Fishery Management Plan for Oregon’s Trawl Fishery for Ocean Shrimp (*Pandalus jordani*)

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Introduction

The Oregon trawl fishery for ocean shrimp (*Pandalus jordani*) is managed by the Oregon Department of Fish and Wildlife (ODFW) as a sustainable fishery, however, historically it has been managed without a written state fishery management plan. The purpose of this initial fishery management plan is to document ODFW's management objectives, regulations, fishery controls and fishery monitoring activities that are designed to maintain the long-term sustainability of the fishery. It is anticipated that this management plan will be updated whenever there are significant changes in the fishery or the regulatory environment or at least every 10 years. The structure of this draft management plan follows, to the extent practicable, the framework for Oregon Fishery Management Plans.

Section 1 - Resource Analysis

I. Species

This plan applies to the Oregon trawl fishery targeting Pacific ocean shrimp (*Pandalus jordani*, also called smooth pink shrimp or, in Oregon, just pink shrimp). Although catch, effort and biological data are collected and summarized here for ocean shrimp catches made from any portion of the ocean (Figure 1), it should be noted that the population dynamics research discussed below has been conducted primarily on just the portion of the ocean shrimp stock inhabiting waters off of Oregon, state statistical areas 19-28 (Figure 1).

II. Description of the shrimp resource

The life history of ocean shrimp has been described for populations in Canadian waters by Butler (1980), for Oregon waters by Zirges and Robinson (1980) and for California waters by Collier et al. (2001). Ocean shrimp are very short-lived (Figures 2 and 3), with a total lifespan that generally does not exceed 4 years in Oregon waters (Zirges and Robinson 1980, Collier et al. 2001). Female shrimp release larvae in March and April that then develop for the next 6 months in the plankton, starting in the near-surface waters and occupying progressively deeper portions of the water column as they grow (Rothlisberg 1975). After molting into their adult form, these "age zero" shrimp begin appearing in shrimp trawls as they recruit to the seafloor in September and October, at a size of about 8-12 mm carapace length. The Oregon fishery captures quantities of ocean shrimp for the following 3 years at ages 1-3, and carapace lengths of about 13-27 mm. Age 1 shrimp typically dominate catches in terms of numbers (Hannah 1999). Shrimp growth is rapid but also highly variable from year to year and has been shown to be density-dependent, with increased growth at lower densities (Hannah and Jones 1991). Ocean shrimp mate in the fall and the externally-fertilized eggs are carried by the females attached to their abdominal appendages over the winter (Figure 3). Egg-bearing females first appear in fishery catches typically in September or October. Fecundity ranges from about 800 eggs for small age-1 females up to about 5000 eggs for large age-3 females (Hannah et al. 1995). Ocean shrimp are protandric hermaphrodites, typically maturing first as males at age 1 and then functioning as females at ages 2 and 3 (Butler 1980, Zirges and Robinson 1980, Collier et al. 2001). However, the rate of sex change in ocean shrimp is variable, and is modulated by changes in their demographic environment (Charnov and Hannah 2002). When age-1 shrimp strongly dominate the population, up to about 60% of the age-1 shrimp develop directly into females (known as primary females) and when older shrimp dominate the population, some shrimp remain male through age 2 (Charnov and Hannah 2002).

Ocean shrimp have been reported from waters ranging from the Aleutian Islands, Alaska, to those off San Diego, California (Collier et al. 2001). The center of the population is located in Oregon waters and commercial quantities of ocean shrimp are found from California to British Columbia, Canada. Ocean shrimp are typically found living on and over green mud or muddy sand substrates at bottom depths between 40 and 150 fathoms (Zirges and Robinson 1980). They migrate vertically in response to reduced light levels near the seafloor (Pearcy 1970), making them unavailable to bottom trawls at night and sometimes during the day when seafloor light levels are reduced. No convincing evidence of horizontal migration has been produced (Collier et al. 2001), however bottom currents are believed to continually redistribute shrimp and may also form slow gyres that concentrate them consistently in some areas. Ocean shrimp feed mostly at night on euphausiids and copepods, but also consume polycheate worms, diatoms, sponges, amphipods and isopods (Collier et al. 2001).

III. Available data

Fishery monitoring program

There are no fishery-independent surveys for ocean shrimp in Oregon waters, thus all of the data used for management are fishery-derived. Examples of fishery-derived data, such as summaries of fish landing tickets, logbooks (Figure 4) and dockside biological samples, can be found in the annual shrimp newsletters available at http://www.dfw.state.or.us/MRP/publications/#Shrimp. A fishery-independent shrimp survey would allow pre-season estimation of shrimp abundance and thus allow direct control of fishing mortality rates through a catch quota. A pre-season abundance estimate cannot be derived from fishery data for several reasons, the most important being that fishing vessels fish in just a portion of the spatial area inhabited by shrimp. In the absence of a survey, pre-season shrimp abundance levels remain unknown and therefore current management regulations (see below) do not act directly to limit fishing mortality. For this reason, ODFW maintains an active program of monitoring the shrimp fishery each season, in order to be able to model the stock dynamics periodically and detect any sustained, fishing-related, declines in stock status. This monitoring program is an integral part of the state's management strategy, in that it is the means by which any significant growth or recruitment overfishing will be detected and addressed through management action. The program includes a mandatory logbook program that allows fishery catch and effort to be identified by state sampling area (Figure 1). It also includes a dockside sampling program that collects biological samples of the catch from all state areas that receive appreciable fishing effort each month during the April through October season. From these samples, the age composition, sex composition (April, September and October only) and average carapace length of the shrimp catch are determined (Hannah and Jones 1991) to facilitate population modeling (Hannah and Jones 2014a).

The success of the monitoring program depends on the cooperation of the fishing fleet to provide accurate logbooks so that catch, effort and samples of the catch can be accurately assigned to statistical areas (Figure 1). To help maintain the support of the industry for the monitoring program, an annual "Pink Shrimp Review" newsletter has been published and distributed free of charge to all Oregon shrimp permit holders (and other interested parties) each February since 1989. This provides vessel operators, owners, deckhands and processors with an up-to-date summary of the results from ODFW's monitoring program. Also included are summaries of any recent research findings and notice of regulatory or management changes, as well as information on any management concerns regarding the fishery.

Discard data

Although bycatch in the Oregon shrimp fishery is maintained at very low levels through mandatory use of high-efficiency bycatch reduction devices (BRDS, Hannah and Jones 2012) and recently through voluntary use (adopted as mandatory 1/18/2018) of LED (light emitting diode) light devices on trawl footropes (Hannah et al. 2015), discard data is produced annually by the Northwest Fishery Science Center's West Coast Groundfish Observer Program (e.g. NWFSC 2009).

