], that's gone. You can only do this and that and the other, and that's gone. We use the crab dredge in the wintertime, they closed that up, that's gone. You know, it's just all the opportunities that we used to have are gone. Whether we caused the demise of some of them or, some of them were just arbitrarily closed because of…I call it political science. They say it's science, but it's politics."

There is a common theme of distrust for science and management within Virginia's small-scale commercial fishing industry that becomes evident through mentioning of regulation. Distrust of scientific advice and management is not unique to Virginia and is considered an unintended consequence of management that can exacerbate socio-cultural tensions, asset losses, and marginalization (Ames 2001; Fulton et al. 2011; Bennett and Deaden 2014; Stoll et al. 2016; Chambers and Carothers 2017). The mentioning of regulation in a negative context was consistent in all interviews with fishermen noting that regulation had either altered their fishing behavior or made it difficult to participate in existing fisheries. It is apparent that the negative connotations of regulation stem from the lack of perceived positive impacts to managed fisheries (e.g., increases in species abundance) and the belief that a number of regulations, especially allocation decisions, are politically driven and not based on sound science. Nonetheless, commercial fishermen are forced to bear the economic and social burdens of regulation, whether driven by politics or otherwise.

The increasing costs associated with fishing were identified as a constraint to new entrants, but also individuals established in the industry. Costs were mentioned in two contexts relative to Virginia, including operational costs (e.g., fuel, bait, gear) and entry costs (e.g., licensing, capital investment). An established fisherman noted the continual rising cost of bait in the blue crab fishery, although an increase in costs were identified in other fisheries as well.

> “And the price of what we buy now, it's outrageous. One crab pot now, if you bought everything brand new, is over $50 apiece and it's ridiculous. It really is, what we have to pay for things. And the price of crabs has increased, but not in comparison with the price of what we have to buy to crab with. And this spring, I was paying a hundred dollars a basket for bait. Used to be 20 something dollars for the razor clams. And it's just things like that. It's really changed tremendously.”

More commonly mentioned were the financial burdens associated with entry to the commercial fishing industry and specific fisheries. In Virginia, several fisheries are managed as limited entry fisheries, including, but not limited to, black drum, blue crab, spiny dogfish, and striped bass (the latter also being managed with individual transferable quotas). Furthermore, entry into the state’s commercial fishing industry is also regulated as limited entry and licenses can only be transferred from one individual to another individual or new entrants can enter a two-year delay process before the license can be utilized. Individuals seeking to pursue commercial fishing as a livelihood are required to purchase an overarching license (i.e., commercial fishing registration) and subsequently, purchase species or gear-specific licenses or permits that allow for wild harvest. In addition to the costs, there is another level of complexity that stems from entering limited entry fisheries. Individuals are also limited to when these licenses and permits become available as one cannot obtain a license or permit unless another relinquishes theirs. The prices of licenses and permits can vary between individual sellers and can be considered a financial burden to new entrants with prices of thousands or tens of thousands of dollars. A multi-generational fisherman related the costs of licenses and permits to resource privatization with predicted costs higher than the capital investment required for most occupations.

> "I mean, you know, if you go buy a boat and a lot of pots, and nowadays, the crabbing and the oystering is limited entry. You have to have the license and if you don't have it, you have to buy it. And crab licenses are going for 10,000 [USD] depending on what size you get. Oyster licenses are going for eight or ten thousand [USD]. You know, so you're talking about, probably talking thirty, forty, fifty thousand dollars [USD] just to get started."

In small-scale commercial fisheries where access to financial capital may be limited, younger entrants and established fishermen attempting to enter new fisheries are likely constrained by this aspect (Chambers and Carothers 2016). Familial involvement in the commercial fishing industry can serve to offset this financial burden and alleviate constraints on entry. One fisherman whose grandfather was a commercial fisherman had a number of licenses and permits and thus, the transfer of permits between family members alleviated the financial burden and ability to obtain fishing access.

> "Well, there's a couple [fisheries] that we might not be able to get into. I mean, see I'm different because I got lucky that my grandfather had already had the crab pot license, peeler pot license, the Class A gill net license. He had the rock tags [striped bass quota]. So I mean, he had everything compared to somebody else just coming into the game. They

> wouldn't even be able to go oystering on a public bottom unless they had $12,000 to $14,000 dollars [USD] to buy an oyster card from the state of Virginia because of the way they got the laws and stuff."

