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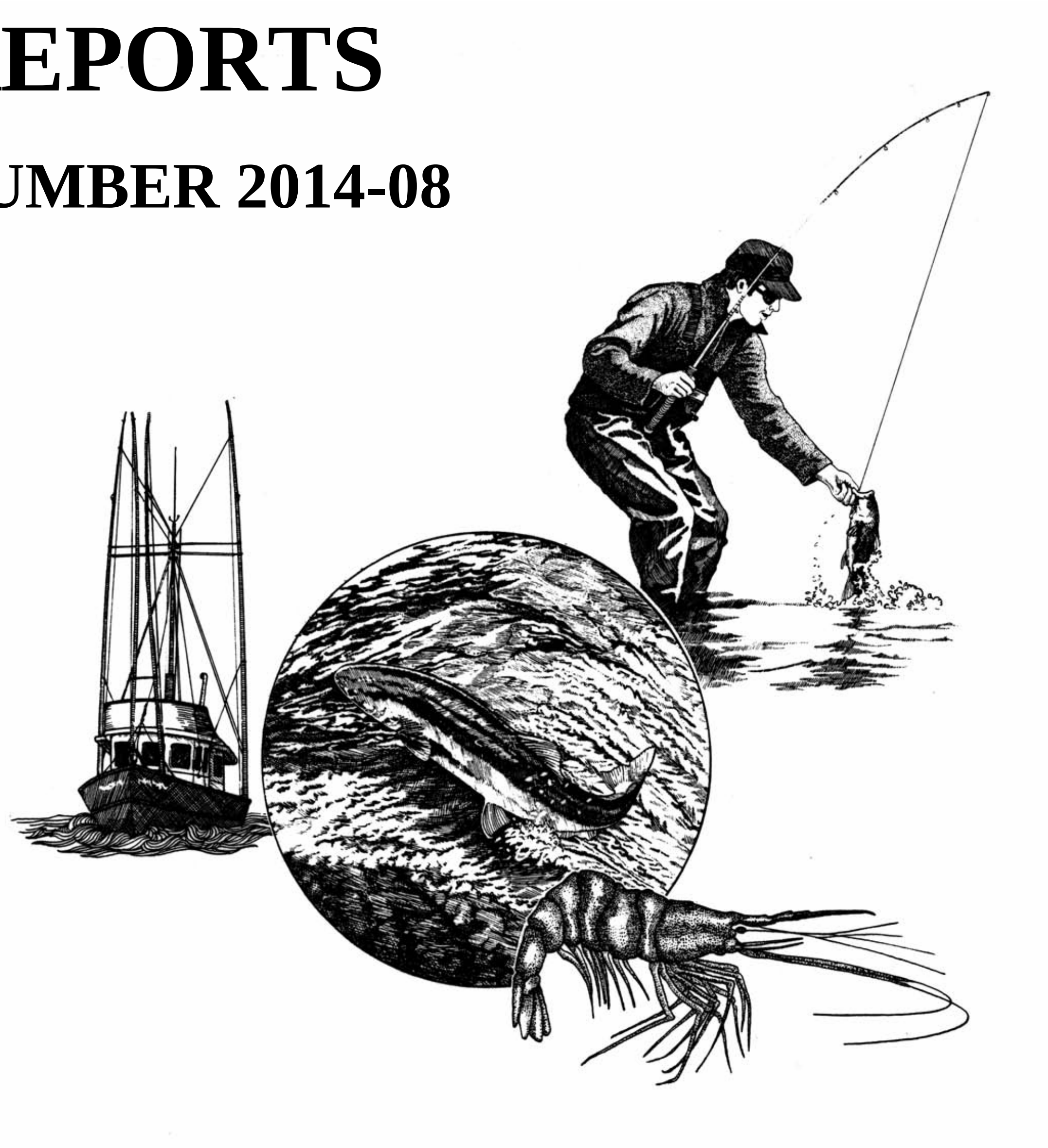

FISH DIVISION

Oregon Department of Fish and Wildlife

The Population Dynamics of Oregon Ocean Shrimp (*Pandalus jordani*)
and Recommendations for Management Using Target and Limit
Reference Points or Suitable Proxies

The Population Dynamics of Oregon Ocean Shrimp (*Pandalus jordani*) and Recommendations for Management Using Target and Limit Reference Points or Suitable Proxies

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Marine Resources Program

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Objective

The research and analysis presented in this document was conducted to develop a scientific framework through which an alternative, more precautionary, management strategy could be evaluated for Oregon's trawl fishery for ocean shrimp (*Pandalus jordani*). The specific intent was to try to relate available practical alternatives for managing this fishery to broadly used tools for managing other fish stocks, such as calculations of B_{MSY} and related target and limit reference points (Mace 1993). This analysis was also conducted, in part, to respond to conditions of the Marine Stewardship Council for continued certification of the Oregon ocean shrimp trawl fishery under their Principles and Criteria for Sustainable Fishing.

Background

History of the fishery

The early years of the Oregon trawl fishery for ocean shrimp 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). Landings for the period 1978-2011 have averaged 25.9 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. Recently (2000-2011), landings (Figure 1) have averaged 25.3 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), peaked in 1981 at 138,900 SREH and has declined to a recent average of 36,624 SREH (Figure 1). The number of vessels participating in the fishery peaked in 1980 at 289 vessels, but was subsequently reduced by a limited entry system that currently allows a maximum of 138 vessels to participate. In recent years (2000-2011), the number of vessels participating in the fishery has averaged 62, partly due to a federal groundfish vessel buyback program implemented in 2003 that also reduced the number of shrimp vessels. In 2011, the National Marine Fisheries Service (NMFS) converted the limited entry groundfish trawl fishery to an Individual Trawl Quota or "catch shares" system. It's presently unclear how this may influence effort in the shrimp trawl fishery, however some vessel operators have expressed concerns that it will increase the number of active shrimp vessels. Extensive time series of summarized data for the fishery, including catch, effort, catch-per-unit-effort (CPUE) and average ex-vessel price can be found in the recent annual fishery newsletters at http://www.dfw.state.or.us/MRP/publications.