IV. Stock status

Ocean shrimp population dynamics

Due to the lack of a fishery-independent survey for Oregon ocean shrimp, all of the population dynamics research to date has been based on recruitment and spawning stock indices derived from fishery-dependent data. These studies have focused on the stock unit directly off of Oregon (state statistical areas 19-28, Figure 1), and have shown that the population dynamics of ocean shrimp are strongly dominated by highly variable recruitment that is in turn related to variation in the ocean environment during the larval period (Hannah 1993, 1999, 2011, Hannah and Jones 2014a). The recruitment index from Hannah (1993) showed over 30-fold variation in recruitment between 1968 and 1989 (year of age one harvest, unless noted). Using an improved recruitment index and a more recent time series, Hannah (1999) measured over 25-fold variation in recruitment for the period 1980-1996. Similar variation was demonstrated using a simplified index for the years 1980-2006 for both southern and northern Oregon waters (Hannah 2011) and more recently for these same areas for the years 1980-2011 (Hannah and Jones 2014a). This wide variation in recruitment success has been related to the timing and strength of the spring transition in coastal currents (Huyer et al. 1979), as reflected in April sea level height (SLH) at Crescent City, California (Hannah 1993, 1999, 2011). A recent update of ocean shrimp recruitment models suggests that average sea level height over a longer portion of the pre-recruit period, April-January, correlates more strongly with recruitment success (Hannah and Jones 2014a).

The mechanism linking low SLH during the pelagic larval period with improved ocean shrimp recruitment is unknown, however, an early and vigorous spring transition lowers spring SLH and also creates conditions that should be favorable for larval survival and retention of larvae in coastal Oregon waters. These conditions include southward surface flow and upwelling of cold, nutrient-rich water (Rothlisberg 1975, Hannah 2011, Huyer et al. 1979). Conversely, a late spring transition prolongs northward surface flow and warm, unproductive surface waters typical of winter conditions. Although the spring transition has been highlighted in most published studies, none of the research to date suggests that other confounded measures, such as sea surface temperature, changes in alongshore currents, or the upwelling of nutrients into surface waters may not actually be the major influence on larval survival or retention. Although an early, strong spring transition improves recruitment generally, there is also evidence that abnormally strong upwelling winds in April-July can depress recruitment locally, probably through excessive offshore transport of larvae (Hannah 2011). Environmental factors like sea surface temperature, upwelling and sea level height can show similar trends over time. Because of this (also called cross-correlation), it can be difficult to use correlative studies to identify likely mechanisms linking environmental variation with recruitment success.

Several of the studies of ocean shrimp population dynamics have attempted to discern the effect of variation in the spawning stock on subsequent recruitment, with little success (Hannah 1993). Some evidence has been presented suggesting the existence of a stock-recruitment relationship, as well as some negative impacts from high April fishery catches of late egg-bearing females (Hannah 1999, Hannah and Jones 2014a). However, multiple regression models that incorporate spawning stock indices and environmental variables such as April SLH or April-January SLH show that environmental effects on recruitment are generally much stronger than the influence of variation in spawning stock (Hannah 1999, Hannah and Jones 2014a). Perhaps more importantly, these studies have also shown a very strong recruit-stock relationship, that is, a strong positive dependence of annual spawning stock on age 1 shrimp recruitment that same year (Hannah 1999). This suggests that although spawner abundance influences subsequent recruitment, spawner abundance is not primarily determined by the level of fishing that year, but rather is mostly driven by the size of the age 1 recruitment entering the fishery *that same year* (Hannah 1999). The strong effects of environmental variation on both recruitment and spawning stock in ocean shrimp suggest that the ability to manage the fishery in a way that produces a stable annual yield is inherently very limited. So, although the stock abundance is naturally highly variable, it is considered to be "healthy", at current and historical levels of harvest and fishing effort.

Studies of the population dynamics of ocean shrimp have resulted in two other findings that are potentially useful for understanding and modeling the stock and fishery. The geographic stock area occupied by newly recruited shrimp has been shown to be roughly proportional to the magnitude of recruitment (Hannah 1995), demonstrating an inverse relationship between stock size and fishery catchability. One consequence of this relationship is a hyperstability in fishing mortality, F (Hannah 1995), which also arises from gear interference at high effort levels. Another useful finding is that estimates of annual egg production do not seem to perform better than a simple index of the number of spawners or spawning biomass in relating spawners to recruits (Hannah 1999). This is most likely a result of demographically-modulated sex change (Hannah and Jones 1991). As ocean shrimp are "fished down", juvenating the age structure, the accelerated sex change maintains a more constant proportion of females in the population.

V. Known threats to the resource

Climate change

The sustainability of the Oregon shrimp trawl fishery over the 1980-2017 period is founded on the balance between fishery harvest and recruitment. Ocean shrimp recruitment success is considered environmentally driven and thus the rapid rebound of the stock from year class failures reflects the relatively high frequency of ocean conditions off of Oregon that are favorable for larval survival and transport and the relatively low frequency of severely adverse conditions (Hannah 1993, 1999). However, considerable evidence supports the contention that the ocean environment varies in much longer cycles than might have been observed since 1980 (Yasuda et al. 1999, Chavez et al. 2003, Shanks and Roegner 2007), the period for which we have estimates of ocean shrimp recruitment. There is also evidence that climate change has begun to alter the latitudinal distribution of fishery resources around the world (Perry et al. 2005, Mueter and Litzow 2008, Nye et al. 2009). Thus it's possible that the recent history showing the sustainability of this fishery may not persist indefinitely into the future.

A recent study suggests that very poor shrimp recruitment off southern Oregon in 2000 and 2002-2004 may be related to a northward shift in the weather conditions that lead to very strong spring-summer upwelling-favorable winds (winds from the north, Hannah 2011). Upwelling of deep-ocean water provides nutrients to the coastal ecosystem, but also results in offshore transport of surface waters and some types of pelagic larvae. Parrish et al. (1981) characterized the California current ecosystem as comprised of two primary zones with regard to the seasonal pattern of upwelling. North of approximately Cape Mendocino, CA, spring-summer upwelling winds have historically been intermittent due to periodic storm systems that bring winds from the south (Hannah 2011, Menge and Menge 2013). The areas farther south have been characterized as the "zone of constant upwelling" in which storm systems are much less frequent and upwelling-favorable winds are more consistent throughout the year (Parrish et al. 1981). Each of these two domains is characterized by species whose life history is adapted, in various ways, to the respective pattern of upwelling and associated amount of offshore transport of pelagic larvae (Parrish et al. 1981). The largest populations of ocean shrimp are found in waters north of Cape Mendocino, CA, in the zone of intermittent upwelling. In 1999 and again in 2001-2003, spring-summer upwelling winds off southern Oregon were much stronger and more persistent than normal, possibly depressing shrimp recruitment in 2000 and 2002-2004, due to excessive offshore transport of larvae (Hannah 2011). This change in the latitudinal pattern of upwelling-favorable winds may, in turn, be related to global warming (Yin 2005, Seidel et al. 2008). This raises the possibility that shrimp recruitment, especially in southern Oregon waters, may become much more variable in the future, similar to the high interannual variability seen off northern California over the last few decades (Hannah 2011, Iles et al. 2012). This possibility underscores the need to maintain a consistent fishery monitoring and sampling program for the ocean shrimp fishery going forward.