First-generation watermen considered the cost and difficulty of obtaining a license or permit as a barrier to entry, however, these individuals acknowledged themselves as evidence that it can be done despite the challenges. This is not surprising as these individuals were not able to transfer licenses and permits between family members and had to develop financial and social capital to obtain fishing rights. Thus, these first-generation fishermen have succeeded in entering the industry and might expect others to be able to do the same with similar efforts.

Multiple studies in small-scale fisheries around the world have addressed the potential impact of privatization of fisheries on new entrants and established fishermen (e.g., Carothers 2011; Witter and Stoll 2017; Beaudreau et al. 2019; Broch 2022). As more fisheries trend towards privatization, there are potential socio-economic consequences that need to be addressed. One such impact of this management regime is the shift from thinking of fishing as a way of life to a business enterprise, although this impact may be considered positive in terms of individual decision-making (Powers et al. 2008). An older fishermen discussed the strategic planning that comes with exiting the industry and the effect of licenses and permits as a commodity.

> "You have to be strategic, especially if you have permits that are worth money. You're going to pay tax on what you liquidate them for. So all of that becomes somewhat strategic, should be, especially if you've invested your whole life in it."

Intra-Industry Diversification Decisions

The ability to diversify between fisheries is a relevant predictor of success as a resource dependent commercial fisherman. Throughout their careers, most fishermen had regularly rotated between species, gears, and locations (both domestic and international) as part of their fishing portfolio. Diversification can reduce risk and income variability of commercial fishermen by providing an opportunity to fish year-round rather than being constrained to particular seasons or locations, as well as allowing for shifting between species based on market price or abundance (Kasperski and Holland 2013; Anderson et al. 2017; Selgrath et al. 2018). The ability to diversify, however, can be constrained by the cost and difficulty of obtaining licenses and permits, management, knowledge, and personal preferences (Sethi et al. 2014; Anderson et al. 2017). Constraints on the ability to switch between species, gears, and locations in response to changes in economic and environmental conditions can result in increased vulnerability of fishermen and fishing communities (Stoll et al. 2016; Holland and Kasperski 2016; Silver and Stoll 2019). Management strategies, such as ITQs or limited entry fisheries, can overlook the socio-cultural aspects (i.e., social identities) tied to commercial fishing that can influence the participation decisions of fishermen, including whether to diversify or specialize (Crosson 2011). Nonetheless, the ability of fishermen to rotate between periods of diversification and specialization lessens the risk of sudden perturbations and allows fishermen to stabilize returns in certain instances (Kasperski and Holland 2013; Finkbeiner 2015; Anderson et al. 2017; Holland et al. 2017).

In Virginia, individual characteristics can also influence levels of diversification, however, these may be correlated with management, such as the number of years with a commercial fishing license or when an individual began fishing (White and Scheld 2021). Fishermen who had participated for more years and entered the commercial fishing industry earlier were more diversified across species and sectors outside of commercial fishing, indicating that the ability to diversify may be more available to individuals with the knowledge and financial and social capital to do so. Although all fishermen interviewed had switched between fisheries at one period, White and Scheld (2021) find that less than half of Virginia's fishermen are diversified between wild species fisheries (clam, crab, finfish, oyster). This indicates a need for further evaluation of diversification as it is probable that levels of individual diversification may be dampened by the broader effect of entry and exit within the fleet (Abbott et al. 2022). In other studies, reasons for entry and exit in commercial fisheries and within species included market prices, proximity to fishing areas, revenues, historical productivity, resource abundance, knowledge of the industry, and personal preferences (Pálsson and Durrenberger 1982; Ward and Sutinen 1994; Pradhan and Leung 2004; Slater et al. 2013; Bucaram and Hearn 2014). Interviews suggested that similar factors play a role in the decision to enter or exit in Virginia's small-scale fisheries, although market conditions were often mentioned as motivation to exit a fishery.

Fishermen noted that the need for adaptation (i.e., diversification) was not always based on individual decision-making but could also be influenced by management and changes in species behavior.