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 (ODFW, unpublished data). Since 1993, bycatch reduction technology has also been developed, including footropes that catch fewer small demersal fish (Hannah and Jones 2000) and codend bycatch reduction devices (BRDS) that greatly reduce fish bycatch and the time and effort needed to sort the catch (Hannah and Jones 2007). In fall 1999, processors implemented split-pricing, the practice of paying different ex-vessel prices for shrimp of

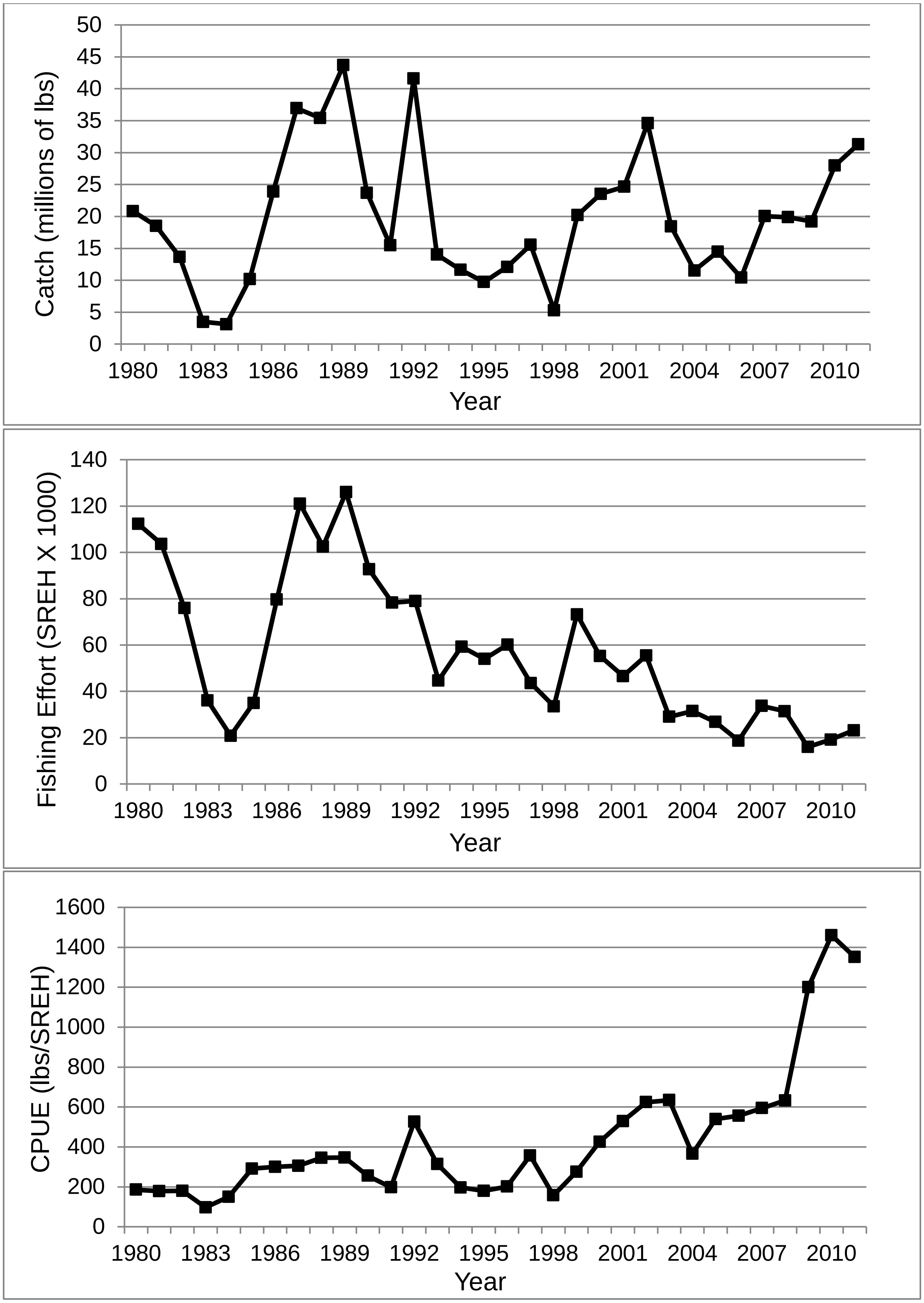

Figure 1. Catch (millions of lbs), effort (single-rig-equivalent hours) and catch-per-unit-effort (CPUE, lbs/ SREH) for the Oregon stock unit.

different sizes, a change that has persisted. This change in economic incentives may have fundamentally altered how vessel operators now target shrimp, shifting the fishery from essentially a target fishery on new recruits (Hannah 1999) to one that targets a more balanced size composition of shrimp.

Shrimp life history

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, 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 or 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 from 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 also 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. 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 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 140 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 if seafloor light levels are reduced by clouds or surface water conditions. 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).

Population dynamics

Due to the lack of a fishery-independent survey for ocean shrimp, all of the recent population dynamics research has been based on recruitment and spawning stock indices derived from fishery-dependent data. These studies 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). 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). This wide variation in recruitment success has been consistently 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).

The mechanism linking low April SLH with improved ocean shrimp recruitment is unknown, however, an early and vigorous spring transition lowers April SLH and also creates conditions that should be favorable for larval survival and retention. 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 published studies, none of the research to date suggests that other confounded measures, such as sea surface temperature, geostrophic currents, or the upwelling of nutrients into surface waters may not actually be the major influence on larval survival or retention. Although an early 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). Generally, the autocorrelation and cross-correlation in ocean environmental variables like sea surface temperature, upwelling and SLH makes it very difficult to use correlative studies to identify likely mechanisms linking the 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). However, multiple regression models that incorporate spawning stock indices and environmental variables such as April SLH show that environmental effects on recruitment are generally much stronger than the influence of variation in spawning stock (Hannah 1999). 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.

Studies of the population dynamics of ocean shrimp have resulted in several 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 the combined effects of demographically-modulated sex change and density-dependent growth (Hannah and Jones 1991). As ocean shrimp are "fished down", juvenating the age structure, accelerated sex change maintains a more constant proportion of females in the population and density-dependent growth increases the number of eggs per female as a function of age.

Oregon's current management strategy

A formal management plan has not been developed for the ocean shrimp fishery. However, the primary management objective for the fishery can perhaps be best described as:

"To maximize net economic yield from the fishery, consistent with preventing the fishery from substantially exacerbating or prolonging the periodic stock declines that result from environmentally-driven recruitment failures in a very short-lived stock."

The ocean shrimp fishery in Oregon is currently managed without target and limit reference points. 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 egg-bearing females are present. Vessels are required to land loads of shrimp with an average count-per-pound of less than 160 shrimp per pound.

Although current management regulations restrain growth in age 1 fishing mortality rates to some degree, they do not act directly to limit the levels of fishing mortality that could be applied to the ocean shrimp resource if fishing effort were to increase substantially. For this reason, ODFW has also maintained an active program of monitoring the shrimp fishery annually, in order to be able to model the stock dynamics periodically and detect any sustained, fishery-related, declines in stock status. This monitoring program is an integral part of the state's management strategy. It includes a mandatory logbook program that allows fishery catch and effort to be identified by state sampling area (Figure 2). 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 from April through October. 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).

Practical alternatives for management of the shrimp fishery

The lack of a fishery-independent survey for ocean shrimp limits the practical alternatives for managing the fishery using a more precautionary approach. Any assessment of current stock size or incoming recruitment of age 1 shrimp depends on the fishery accessing the stock (and being sampled) for a period of several months before the need for more conservative management that year can be established. Since some fishing will need to take place each and every year, regardless of stock status, this means that periodically, the ocean shrimp stock may technically be "overfished". However, if data collected from this initial fishing period can be used to accurately identify that a pre-set stock size threshold is likely to be crossed, a variety of actions are available to reduce fishery impacts on that year's spawning stock.