VI. Sustainable harvest levels

The population dynamics research conducted on ocean shrimp to date suggest the stock is highly resilient to harvest pressure under current management regulations (detailed below) and modern and historical levels of effort. However, a more precautionary management strategy involving catch-based action levels as proxies for target- and limit-based management has been developed for implementation in very low abundance years.

VII. Prioritized list of research needs

In interpreting the research needs listed below, it should be noted that regardless of what priority is assigned to any particular component, the completion of research in any given year will always depend on availability of staff, equipment and funding. The availability of research funding for shrimp field studies within ODFW can be highly variable from year to year.

Continued investigation of shrimp population dynamics in relation to fishing and the environment (Priority 1)

Ongoing efforts to sample the fishery, analyze sample and logbook data and periodically re-evaluate environmental models, trends in the fishery and any new evidence relating to fishery-driven stock declines is the top priority. This work is the basis for current management of the shrimp fishery, using primarily just a 7-month open season, a limited entry system and a maximum count-per-pound regulation. This type of research can take various forms. The most recent example can be found in Hannah and Jones (2014a).

Develop methods to further reduce non-target catch (Priority 2)

The shrimp fishery has made great strides in reducing bycatch with BRDS, and recently with LED lights attached to the fishing lines of trawls (Hannah et al. 2015). Maintaining low levels of fishery bycatch remains a priority because of the "threatened" status of eulachon (*Thaleichthys pacificus*), as discussed below. This work may take various forms going forward depending on the status of eulachon and trends in estimates of bycatch.

Improve our understanding of ecosystem effects of the fishery and develop methods to reduce impacts (Priority 3)

Research on ecosystem effects is the lowest research priority simply because the ODFW marine research program is small and the issue of ecosystem effects of west coast fisheries is large and complex (large spatial scales, effects from multiple fisheries, a generally poor understanding of many species that are not the focus of major fisheries, etc.). We occasionally conduct studies of limited scope that help some with specific ecosystem issues related to the shrimp fishery. For a recent example, see Hannah et al. (2013).

Section 2 - Harvest Management Strategy

I. Species

This harvest management strategy applies to the Oregon trawl fishery targeting Pacific ocean shrimp (*Pandalus jordani*).

II. Management objectives

Pursuant to Oregon Revised Statutes chapters 506-509, 511 and 513, the Oregon Fish and Wildlife Commission has the authority to establish management objectives and associated administrative rules (OAR sections 635-005-0575 through 635-005-0645) for the commercial fishery for ocean shrimp.

Long-term management objectives

1. Maximize biomass yield from the ocean shrimp fishery, consistent with detecting and addressing any significant growth or recruitment overfishing that develops, and,

2. Operate the fishery, to the extent possible, under a stable regulatory environment that allows vessel operators maximum flexibility in deciding where, when and how to fish for ocean shrimp, and,

3. Through collaborative research with vessel operators and the sharing of research findings, develop and implement measures to minimize direct bycatch mortality, the unseen mortality of animals that escape capture and any adverse effects on seafloor habitat from the operation of the fishery.

Short-term management objectives

1. Maximize yield from the ocean shrimp fishery, consistent with detecting and addressing any significant growth or recruitment overfishing that develops, and,

2. Operate the fishery, to the extent possible, under a stable regulatory environment that allows vessel operators maximum flexibility in deciding where, when and how to fish for ocean shrimp.

III. Current issues

Eulachon bycatch

A significant external factor that creates uncertainty about the future management and productivity of the Oregon shrimp fishery is the evolving status of federal rules limiting the take of eulachon, a common bycatch species in the fishery. In 2010, the southern distinct population segment (DPS) of eulachon was listed as “threatened” under the Endangered Species Act (NMFS 2010). Presently, regulations directly limiting the “take” of eulachon in the fishery under section 4D of the Endangered Species Act have not been enacted, however they could restrict ODFW’s options for managing the shrimp fishery in the future.

Considerable progress has been made in developing and implementing gear modifications that reduce fish bycatch in the shrimp fishery (Hannah and Jones 2007). The mandatory use of rigid-grate bycatch reduction devices with a maximum bar spacing of just 0.75 inches reduces the catch rates of eulachon (Hannah et al. 2011) and a variety of footrope modifications that reduce bycatch have also been used voluntarily by some vessels for many years (Hannah and Jones 2000). Recently, a video analysis of the behavior of eulachon escaping from shrimp trawls via rigid-grate BRDs has also shown that they are in excellent condition suggesting a high probability of survival (Hannah and Jones 2012). Also, a recent pair of studies estimating the fishing mortality rates of eulachon in the regional shrimp trawl fishery showed that recent and anticipated levels of shrimp trawl effort pose very little risk to the recovery of southern DPS eulachon (Hannah 2014, 2016). A July 2014 field study testing the use of artificial light as a bycatch reduction tool for the fishery demonstrated reductions in bycatch of eulachon of over 90% by weight with 10 green Lindgren-Pitman Electralume® LED lights attached to the trawl fishing line (Hannah et al. 2015). This reduction was over and above that already achieved with BRDs. A survey of the active fleet showed near-complete adoption of this new technology occurred within about 2 months of the research being completed. With the strong support of industry, mandatory use of footrope lighting devices were adopted into rule in January of 2018. An important benefit of this new bycatch reduction technology is that most eulachon now do not even enter the trawl but escape under the trawl net. Relative to entering the trawl net and then being excluded via the BRD, this technology should reduce physical stress on eulachon from their encounter with the trawl. However, despite this progress, eulachon are likely to continue to be a significant bycatch in the Oregon shrimp trawl fishery, due to their small size and the large degree to which their ocean distribution and that of ocean shrimp coincide. As a result, additional federal restrictions on eulachon bycatch in the fishery could still influence ODFW/MRP's ability to manage the fishery as it has historically.

Habitat Impacts

The issue of adverse habitat impacts from trawling may influence the management of Oregon's shrimp fishery in the future. Only very limited research has been conducted on the physical effects of trawling in soft-bottom habitats off of the U.S. west coast and definite impacts on fish production have not been established, however some impacts on structure-forming invertebrates have been identified (Hannah et al. 2010, Hannah et al. 2013a). Recent Oregon studies suggest however that these soft-mud habitats may be more dynamic than previously thought, and that densities of some structure-forming invertebrates can increase very rapidly, even in areas in which some trawling is taking place (Hannah et al. 2013b). Additional studies are needed to determine the effects of habitat disturbance from shrimp trawls on fish production as a function of changes in trawling effort.

Designation of essential fish habitat

The National Marine Fisheries Service is responsible for designating and protecting essential fish habitat (EFH). Areas designated as EFH can change as new information on species habitat requirements and habitat is developed. As a result of ongoing research on EFH, the areas open to the use of shrimp trawl gear may change.