> "I mean, the laws make you adapt to start with. And then the fish, you know, their trends are different now than when I first started. I mean, originally, you used to be able to run out of Ocracoke and Hatteras and target species that you now won't. You know, you wouldn't even think of going out of that area. You'd more run out of Wanchese or maybe even the Chesapeake Bay."

Due to the interconnectedness of commercial fishing and ecological systems, fishermen are acutely aware of changes that occur within species and habitats. Interviewees noted several changes, including the size of blue crabs.

> "The crabs are getting smaller. It's a ton more little, small, mature females now that you can't sell than it was 20 or 30 years ago. You never saw a little small, female 20 years ago. You'll see a mature female three or four inches long, and the only thing you can do is throw it back overboard cause doesn't anybody want it. And that has really hurt with the crabbing. It really has."

Another fisherman cited changes in the environment that were noticeable during the crabbing season and could be indicative of water quality and habitat degradation.

> The pots get so dirty now. Crab pots, up the rivers. They didn't used to get that dirty. Like in the Bay even, the foxtail grass will grow on the pots. Back in the day, back when my grandfather was younger, he said you could put a pot out in March and take it up in November and never would have anything on it. But you know, now it's just like the growth is…like you put a crab pot up York River, up around West Point. It's, with no anti-fouling on it, it'll be dirty in five days. You won't be able to see through it."

This concept of socio-ecological systems is tied to the resilience and the ability of fishermen to adapt to changes in ecological resources (Young et al. 2006; Jepson and Colburn 2013; Fuller et al. 2017). Furthermore, the use of local ecological knowledge (LEK) and its benefit in sustaining social identities has been identified as a means to understand changes within the fishing industry (Ames 2001; Garavito-Bermúdez and Lundholm 2017; Selgrath et al. 2018; Dyrset et al. 2022). Interviewed fishermen recognized declines in various species and similar to what Johnson et al. (2014) and Papaioannou et al. (2021) found, a number of fishermen referenced species declines as cyclic with hopes that the species would rebound based on prior experiences from other fishermen or themselves. Some fishermen noted that the distribution of species in Virginia had changed with historically valuable species disappearing such as shad or herring and new species emerging, including ribbonfish (*Trichiurus lepturus*) and white shrimp *Litopaenus setiferus*). This northward shift in species distributions represents a need for adaptability within the commercial fishing industry, although these emerging opportunities can provide economic benefits to fishermen (Lucey and Nye 2010; Dubik et al. 2018; Pinsky and Fogarty 2022).

Fishermen were asked whether they would consider diversification into the emerging white shrimp or invasive blue catfish (*Ictalurus furcatus*) fisheries in Virginia. The shrimp fishery is currently experimental, and individuals have to be granted a permit for participation. Fishermen were asked to base their response on the premise that the fishery was open-access. A number of individuals stated that they had or considered applying for an experimental shrimp permit and most fishermen regarded the fishery as a positive change that allowed for additional fishing opportunities. One fisherman expressed his interest in obtaining a permit for the shrimp fishery and highlighted the shift in available opportunities, as well as the need to be able to switch between fisheries as they emerge.

> "Yeah, I'm interested in that [experimental shrimp permit]. It's very interesting because it always seems like when one thing disappears, something else will show up and you kind of wonder with the crabs disappearing, maybe the shrimp are showing up to give us something else to do."

The sentiment regarding the invasive blue catfish fishery was slightly different as more fishermen were concerned with the removal of the species for ecological reasons. The blue catfish population has flourished and expanded throughout Virginia since its introduction as a recreational trophy fishery in the 1970's (Fabrizio et al. 2018). The blue catfish is thought have negative impacts on other species, including blue crab and various finfish, and this perception was noted in several interviews. Fishermen remarked concerns about the prey species of blue catfish, as well as the rate of expansion. Several fishermen had already begun diversification into the blue catfish fishery, although market price and availability of USDA approved processors was considered a constraint to expanding within the fishery. Others noted that market price or local availability in nearby fishing locations were reasons for not diversifying into this fishery. More consistent with the blue catfish fishery (and likely a result of market price), fishermen were less willing to switch fishing locations to pursue this emerging opportunity. In both the shrimp and blue catfish fishery, the age of the fisherman played a role in individual decision-making to diversify with older fishermen less likely to consider these options and not alter participation from current fisheries. This indicates that emerging fisheries may be well-suited for new entrants to the industry, especially white shrimp where harvest can provide economic and ecological benefits to fishermen.