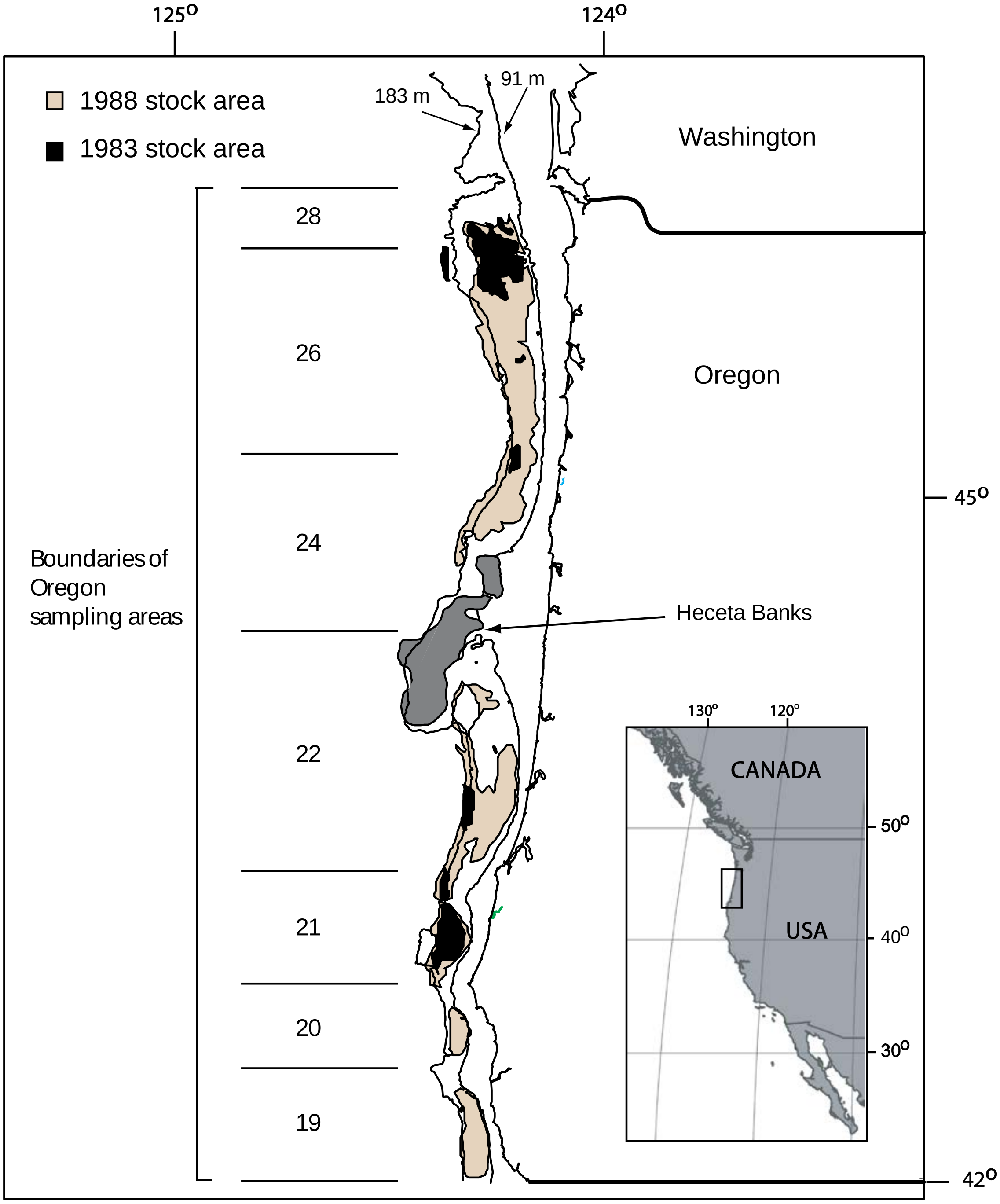

Figure 2. Map of the Oregon shrimp grounds showing state statistical sampling areas 19-28 which comprise the stock unit for population dynamics studies. Also shown are the estimated geographic stock area in a very low and a high production year, 1983 and 1988 respectively.

Stock reconstruction model

To identify historically low stock conditions that might have benefited from additional limits on fishing, a historical stock reconstruction analysis was conducted. A separable VPA, catch-at-age model was fitted to catch-at-age data (ages 1-3) from 1980-2011 as input. The stock unit considered was limited to state sampling areas 19-28 (Figure 2), as has been done for most previous studies of ocean shrimp population dynamics in waters off Oregon (Hannah 1995, Hannah 1999, Hannah 2011). A value for natural mortality of 0.96/y was assumed, following Martell et al. (2000) for British Columbia stocks. It's possible that natural mortality is higher for Oregon ocean shrimp stocks, but the use of this lower value was considered conservative. The model estimated an annual value for fishing mortality F, as well as age-1 recruitment on April 1. The typically modest catches of age zero shrimp that happen each fall were excluded from the model for simplicity. Age 1 selectivity was estimated within the model, but constrained to a step function with a single value for the years 1980-1998, and a lower value for the years 1999-2010, to capture any reduction in age 1 selectivity as a result of the switch to split-pricing, as mentioned above. Selectivity of age 2 and 3 shrimp was assumed to be 1.0. The model was fitted with the "solver" function in Microsoft Excel by minimizing the sum of the squared log deviations of predicted and actual catch-at-age. Annual model estimates of the spawning stock on November 1 were converted into spawning stock biomass using a catch-weighted average of September-October sample estimates of mean carapace length by area (Figure 2) and a length-weight relationship from Zirges et al. (1982).

The modelling results show a reasonable fit to catch-at age data (Figure 3). The residuals from the fitted model (Figure 4) do not show a time trend or any indications of specific fitting problems. They do show an alternating pattern of positive and negative residuals, however this may be due to applying a model that assumes constant catchability within calendar year to a stock in which catchability is known to vary by cohort (Hannah 1995). Age-1 selectivity was estimated within the model to be 0.578 prior to 1999 and 0.465 from 1999 onward. The model estimates of annual fishing mortality (Figure 5) show wide variation but no systematic decline in recent low-effort years, as would be expected with highly variable catchability and hyperstability in F (Hannah 1995). Although annual fishing mortality estimates (Figure 5) generally increased with greater fishing effort (effort is external to the VPA model), the curvature in this relationship reflects the gear interference that occurs in this fishery at high effort levels, as well as the decline in catchability at high stock sizes. The estimated age-1 recruitments (Figure 6) show the extremely wide variation in recruitment demonstrated in several earlier studies, an approximately 14-fold variation from minimum (1983) to maximum (1988) in this analysis. The earlier studies used different time series of fishery-dependent data and constructed different types of indices based on summed catch at age 1 and catch-per-unit-effort data (Hannah 1993), summed catch-at-age (Hannah 2011) or a combination of these methods with direct estimates of geographic stock area from logbook data (Hannah 1999). The natural log of recruitment, as estimated from the catch-at-age model fitted here, was also significantly negatively correlated with April sea level height at Crescent City, California in the larval year (Figure 7, $P<0.05$, Hannah 1993, 1999, 2011). A stronger correlation was found with a longer seasonal average of SLH using the months of April-January (Figure 7), a finding that is consistent with prior unpublished analyses (ODFW, unpublished data). Neither log recruits nor the residuals from this "best" environmental relationship, show any evidence of a relationship with spawning stock biomass in the parent year (not shown), consistent with the findings of Hannah (1993), but contrasting with the findings of