Climate change

As discussed above, climate change has the potential to alter the latitudinal distribution of ocean shrimp due to effects on the storm track and the seasonal and latitudinal distribution of upwelling-favorable winds. Increasing acidification of ocean waters due to increased CO_2 concentrations in the atmosphere (Feely et al. 2004), as well as episodes of seafloor hypoxia (Grantham et al. 2004), have also been linked to human impacts on climate. The impact of these types of changes in the ocean environment on the population dynamics of ocean shrimp are currently unknown.

IV. Description of the fishery

The Oregon shrimp fishery targets Pacific ocean shrimp (also called smooth pink shrimp or, in Oregon, just pink shrimp) with double-rigged, high rise otter trawl gear at depths ranging from about 40 to 150 fathoms, typically in areas of the ocean with soft mud or mud/sand substrates (Zirges and Robinson 1980). The fishery is interjurisdictional in nature, in that vessels licensed in any of the states of Washington, Oregon or California frequently fish in waters off the coasts of the other states and then land shrimp back into ports of their home state. The early years of the fishery have been summarized by Zirges and Robinson (1980). The modern fishery is considered to have started in the late 1970's following the entry of larger trawl vessels equipped with double-rigged, high-rise box trawls and more modern electronics (Zirges and Robinson 1980, Hannah and Jones 1991, Hannah 1993). Annual landings for the modern period (1978-2017) have averaged 28.5 million lbs and have ranged from a low of 4.8 million lbs in 1984 to a high of 56.7 million lbs in 1978 (Figure 5). Recently (2000-2017), landings have averaged 31.4 million lbs. Catch in the fishery varies greatly from year to year due to environmentally-driven variation in recruitment (Hannah 1993).

Fishing effort, measured in single-rig-equivalent hours (SREH, Figure 5), peaked in 1980 at 157,500 SREH and has declined to a recent (2000-2017) average of 37,533 SREH. The number of vessels participating in the fishery peaked in 1980 at 289 vessels (Figure 5), but was subsequently reduced by a limited entry system that currently allows a maximum of 138 vessels to participate. In recent years (2000-2017), the number of vessels participating in the fishery has averaged 64, partly due to a federal groundfish vessel buyback program implemented in 2003 that also reduced the number of active shrimp vessels. In 2011, the National Marine Fisheries Service (NMFS) converted the limited entry groundfish trawl fishery to an Individual Trawl Quota (ITQ) or "catch shares" system. It's presently unclear how this may influence effort in Oregon's shrimp trawl fishery, however some vessel operators have expressed concerns that it will increase the number of active shrimp vessels.

During the modern period (after 1978), a variety of external developments have also influenced the fishery, resulting in slowly increasing efficiency and changes in how vessels target shrimp. More advanced netting materials have been adopted and vessel electronics have steadily improved. Recently, some vessels have increased the height of the trawl doors they fish to try and increase catch rates. Since 1993, bycatch reduction technology has also been developed, including footropes that catch fewer small demersal fish (Hannah and Jones 2000) and codend BRDs that greatly reduce fish bycatch and the time and effort needed to sort the catch (Hannah and Jones 2007). Fish bycatch was reduced further in 2012 when rigid-grate BRDs with a maximum bar spacing of just 0.75 inches were mandated (Hannah and Jones 2012) and again recently with the use of LED lights attached to the trawl footrope (Hannah et al. 2015). In fall 1999, processors implemented split-pricing, the practice of paying different ex-vessel prices for shrimp of different sizes, a change that has persisted. This change in economic incentives may have fundamentally altered how vessel operators target shrimp, shifting the fishery from essentially a target fishery on new recruits (Hannah 1999) to one that targets a more balanced size and age composition of shrimp in most years (Hannah and Jones 2014a).

Fishery Economics

Oregon ocean shrimp compete in the worldwide market for coldwater shrimp, which is dominated by production of the northern shrimp (*Pandalus borealis*) from waters off Canada, Greenland, Norway and Iceland (Roberts 2005). Oregon ocean shrimp are somewhat smaller than northern shrimp, and consequently enter the marketplace primarily as a machine-cooked-and-peeled, individually quick frozen (IQF), product form. Recently, processors have started experimenting with whole, raw IQF shrimp for export markets and for local cooking and peeling during the annual November-March season closure. Ocean shrimp command a relatively low ex-vessel price (Figure 6) in comparison with many other seafood products, requiring that they be harvested in volume to be caught profitably. The ex-vessel price paid for Oregon ocean shrimp is also influenced broadly by international prices for various shrimp product forms and thus by production levels of other coldwater and warmwater (mostly Penaeid) shrimp fisheries, as well as aquaculture production levels of warmwater shrimps (Roberts 2005).

Total ex-vessel value of the Oregon ocean shrimp fishery varies widely with recruitment levels (Figure 6), ranging from a low of about 2.5 million dollars in 1984 to more than 40 million dollars in 2015. The fishery contributes significantly to the total ex-vessel value of all Oregon commercial fisheries, representing, on average, 13.6% of the total 2008-2012 ex-vessel value (The Research Group LLC 2014). As a result of recent strong shrimp recruitment, high catch-per-unit-effort (Figure 7) and a reduction in the number of vessels participating in the fishery (Figure 6), ex-vessel value per vessel (Figure 6) has risen to record levels. If this high ex-vessel value per vessel continues going forward, it could lead to increases in the number of vessels participating in the shrimp fishery, especially if effort shifts from the limited entry groundfish trawl fishery ITQ program continue.

Although many additional factors influence the economics of the fishery, including for example, changes in the cost of insurance and diesel fuel, two fairly recent structural changes are notable. The introduction by processors in 1999 of “split pricing”, as described above, has reduced the economic incentive for vessels to strongly target age-1 shrimp. The use of split pricing has continued to develop in complexity and currently some processors are using a 4-tiered ex-vessel price structure based on shrimp size. Also, the 2007 certification of the Oregon fishery under the Marine Stewardship Council’s “sustainable fisheries” program has the potential to increase demand for Oregon ocean shrimp in relation to other shrimp product forms from uncertified fisheries.

V. Other social and/or cultural uses of the resource

No other uses of the ocean shrimp resource have been identified.

VI. Biological Reference Points and Fishery Controls

Current management regulations

Current management relies on a combination of restrictions on the total number of vessels, the months that can be fished each year and the average size of shrimp that can be landed. The number of permitted vessels is currently capped at 138, and there are statutory restrictions on issuing any new permits until the number of vessels declines substantially. The season is open only for the months of April through October, leaving closed the primary months when female shrimp are egg-bearing. Vessels are required to land loads of shrimp with an average count-per-pound of fewer than 160 shrimp per pound. Analyses of time series data on ocean shrimp stock and recruitment have shown that this approach to harvest management has maintained a sustainable fishery (Hannah 1993, Hannah 1999, Hannah 2011, Hannah and Jones 2014b). To minimize fish bycatch, vessels are required to use high-efficiency BRDs in all trawl nets for all fishing (Hannah and Jones 2012).