Inter-Industry Diversification

A number of fishermen indicated previous or current participation into non-fishing related sources of income. Diversification into additional employment (marine-related or otherwise) can be a potential livelihood strategy that enables individuals to fish when conditions are optimal and have another source of income when conditions are unfavorable (Garrity-Blake 1996; Allison and Ellis 2001; White and Scheld 2021). Individuals varied in how diversification occurred outside of commercial fishing as some individuals were diversified into non-marine related industries (e.g., military, truck driving, concrete, fabrication, construction), while others participated in non-fishing marine-related industries including employment at the state shipyard, marine welding, aquaculture, and seafood sales and processing (including retail, wholesale, and restaurants). Fishermen who held additional employment prior to fishing full-time often noted that fishing was still an integral part of their lives with many individuals participating on a part-time or seasonal basis. Fishermen who eventually returned to fishing full-time expressed similar ideas that their participation in non-fishing related employment was not as satisfactory or did not evoke the same passion as commercial fishing.

The transition from commercial fishing to aquaculture has been proposed as a viable alternative to the challenges of commercial fishing (Cleaver et al. 2018; Stoll et al. 2019). There is evidence that diversification into the aquaculture sector is already occurring in Virginia with 13% of commercial fishermen diversifying into aquaculture and a substantial portion of the aquaculture sector being comprised of commercial fishermen between 1994-2018. Interviewees who were not already participating in aquaculture were asked whether shellfish farming would be a potential option in the future. Fishermen that had or continued to participate in aquaculture (n=13) seemed to consider it as a natural extension of diversification in commercial fishing and a means of supplementing income from more variable wild harvest. One fisherman diversified into the aquaculture sector after a wild species fishery closure, while others were only temporarily involved due to research, funding, or personal interest. Interestingly, the definition of aquaculture between fishermen varied, with most discussion surrounding oysters, but also including soft shell blue crab shedding in tanks. Deterrents from participation in aquaculture was accredited to capital investment, lack of challenge in following target species and the day-to-day predictability of the sector. One fisherman also argued that the effort involved in aquaculture was extensive despite producing the "same amount of things that you could do the old-fashioned way." Other fishermen suggested that aquaculture was more similar to farming than fishing and was too different to consider as an alternative or diversification option. These findings align with Slater et al. (2013) who find that aquaculture and other substitutes must possess the same characteristics and fishing in order to be an attractive alternative.

Case Study of Diversification

Diversification can be used to offset impacts of adverse economic, ecological, and management changes. A recent adverse event, COVID-19, placed an unprecedented shock on various aspects of the commercial fishing industry and seafood supply chain (Bennet et al. 2020; Wang et al. 2020). The pandemic altered Virginia's seafood industry through changes in market price, movement of product, and post-harvest employment. The long-term socio-economic effects of the pandemic on commercial fishing are not understood. However, fishermen recognized the immediate impacts as positive and negative depending on participation in different fisheries and sectors. This indicates further support for diversification within and outside of the commercial fishing industry as an adaptive strategy. Interviewed fishermen were primarily reliant on the ability to switch between species and additional sources of income throughout the pandemic.

Individuals participating in finfish fisheries, especially striped bass, were affected by the pandemic as restaurants around the nation closed down and the transport of product was limited. The price of the striped bass was "less than half of what they usually are" which forced fishermen to exit the fishery unexpectedly and "save quota" for when the market became available. Similar impacts were noticed in the oyster fishery as product marketing of this species caters to the restaurant industry. An interviewee who is almost fully specialized in the oyster fishery stated that he had switched to planting oyster seed as a way to maintain his crew, but at a personal expense.

In contrast, the blue crab fishery was positively impacted by the pandemic in the short-term. This fishery primarily serves wholesale and retail markets, which remained viable during COVID unlike the restaurant industry. Many fishermen switched to crabbing to counteract closures in other fisheries.

Fishermen expressed that the market price for crabs were well above the average annual price, indicating that individuals with the ability to diversify, or those who specialized in this fishery likely benefited from capitalizing on favorable conditions. One fisherman who participated in the whelk (conch) fishery and was affected by international market closures switched to crabbing following the onset of the pandemic. This fisherman noted that crab market prices were low at the start of the pandemic but increased with time.