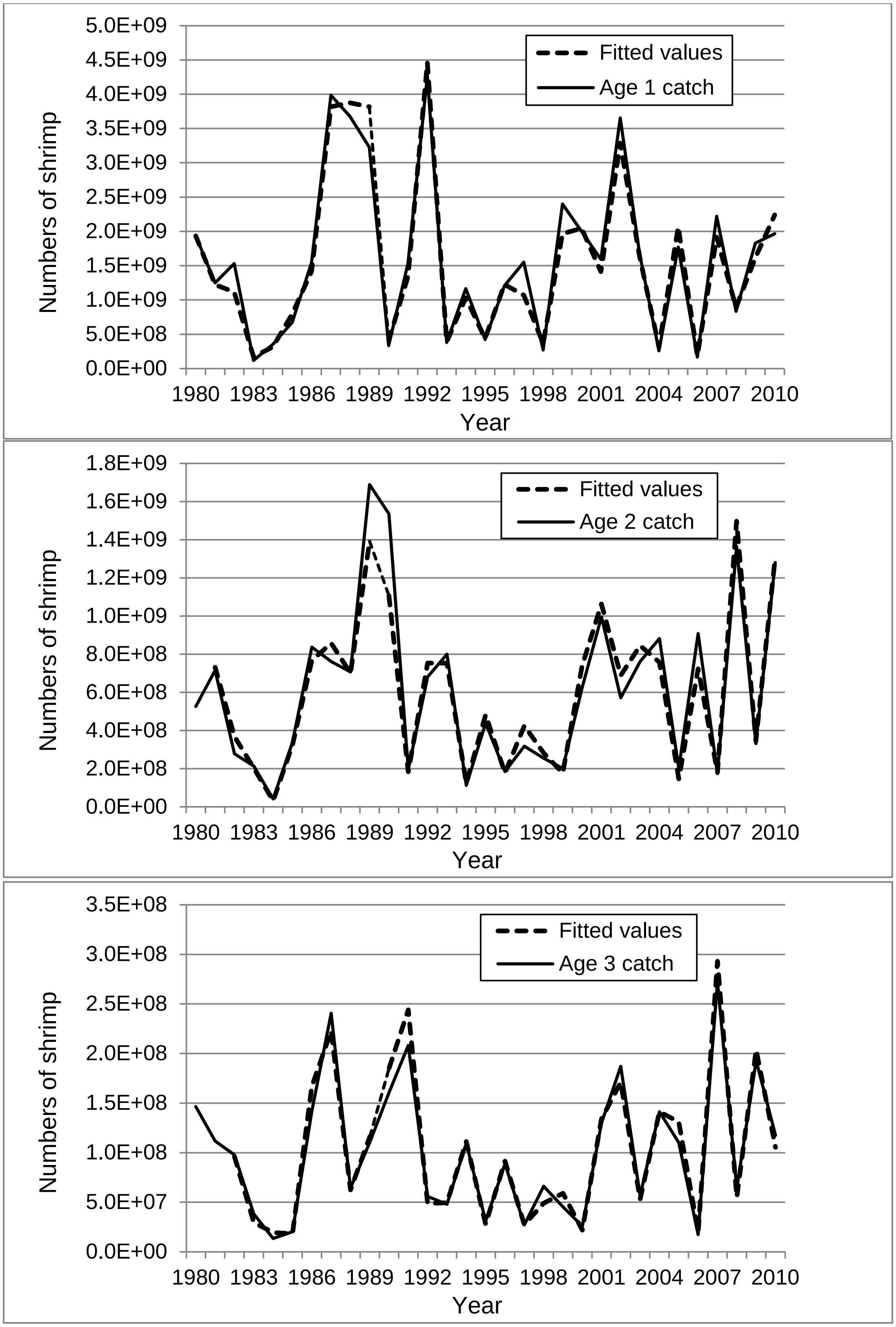

Figure 3. Comparison of ocean shrimp catch at ages 1-3 with model-estimated catches.

Hannah (1999) of some preliminary evidence for a stock-recruit relationship. It should be noted that the environmental relationships shown in Figure 7 do not show good predictive ability for annual recruitment, but mostly reflect a few instances in which warm-phase El Niño Southern Oscillation (ENSO) events causing sharply elevated SLH coincided with severe year class failures in ocean shrimp the following year.

The time series of model estimates of spawning stock biomass (kg, Figure 8) show that the lowest biomass to date occurred in 1983, at a level of about 2.9 million kg. This level was approached again in 1998, and in each case, spawning stock biomass rebounded by the following year. It's notable that these two low levels of spawning biomass were both associated with very strong extra-tropical, warm-phase, ENSO events during the larval year, again showing the dominance of environmental variation and same-year recruitment in determining spawning stock biomass.