Reference Points

Hannah and Jones (2014b) evaluated alternatives for a target- and limit-based management system for ocean shrimp to provide more precautionary management during severe environmentally-driven declines in stock abundance. Briefly, a stock-reconstruction model was used to identify years of extremely low spawning stock abundance that might have benefitted from restrictions on fishing. Their analysis developed proxies for target- and limit-based reference points at which actions could be taken to restrain fishing mortality. Based on the modeling results in Hannah and Jones (2014b) and input from the shrimp industry, target- and limit-based action levels have been established for management of the ocean shrimp fishery going forward (Table 1).

Table 1. Action levels for management of the ocean shrimp fishery.

June average shrimp catch/trip	Current season will close	Following season will open
More than 12,500 lbs	October 31	April 1
Less than 12,500 lbs	October 15	April 15
Less than 10,000 lbs and prior April-January SLH exceeds 7.5 ft.	As soon as possible	April 15

A June catch-per-trip value of less than 12,500 lbs was selected as a catch level that signals the need for some additional precautionary management of shrimp spawning stock biomass. This action level was selected as a proxy for target-based management. Thus when June catch-per-trip drops below this level, the ocean shrimp season will be closed October 15th and will not reopen until April 15th of the following year, to provide some increased protection for egg-bearing females.

When there are indications of an even more severe stock decline, the "limit" action level is reached and fishing is suspended. This is considered to be the case when the mean Crescent City SLH from April of the year prior to January of the current year exceeds 7.5 ft and June catch-per-trip in the current year drops below 10,000 lbs. Continuing to fish under these low-abundance conditions creates an elevated risk of the spawning stock falling below the lowest level previously observed (Hannah and Jones 2014b). The choice of 10,000 lb for June catch-per-trip is based on the 1983 and 1998 values of less than 7,500 lb per trip, adjusted upward by 2,500 lb/trip to account for improvements over time in fishing vessel efficiency. When these two conditions coincide, the shrimp trawl fishery will be closed as soon as possible for the remainder of the season and not re-opened until April 15th of the following year. Under this level of severe stock decline, this action will provide the maximum protection possible for that year's spawning stock biomass and egg-bearing females. Since these target- and limit-based action levels are based on a historical stock-reconstruction model, it is recommended that the assumptions, analysis and action levels be re-evaluated every 5-10 years. Because climate change and other factors are also slowly altering SLH, it is advisable to periodically re-evaluate the relationship between ocean shrimp recruitment and SLH as well.

Section 3 –Glossary of terms and literature cited

I. Glossary of terms

Catchability – The proportion of a population or age group removed by a single unit of fishing effort.

Cross-correlation – The tendency for different variables to change in a similar manner over time.

Ex-vessel price – The price per pound paid to the vessel for shrimp that processors buy.

Limit-based management – Managing a fishery by closing it or reducing catches when a pre-set limit is reached or projected to be reached. The "limit" is typically chosen in an effort to maintain some minimum level of spawning biomass.

Population dynamics - The study of all of the many factors that cause fish stocks to vary in size over time.

Recruitment – The number or biomass of new young individuals entering a fishery for the first time.

Recruit-stock relationship - A mathematical relationship describing how the number of newly recruited individuals influences the number of spawners that same year. For a short-lived stock, this may be a nearly linear relationship, with the spawning stock dependent on recruitment that same year. For a long-lived stock there may be virtually no recruit-stock relationship.

Spring transition - The weather-driven change in ocean surface currents over the continental shelf and upper slope from mostly northwards in the winter to mostly southwards in the spring and summer.

Stock reconstruction model – A type of virtual population model that can be used to estimate a time series of spawning stock, recruitment and fishing mortality rates based on fishery catch-at-age and assumptions of constant natural mortality and catchability.

Stock-recruit relationship – A mathematical relationship describing how the size of the spawning population influences the size of new recruitment of young individuals to the population at a later time. The simplest example would be an upward sloping line, with more spawners generating more new recruits.

Target-based management – The practice of limiting fishery catches to try and always maintain a level of spawning biomass that is projected to reliably produce a known level of sustainable catches, typically maximum sustainable yield (MSY).

Upwelling – The transport of deep ocean water towards the surface. Often associated with offshore transport of surface water.

II. Literature cited

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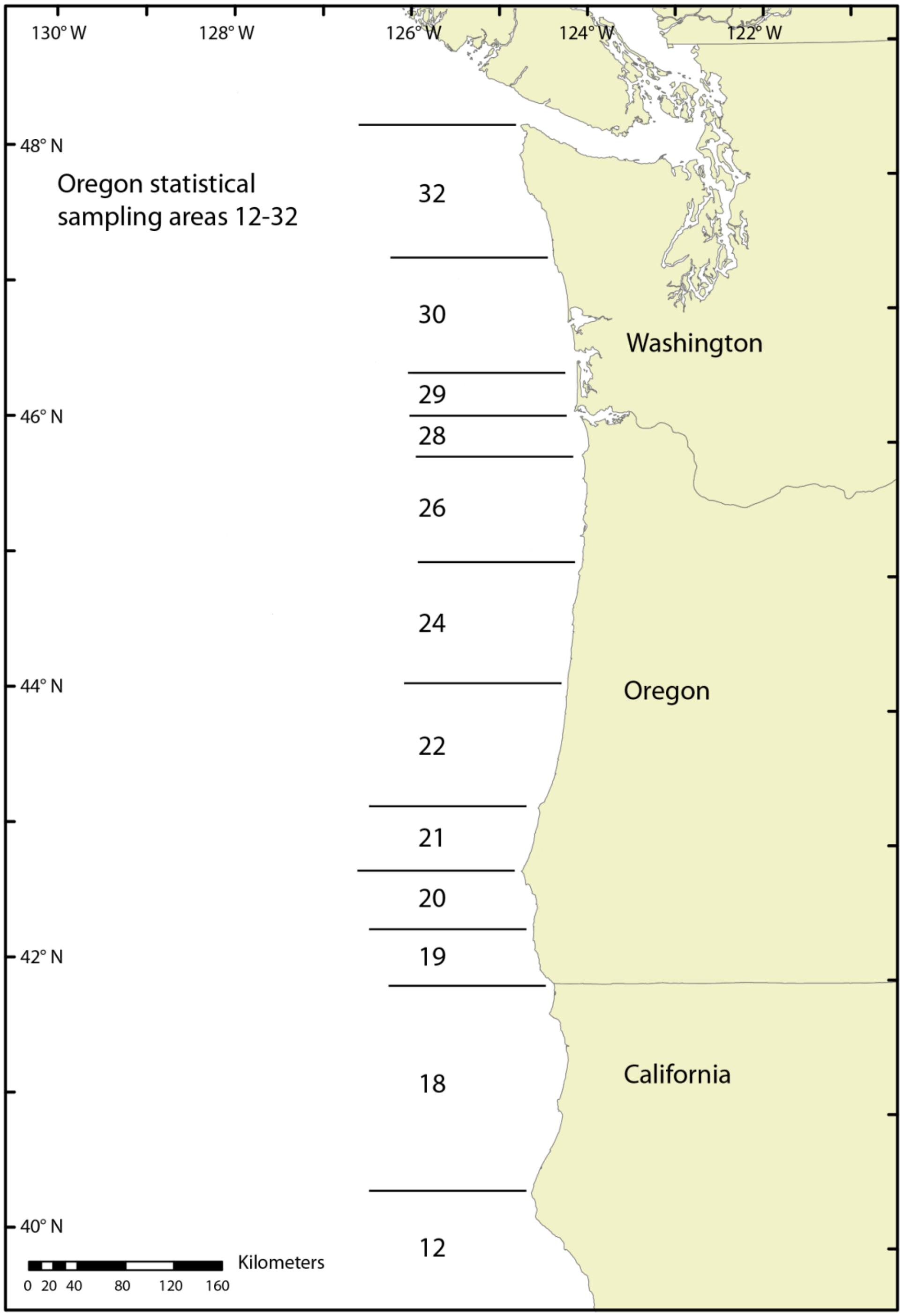