> "The talk of the virus was starting to go around and by the end of February, we couldn't sell the conchs [whelks]. We had to take our gear up. We had to take them up, our market, our guys were like we're sorry but we just, we can't sell it. China shut down, the US, most of New York shut down. There's nowhere for them to go. So we had to take our gear up and it was setting up to be a really good spring. So we had to go crabbing. We went crabbing, set crab pots on March 17th and got $50 opening day for our crabs, which was half, if not less than half of we're used to or you know, hoping to get. But at the turn, it ended up being a good summer crabbing, even with the pandemic going on because I guess the crab houses made changes and they made it so that they could still serve crabs through the windows."

While the pandemic had extreme economic and social implications on Virginia's commercial fishermen and fishing communities, an individual suggested that the pandemic had made the industry more resilient by encouraging new perspectives and provoking creativity.

> "But I think, you know, there's some healthy things about it as well. A lot of people were forced to look at things differently and they did. They adapted. And I think some people were able to become a little more efficient with what they were doing because of the pandemic. So it was kind of a silver lining with some of it."

This perspective mirrors the findings of Smith et al. (2020) who find that fishermen in the US Northeast, including Virginia, were able to adapt to the pandemic through different marketing and diversification strategies such as supplementing incomes from non-fishing employment or government assistance, or temporarily exiting the industry. In Virginia, fishermen are able to market certain species directly to the consumer and it is possible that this strategy enabled some fishermen to sustain a living until conditions returned to normal. This may be especially true for fishermen who only sell their catch to processing entities, which were limited during the pandemic due to health concerns and labor shortages. Adaptive strategies formulated during the pandemic can be evolved to increase resilience during other unforeseen events (Love et al. 2021).

Conclusions

> "But it's what they live for. It's all they've done is work on the water and you know, it's what keeps them [commercial fishermen] going, and I get it."

Virginia's small-scale commercial fisheries are deeply embedded within the social identities of fishermen and fishing communities in the state. It is therefore of value to managers and researchers to consider the economic and societal consequences associated with declines in small-scale commercial fisheries and more importantly, to understand why these declines are occurring. Declines in Virginia are widespread across the commercial fishing sector in terms of the number of fishermen, as well as levels of participation in the seafood sales and processing and aquaculture sectors (White and Scheld 2021). These declines are likely caused by a combination of factors that have intensified through increasing regulations, environmental changes, and shifts in socio-cultural norms. A particularly problematic phenomenon is the "graying of the fleet" where the commercial fishing industry is disproportionally comprised of older individuals and there is limited new entry to the industry. This issue is not limited to Virginia and has been recognized around the United States with efforts to increase participation of younger individuals in the industry with the passing of the Young Fishermen's Development Act in Congress (H.R.1240). It remains unclear whether the aging commercial fishing population is due lack of interest from younger individuals, societal shifts in what constitutes a viable career path, or a mixture of these factors among others (Powers et al. 2014). Younger individuals raised in fishing communities are indubitably aware of the challenges and volatility associated with commercial fishing and may consider employment opportunities with more short- and long-term stability.

This research highlights other factors, such as the privatization of fishery resources, that may serve as critical barriers to entering the commercial fishing industry. Obtaining licenses and permits has become increasingly difficult in Virginia with most fisheries being limited entry and a significant portion of these having no available licenses or permits. Those with potential openings are often at a prohibitive financial cost. Furthermore, the overarching commercial fishing license requires either individual-to-individual transfer or a two-year delay period before the license can be used. This limits potential fishermen to working as crew on another fisherman's boat or finding alternative employment to supplement income during the delay period. Privatization management regimes are based on rebuilding species stocks and maintaining sustainable fishing pressures in response to declining species abundances. This presents another challenge for older, established fishermen, as well newer entrants, with the need adapt to shifts in species availability and distributions. However, these shifts can provide new opportunities to fishermen as markets develop for emerging species.