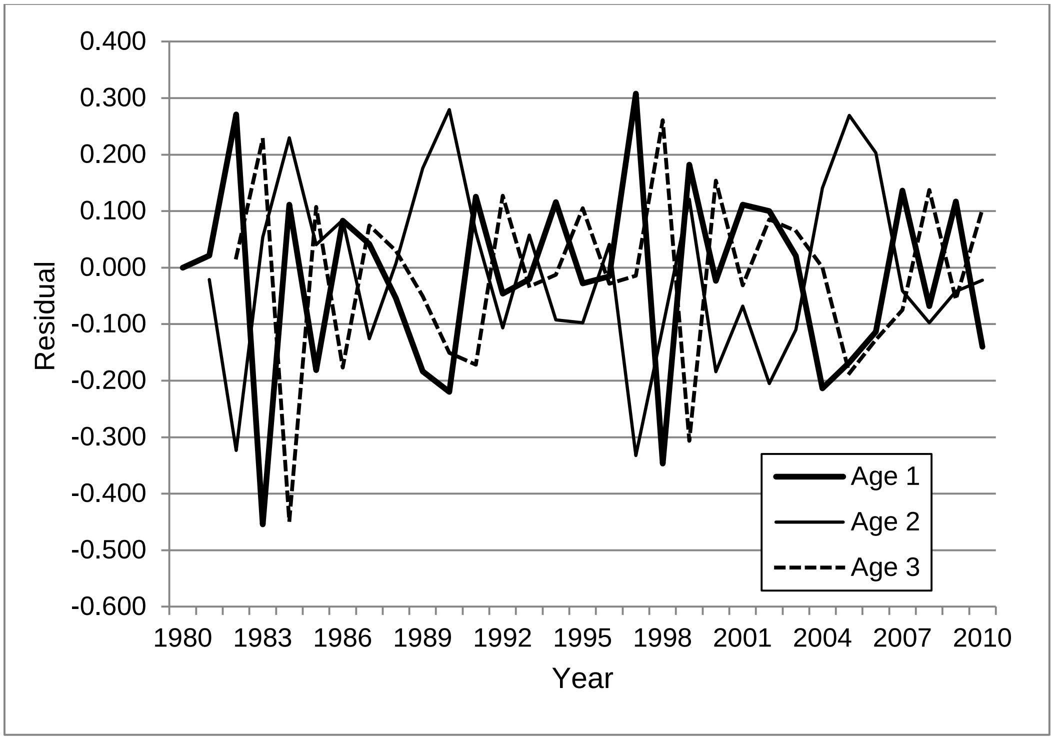

Figure 4. Standardized residuals of model fit to ocean shrimp catch at-age-data.

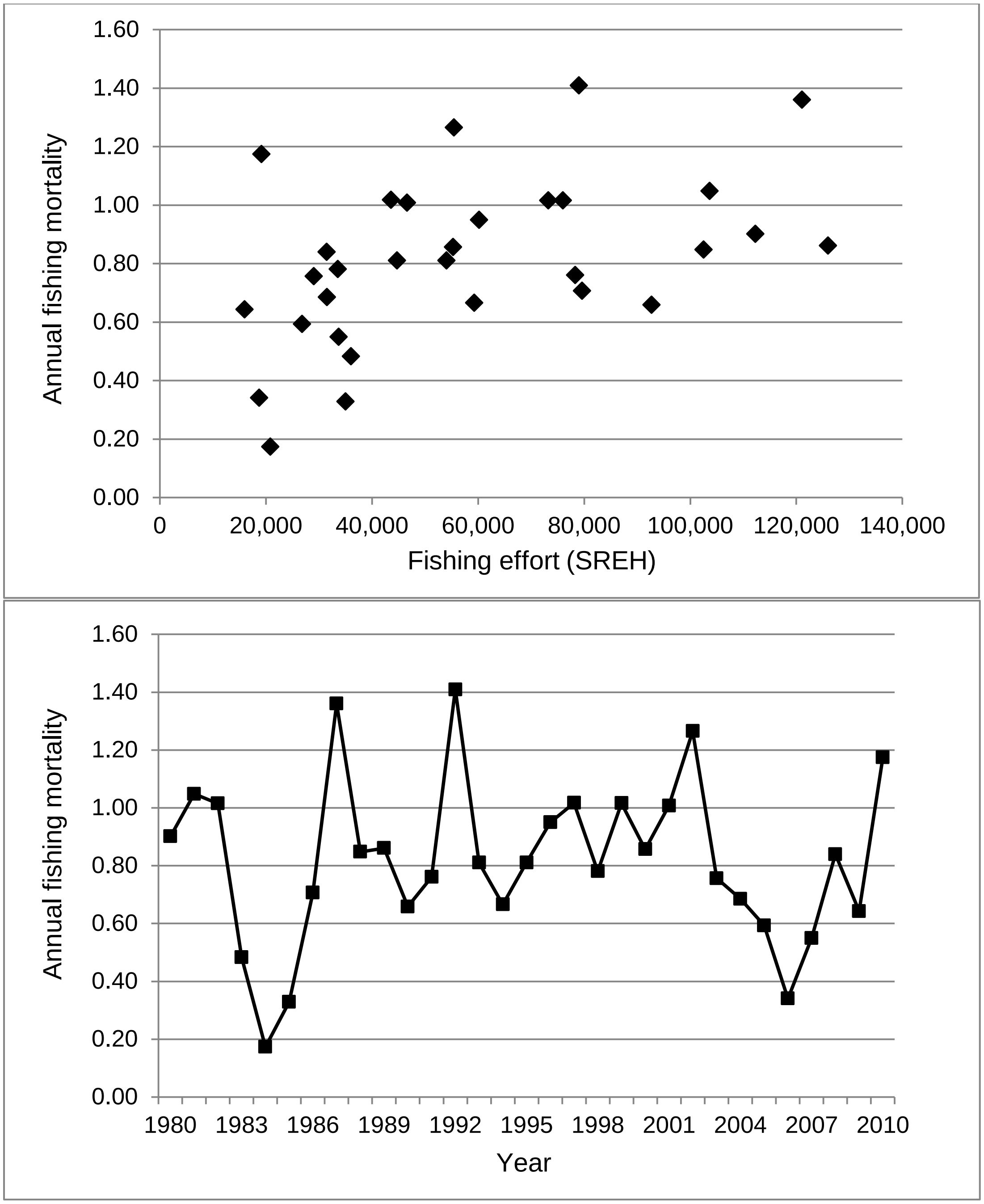

Figure 5. Annual model estimates of fishing mortality, F, by year (lower panel) and compared to annual fishing effort (SREH, upper panel).

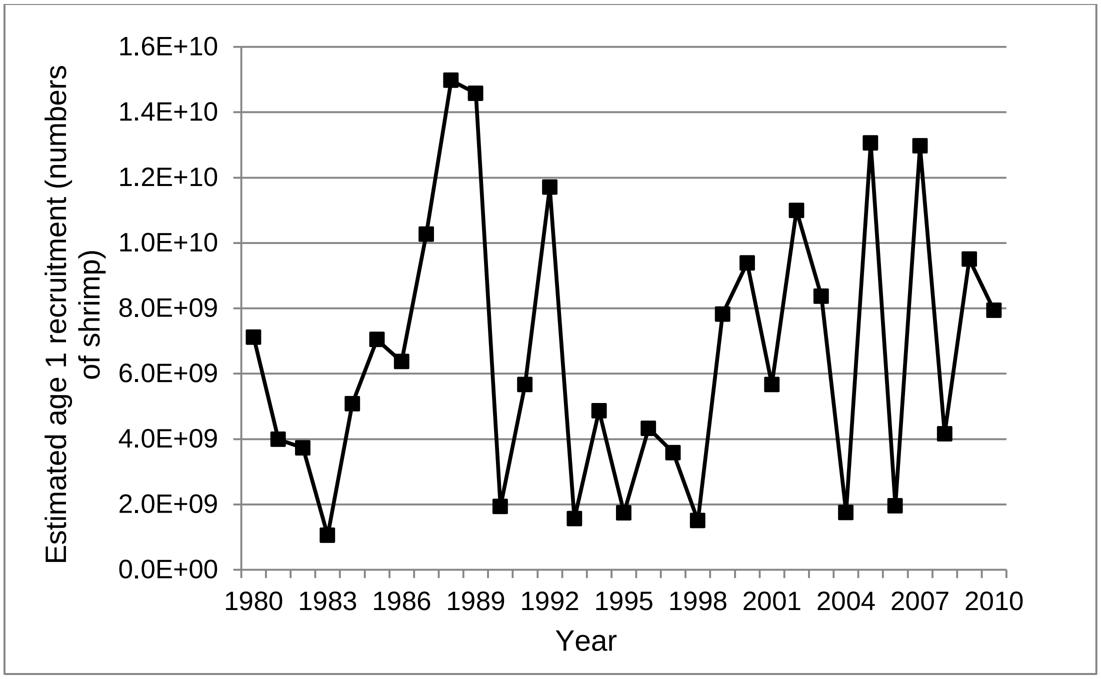

Figure 6. Estimated annual age-1 recruitment of ocean shrimp by year, 1980-2010.