Figure 1. Map of Oregon state statistical sampling areas 12-32.

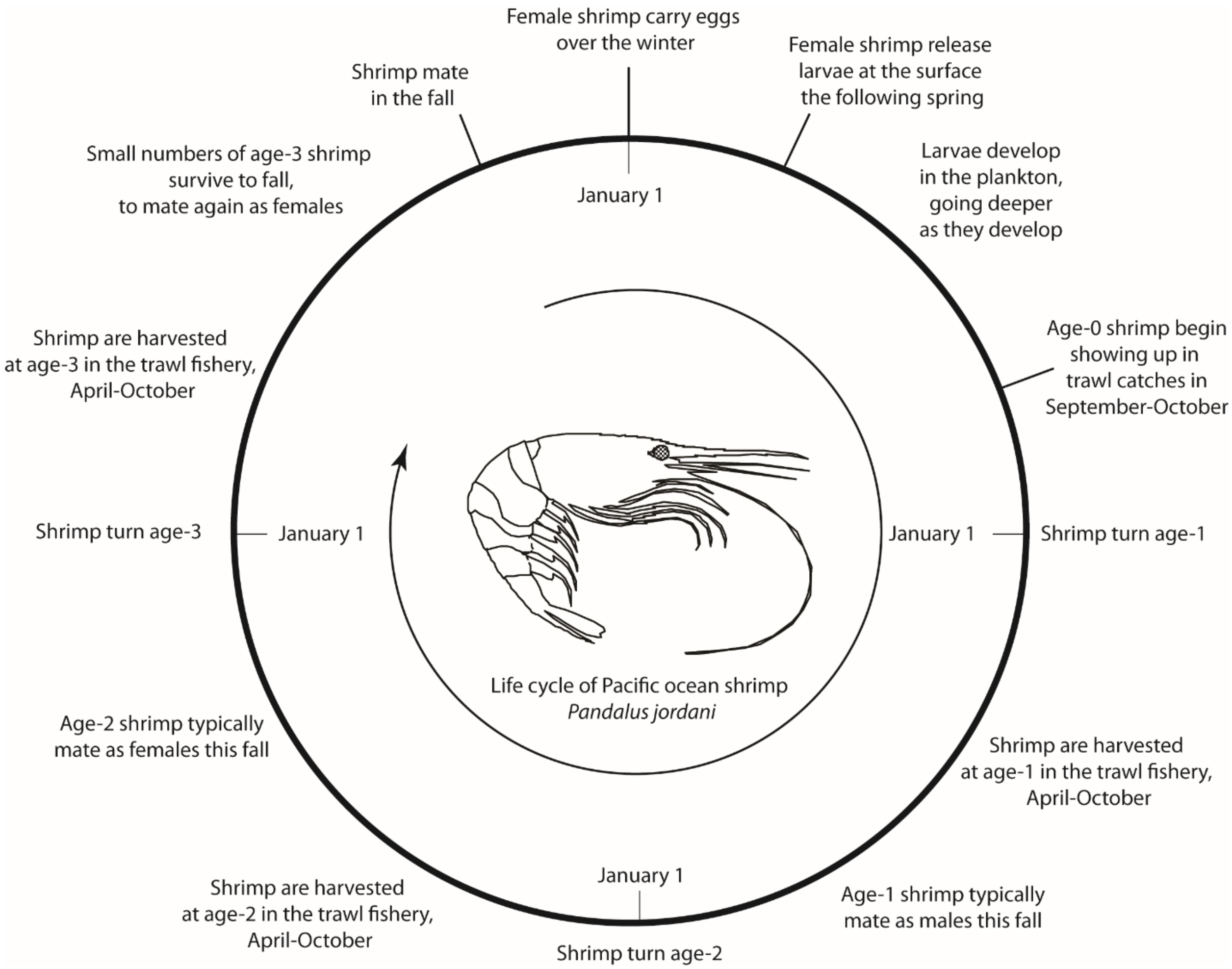
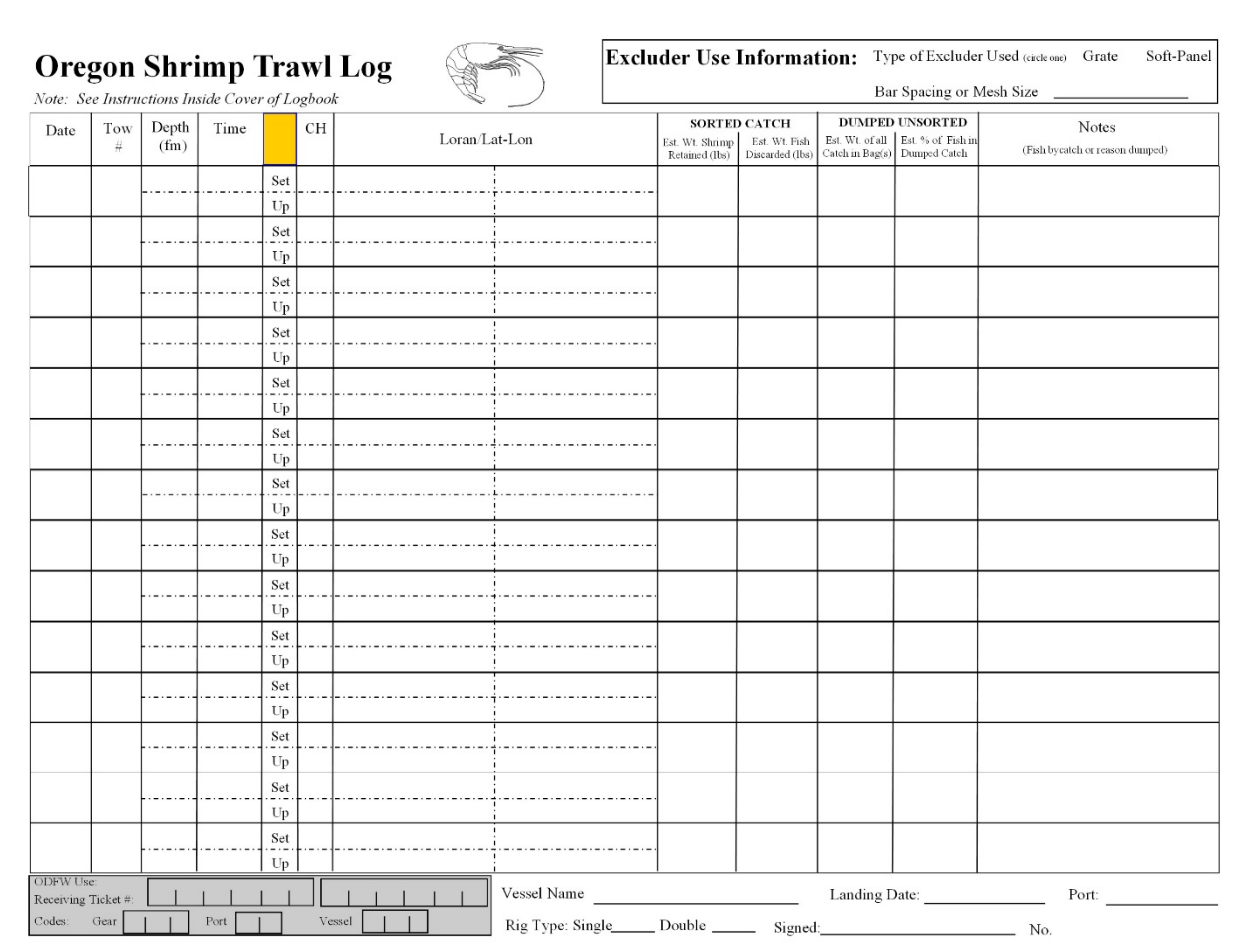