Despite declines in small-scale commercial fisheries in Virginia and the broader US, commercial fishing is integral to the identities of individuals and communities and is associated with place attachment, job satisfaction, and well-being, all of which serve to increase resilience to adverse impacts. There is an inherent pride in being a commercial fisherman and thus, Virginia can capitalize on the knowledge of fishermen to understand and preserve the significance of commercial fishing to individuals and fishing communities. Small-scale commercial fisheries, including those in Virginia, are dynamic and constantly evolving in response to the environment, market, and management as a means of sustaining the fishing livelihood. It is likely that fishermen will continue to adapt throughout their careers and an evolving understanding of these changes is beneficial for fishery managers, as well as local and state government.

There is an opportunity to expand this research through additional interviews and observational methods that capture the role of diversification as an adaptive strategy. Since the interviews were completed, one fisherman shared that, in addition to fishing, they had invested in an oyster shucking house and diversified into the seafood sales and processing sector. Future ethnographic research could be used to track ongoing changes with the fishermen interviewed in this study to investigate changes on varying temporal scales.

The perspectives of fishermen can be used to better understand individual decision-making based on changes in regulation, markets, or species availability and how these changes may impact the socio-cultural wellbeing of fishermen in Virginia and the broader Mid-Atlantic. Furthermore, managers can use this information to create workforce development strategies that ensure the long-term sustainability of Virginia’s commercial fishing industry that provides economic and social benefits to local communities and the state and serve to preserve the commercial fishing livelihood for the future.

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CONCLUSION

This dissertation applied both quantitative and qualitative approaches to characterize changes in participation and diversification in small-scale commercial fisheries of Virginia, USA. Prior to this dissertation, there was limited knowledge regarding the extent of diversification and how diversification patterns have changed throughout time in this region. Furthermore, the potential drivers of diversification behavior in Virginia were not well understood and represented a knowledge gap that could be valuable to fishery managers in predicting how fishermen will respond to adverse events or in developing strategies to increase resiliency to such events. Likewise, the drivers of diversification can be used to understand the potential to expand or develop markets for emerging species. This dissertation finds that while the extent of diversification in Virginia's small-scale commercial fisheries is somewhat limited, diversification within and outside of the commercial fishing industry may serve as an important adaptive strategy.

There is evidence that diversification provides similar income stabilization benefits to small-scale fishermen in Virginia as it does in other developed fisheries. Within the commercial fishing industry, fishermen can switch between species, gears, or fishing locations. Fishermen that were more diversified had annual incomes that were higher and less variable compared to fishermen that were less diversified (Chapter II). There is also evidence that diversification provides inter-annual benefits with fishermen remaining in the commercial fishing industry for longer, possibly because they are more diversified or have more opportunities to diversify (Chapter I and II). It is unclear if income stabilization is the benefit driving this behavior and could be explored in future research. Despite the suggested benefits of diversification, Virginia's small-scale commercial fishermen have remained relatively specialized throughout time.

Changes in levels of participation and diversification within Virginia's small-scale commercial fishing industry are likely attributed to interrelated and complex factors that reflect the volatility of the small-scale commercial fishing industry. These factors are often unpredictable and include changes in market forces, regulation, environmental conditions and socio-demographics. There is evidence that participation and diversification patterns can shift through time in response to adverse events. For example, fishermen with a license or permit for wild hard clam or wild eastern oyster show similar participation characteristics in earlier years with diversification across species likely due to similarities between the fisheries. In more recent years, however, fishermen with a license or permit for wild clam became less similar to fishermen with licenses or permits for other fisheries. It is probable that changes in participation are indicative of species declines, changes in ex-vessel values, or increased competition with clam aquaculture. Nonetheless, changes in participation and diversification may indicate broad demographic shifts in resource dependence, which can be problematic as commercial fishing is often integral to the economies and establishment of socio-cultural norms within coastal communities.

This dissertation provides direct evidence that fishermen diversify across sectors as a livelihood strategy, although at limited levels. Less than one-third of commercial fishermen are diversified into marine-related industries such as aquaculture, chartering, or seafood sales and processing, however, participation in these industries can drive diversification behavior. Fishermen with additional ties to the commercial fishing industry (i.e., licenses or permits for marine-related industries) are more likely to increase diversification in a given year. Furthermore, there is overlap between fishermen participating in commercial fishing, aquaculture, and seafood sales and processing, which may be used to create economies of scale and scope across seafood industries. A thorough investigation of these relationships can be used to determine how fishermen leverage resources to increase market access and ultimately, revenues. It is worth noting that diversification can and is occurring in other marine-related sectors (e.g., net mending, marine welding) or non-marine related sectors (e.g., construction, government, education) (Chapter III and IV). Chapter III finds that fishermen derived almost half of their annual income from commercial fishing and an equal amount indicated having at least one additional source of income outside of commercial fishing. Estimates of diversification, broadly defined, could be much higher and further exploration of participation and diversification into additional sectors (outside of commercial fishing) could be useful to assess levels of resource dependence.