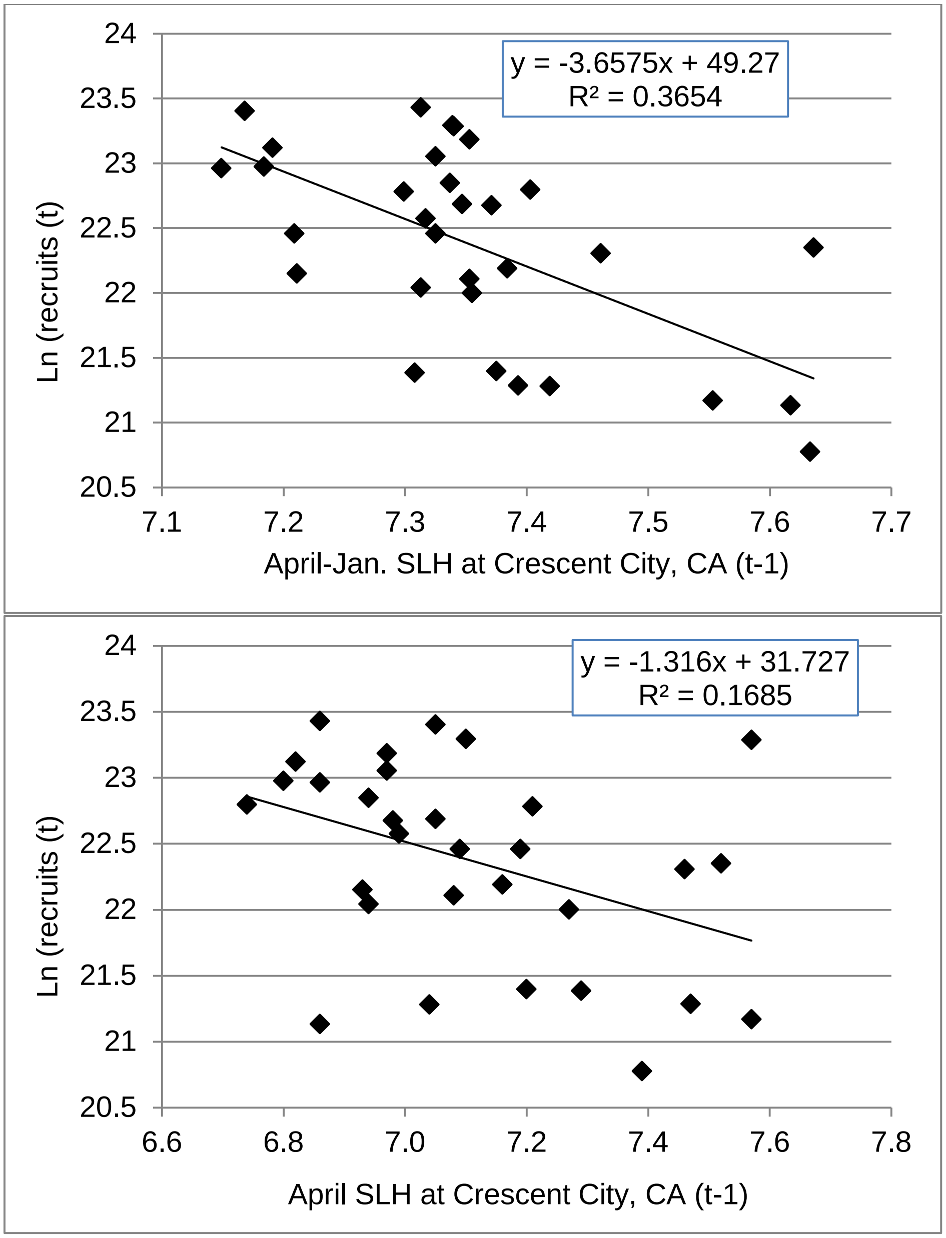

Figure 7. Natural log of model-estimated age 1 ocean shrimp recruitment versus April-January (upper panel) and April (lower panel) mean SLH at Crescent City, California, in the year prior to recruitment to the fishery.