Figure 2. Schematic of the life cycle of Pacific ocean shrimp *Pandalus jordani*.

Figure 3. Sizes of age-1 (bottom), age-2 (middle) and age-3 (top) ocean shrimp in relation to a penny. Note that the age-3 female shrimp at the top is carrying greenish eggs under the abdomen.



Oregon Shrimp Trawl Log

Note: See Instructions Inside Cover of Logbook

Excluder Use Information: Type of Excluder Used (circle one) Grate Soft-Panel

Bar Spacing or Mesh Size ________________

Date	Tow #	Depth (fm)	Time		CH	Loran/Lat-Lon	SORTED CATCH Est. Wt. Shrimp Retained (lbs)	Est. Wt. Fish Discarded (lbs)	DUMPED UNSORTED Est. Wt. of all Catch in Bag(s)	Est. % of Fish in Dumped Catch	Notes (Fish bycatch or reason dumped)
				Set							
				Up							
				Set							
				Up							
				Set							
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ODFW Use:
Receiving Ticket #:
Codes: Gear Port Vessel

Vessel Name ______________________ Landing Date: ______________ Port: ____________

Rig Type: Single_____ Double _____ Signed:______________________ No.

Figure 4. The format of the Oregon shrimp trawl logbook.

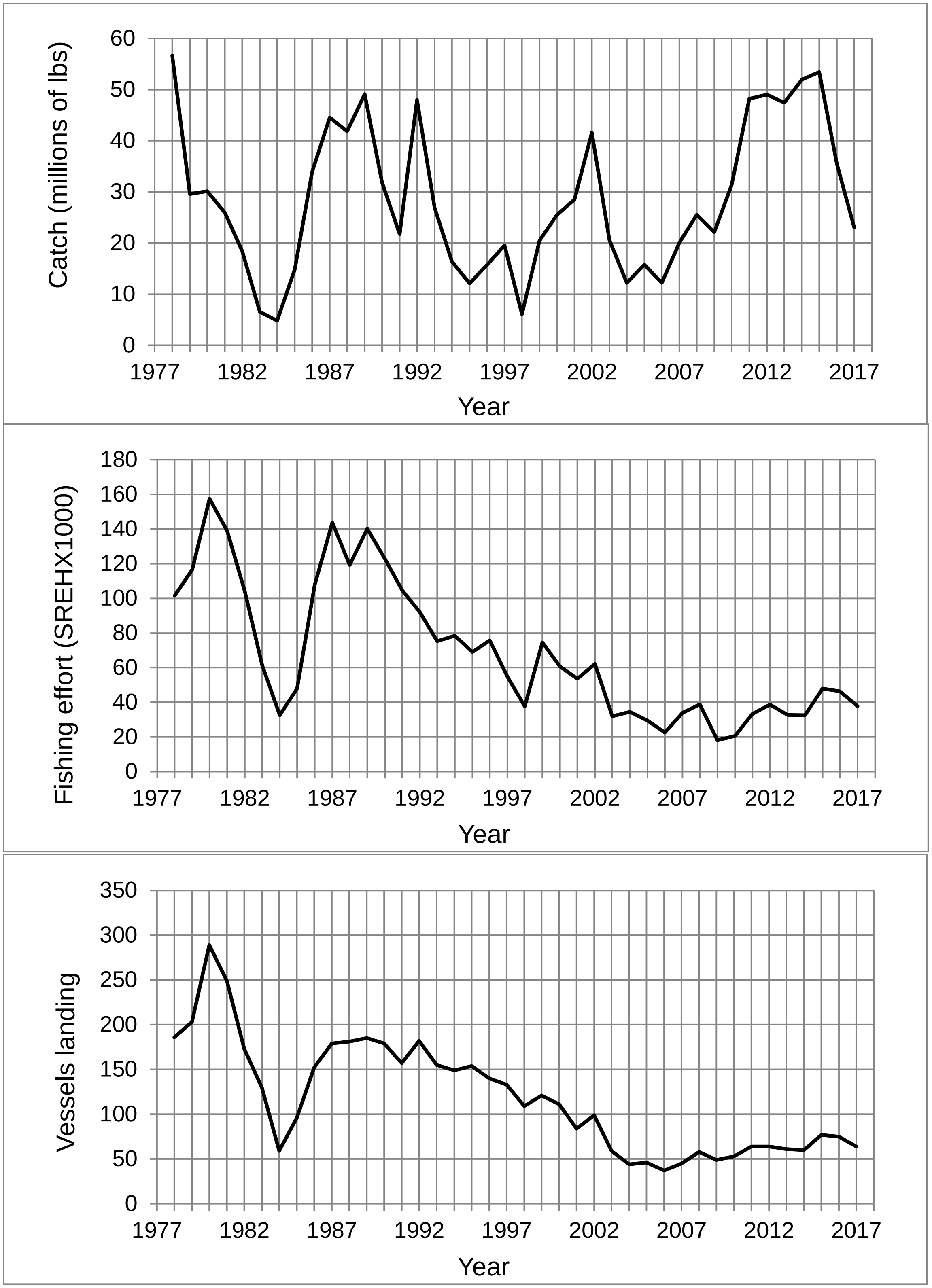

Figure 5. Catch (millions of lbs), effort (thousands of single-rig-equivalent hours) and number of vessels landing, for ocean shrimp landed into Oregon (1978-2015).