Another major finding of this dissertation is evidence for the graying of the fleet phenomenon occurring in Virginia's small-scale commercial fisheries. Although it was speculated that the commercial fishing population was disproportionally comprised of older individuals, various chapters confirmed this notion. There has been a declining trend in the number of commercial licenses sold in the state of Virginia, however, the number of senior commercial fishing licenses (≥ 65) has risen at a faster rate. Furthermore, a number of fishermen indicated retirement or pension benefits as supplemental income for commercial fishing in survey responses (Chapter III). This demographic shift is concerning as a lack of new entrants into the commercial fishing industry could lead to broad societal and economic consequences. Recognized as a nationwide problem, there has been recent legislative action to encourage participation of young fishermen through the Young Fishermen's Development Act (H.R. 1240), which provides funding opportunities for training, education, outreach, and technical assistance to younger individuals interested in the commercial fishing industry. It is hopeful that programs of this type can be used for workforce development and counteract declines in fishing industry participation, although additional legislation is likely needed to reduce barriers to entry and lessen constraints to diversification within the commercial fishing industry. One such barrier to entry and diversification is the difficulty and cost of obtaining licenses or permits. In Virginia, there is evidence that the longer an individual is in the commercial fishing industry, the less likely one is to alter participation behavior. Anecdotally, fishermen might retain licenses or permits even if they are not being used to strategically increase selling price or for potential use in the future, especially in fisheries that are managed as limited entry or quota-based. As a result, obtaining a license or permit can be a financial burden to someone attempting to enter the fishing industry or seeking to diversify across fisheries. This may be especially true for individuals that do not have family ties to the commercial fishing industry.

Another key finding, and potential opportunity for future exploration, is the impact of ongoing environmental change on constraining or enhancing diversification opportunities. There is evidence that species distributions are shifting with changes in environmental conditions and, as such, fishermen will either need to follow shifts in species distributions or consider diversifying into other established or emerging fisheries. In Virginia, opportunities to capitalize on emerging and invasive species fisheries exist with the expansion of the invasive blue catfish (*Ictalurus furcatus*) and likely climate-induced range shift of white shrimp (*Litopenaeus setiferus)*. These opportunities can provide economic benefits for small-scale fishermen, although there are potential barriers to diversification. Chapter III was used to investigate the willingness of commercial fishermen to participate in the invasive blue catfish fishery. The findings indicated that ex-vessel value was the primary driver of participation decisions, although observed and unobserved individual characteristics can also play an important role in diversification behavior.

Despite declines in small-scale commercial fishery participation throughout the United States, commercial fishing is integral to the identities of individuals and communities and serves to increase resilience to adverse impacts. This dissertation contributes to a better understanding of participation and diversification in Virginia's small-scale commercial fisheries, including drivers of diversification behavior, and results can likely be applied to other small-scale fishing communities with similar characteristics. Diversification can be an important adaptive strategy of commercial fishermen and the decision to diversify is likely dynamic and influenced by a suite of factors. Thus, it is important that fishery managers and policy makers consider how participation and diversification characteristics may change in response to the economy, environmental, management itself, or other exogenous factors. Given the limited extent of diversification in Virginia's small-scale commercial fisheries, there is substantial opportunity for fishery managers to enhance diversification opportunities as a means of reducing vulnerability and enhancing resiliency in coastal fishing communities. Furthermore, encouraging participation in the commercial fishing industry and expanding diversification opportunities can help meet the demand for domestic seafood production, rather than increasing reliance on imported products. Managers can also use the findings of this dissertation to create workforce development strategies that ensure the long-term sustainability of Virginia's commercial fishing industry and preserve the commercial fishing livelihood for future generations.