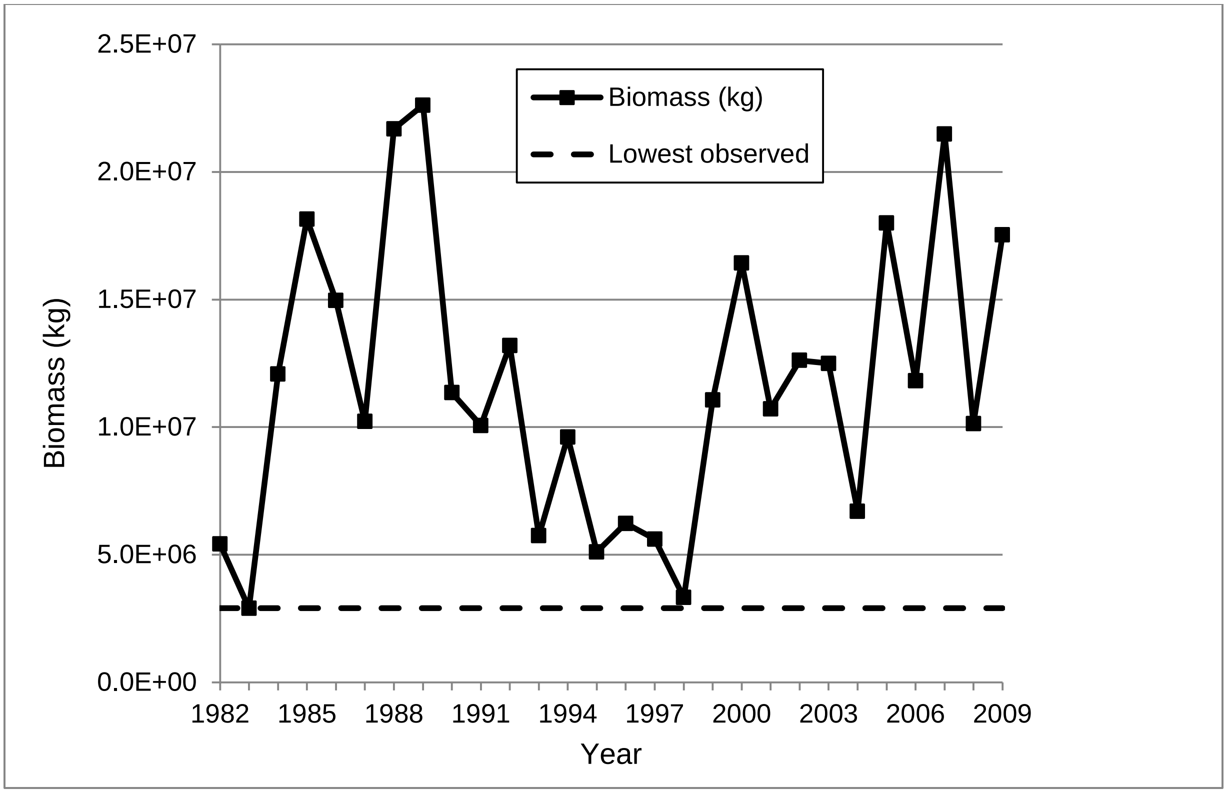

Figure 8. Model estimates of ocean shrimp spawning biomass, 1982-2009 compared to the lowest observed spawning biomass (1983, heavy dashed line).

Proposal for target and limit reference points

Resilience and vulnerability to overfishing

In evaluating target and limit reference point strategies for ocean shrimp, it's notable that target reference point strategies, in general, were developed to try and strike a reasonable balance between fishing mortality rates that are too low to maximize yield and the negative consequences of overfishing, given inevitable uncertainty about stock size and productivity (Clark 2002). Although Oregon's management strategy for ocean shrimp is less precautionary than those applied to many longer-lived fishery resources, a less precautionary approach is appropriate for ocean shrimp because the consequences of overfishing this stock are much less severe than for most fish stocks. Moreover, the consequences, in terms of lost yield, of too conservative harvest management, are much greater for ocean shrimp. The problem of lost yield is simply a function of a very short-lived stock with high natural mortality rates. Martell et al. (2000) estimated natural mortality rates for British Columbia stocks of ocean shrimp at 0.96/y. Hannah's (1995) monthly estimate of 0.15/month suggests an annual natural mortality rate of 1.81/y. Gotshall (1972) estimated natural mortality rates for California stocks that ranged from 0.384 to 1.879, for just the winter months. Such high rates of natural mortality show that if significant yield is not captured from the ocean shrimp stock in the first year of recruitment to the fishery (age 1), much of the yield is lost to natural mortality and is not recoverable.

In evaluating the consequences of overfishing ocean shrimp, several other factors are worth considering. The worst socio-economic consequences of overfishing occur with long-lived stocks that recover slowly, stocks that restrict fishery access to other species (mixed-stock fisheries) and stocks that influence multiple fisheries. Ocean shrimp are short-lived and show a strong ability to rebuild quickly from low population levels, having done so at least 4 times in the modern historical catch series beginning in 1980 (Figure 1). Trawling for ocean shrimp is a single species fishery and thus low population levels of ocean shrimp do not restrict fishery access to other species and impact only the ocean shrimp industry. As such, there is an effective "economic feedback loop" connecting catch rates and fishing effort, as shown by the drops in effort when the stock has declined to low levels (Figure 1).

The historical catch data for ocean shrimp show that any potential consequences of technical "overfishing" of ocean shrimp have been minimal and short-lived, however, the high effort levels of the early 1980's show that if the ex-vessel price is high enough and the other fishery alternatives for vessels are poor enough, substantial fishing effort can develop even when the stock is at lower abundance levels. Thus, some system to constrain harvest rates on the stock when it reaches very low abundance levels is in the best long term interest of the industry.

Suitable limit and target reference points for ocean shrimp

Given this stock's proven ability to rebuild very quickly from the lowest levels observed to date, B_{loss} (lowest observed spawning stock) is an appropriate LRP. If conditions can be identified in-season that accurately predict that the stock may be approaching B_{loss} with continued fishing, the fishery can be closed to prevent the "testing" of even lower spawning stock biomass levels which could result in impairment of reproductive capacity or delayed stock rebound. This strategy is very similar to that used for 3 short-lived penaeid shrimp stocks in the Gulf of Mexico, where environmental conditions also principally determine stock size (Gulf of Mexico Fishery Management Council 2005).

The very rapid stock rebuilding potential of ocean shrimp, along with environmentally-driven recruitment and scant evidence for a stock-recruit relationship makes it difficult to specify an appropriate target reference point that is in any way related to maximum sustainable yield (MSY). A reasonable alternative is to develop an input control rule that reduces the fishery's impact on egg-bearing females whenever there is in-season evidence that spawning biomass may be very low, but significant uncertainty remains. Such an approach would be similar in intent to a target reference point and should meet the requirements of the Marine Stewardship Council that we "maintain the stock at a level consistent with B_{MSY} or some measure or surrogate *with similar intent or outcome*".

In-season prediction of low spawning stock biomass

Although low spawning stock biomass for ocean shrimp is typically a result of failed recruitment from a poor ocean environment during the larval year, it could also be created by extremely heavy fishing or very high natural mortality during an average year. Accordingly, evaluation of indicators of both the ocean environment in the larval year and fishery catch rates during the year of age-1 recruitment should be considered as in-season indicators of stock status. We evaluated the time series of April-January SLH (Crescent City, CA) during the larval year as a potential pre-season indicator of ocean shrimp stock status. As a proxy for the actual biomass of shrimp on the shrimp grounds in a given year, we evaluated the predictive ability of June catch per trip. We chose this month because this is when large numbers of age 1 shrimp begin entering typical trawl catches and is potentially the first "fishery signal" of a weak incoming year class. Also, typically any delays in fishing due to price disputes between processors and fishermen have been resolved by June and the fleet has had adequate time to "prospect" the shrimp grounds and locate concentrations of newly recruited shrimp.

The time series of April-January SLH shows the effect of the two strong ENSO events in sharply elevating SLH (Figure 9). April-January mean SLH values above 7.6 ft were associated with both strong events. The 1983 ENSO elevated SLH well into 1984, however model results suggest that spawning stock biomass in 1984 was not depressed (Figure 8). Saelens and Zirges (1985) speculated that the shrimp stock was shifted northwards in 1984 due to the strong ENSO, resulting in very low catches off Oregon, a phenomenon that may have been reversed in subsequent years, accounting for higher catches of the 1984 year class at older ages and the rebound in spawning stock biomass. The time series of June catch per trip (Figure 9) shows that both of the very low spawning biomass "events" were associated with June catch per trip of less than about 7500 lbs. However, somewhat higher spawning biomass levels in 1982 and 1984 were also associated with June catch per trip below 7500 lb (Figures 8 and 9).