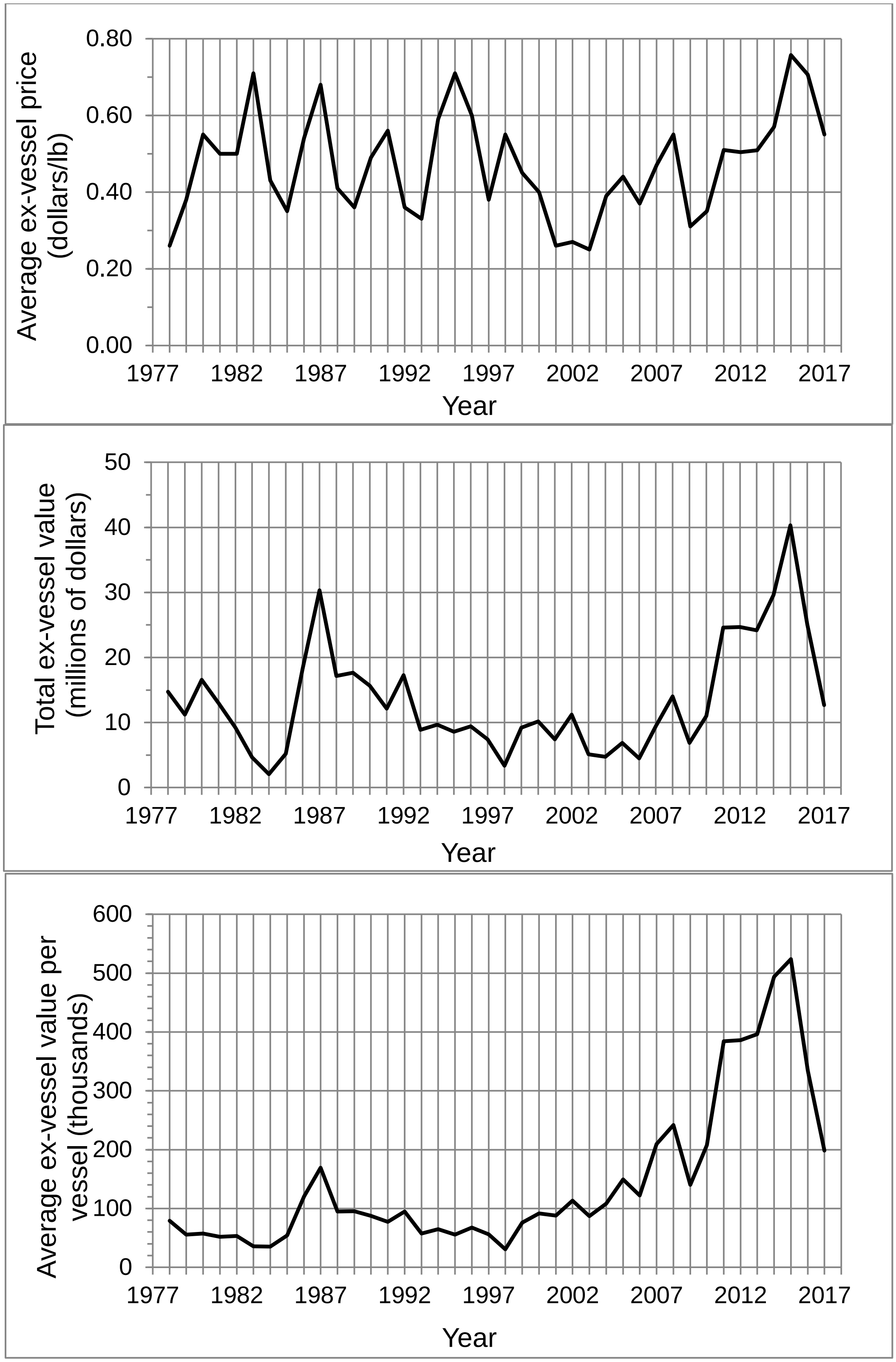

Figure 6. Average ex-vessel price, total ex-vessel value and ex-vessel value per participating vessel, for ocean shrimp landed into Oregon, 1978-2015.

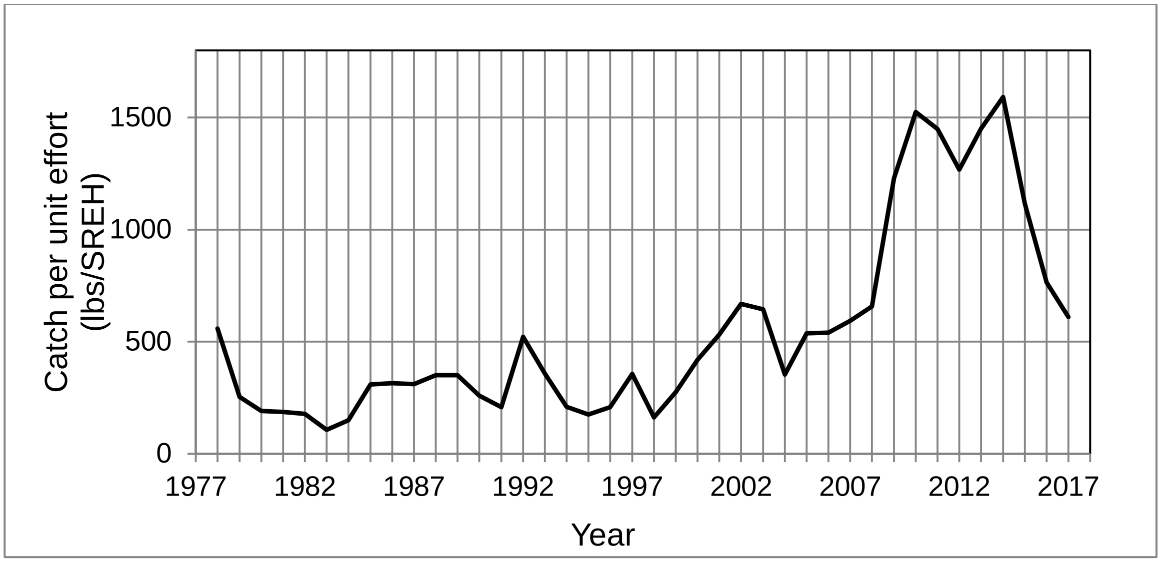

Figure 7. Catch-per-unit-effort (lbs/ single-rig-equivalent hour) for ocean shrimp landed into Oregon (1978-2015).