Proposed in-season action levels and actions for target- and limit-based management

Based on the above results, the following approach for implementing target- and limit-based management is proposed for consideration, recognizing that a variety of options exist both for potential in-season indicators of stock status as well as in-season management actions:

As a limit

We propose that a mean April-January SLH greater than 7.5 ft at Crescent City, CA during the larval year, in combination with a June catch per trip in the age 1 harvest year of less than 10,000 lbs provides very strong evidence that there is risk of November spawning stock biomass falling below the lowest level previously observed if fishing were to continue through October. 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. We propose that if and when these two conditions coincide, the shrimp trawl fishery be closed as soon as possible for the remainder of the season and not re-open until April 15th of the following year to provide the maximum protection possible for that year's spawning stock biomass and egg-bearing females.

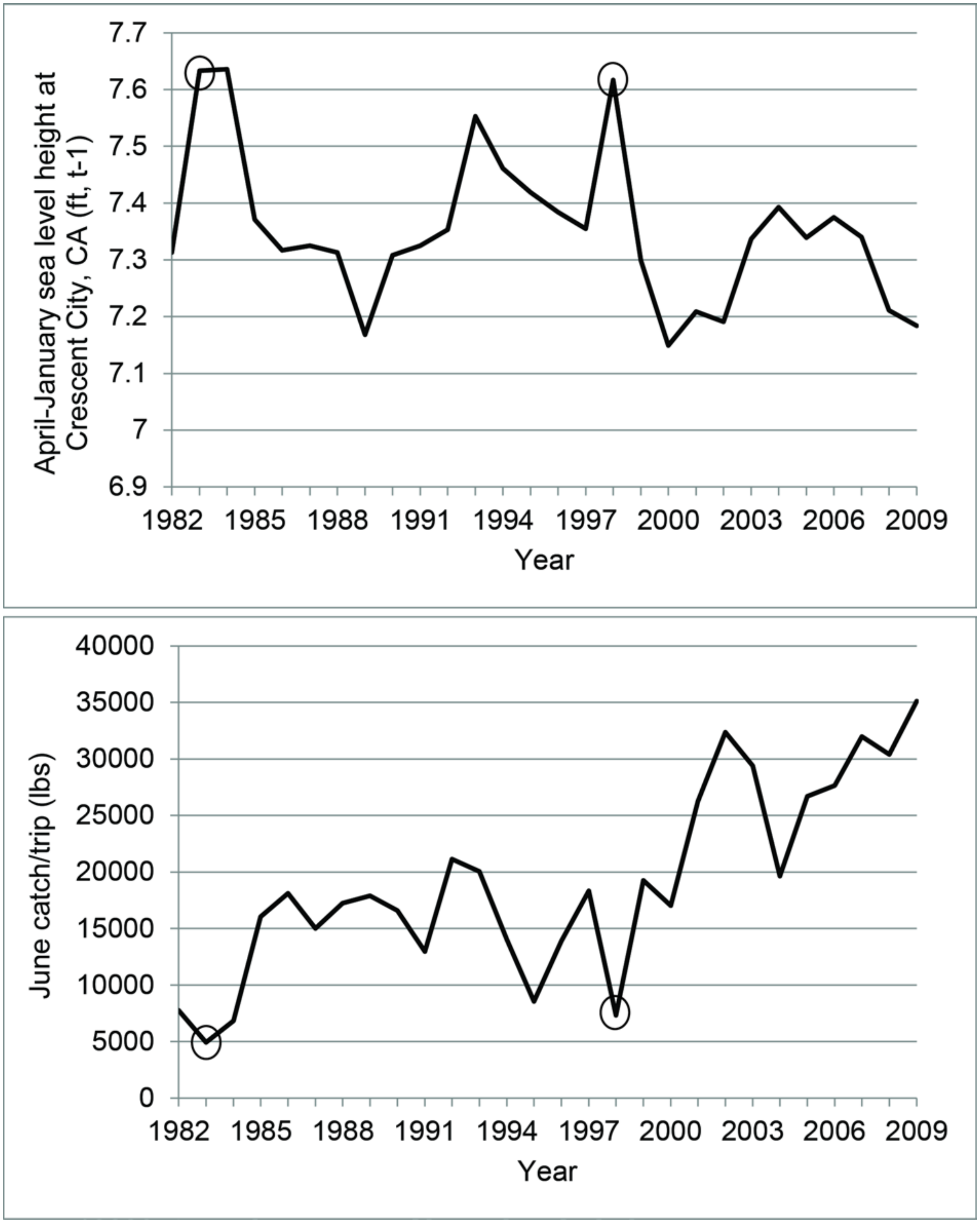

Figure 9. Upper panel shows April-January mean sea level height (feet) at Crescent City, California in the year prior to the year shown (t-1). Lower panel shows June catch/trip (lbs) of ocean shrimp by year. Circled years are 1983 and 1998, years of very low ocean shrimp recruitment and subsequent low spawning.

As a target

Suggesting an approach for target-like management is more difficult for ocean shrimp. However, such an approach should recognize that environment-recruitment models frequently break down over time (Myers 1998), and also that there are indications that global climate change could significantly alter recruitment patterns of ocean shrimp over time (Hannah 2011). Thus, a potentially appropriate action level for ocean shrimp should be based primarily upon in-season catch rates, providing a "back-stop" for the possibility of unexpected environmental changes that could result in persistent low levels of reruitment. We propose that a June catch per trip value of less than 12,500 lbs, regardless of the ocean conditions during the larval year, indicates the need for additional precautionary management of spawning stock biomass. We propose that should June catch per trip drop below this level, the ocean shrimp season should close October 15th and not reopen until April 15th of the following year, to provide increased protection for egg-bearing females.

Looking back

Had these in-season action levels been in place historically, the ocean shrimp fishery would have been closed somewhere around July 15th in 1983, 1984 and 1998. This would have been due to a combination of *both* persistently high sea level during the prior larval year (Figure 8) and June catch levels below 10,000 lb/trip (Figure 9). Curtailment of late October and early April fishing on egg-bearing females, based strictly on June catch per trip falling below 12,500 lbs, would have also been implmented in 1982 and 1995 (Figure 9). Since these proposed recomendations are based on a retrospective analysis, it is recommended that stock reconstruction analysis and evaluation of environmental and spawning stock effects on recruitment be evaluated every 5-10 years and the effectiveness of these in-season "action levels" be reviewed.

Statutory limits on implementation of in-season management measures

Any in-season closure of the Oregon shrimp fishery would prohibit both landings of ocean shrimp into Oregon ports as well as removals of ocean shrimp from waters off of Oregon by commercial vessels landing into either California or Washington. However, removals from ocean waters off of the states of California or Washington, resulting in landings into California or Washington ports (for permitted vessels), absent actions by those states, would continue.

Acknowledgements

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