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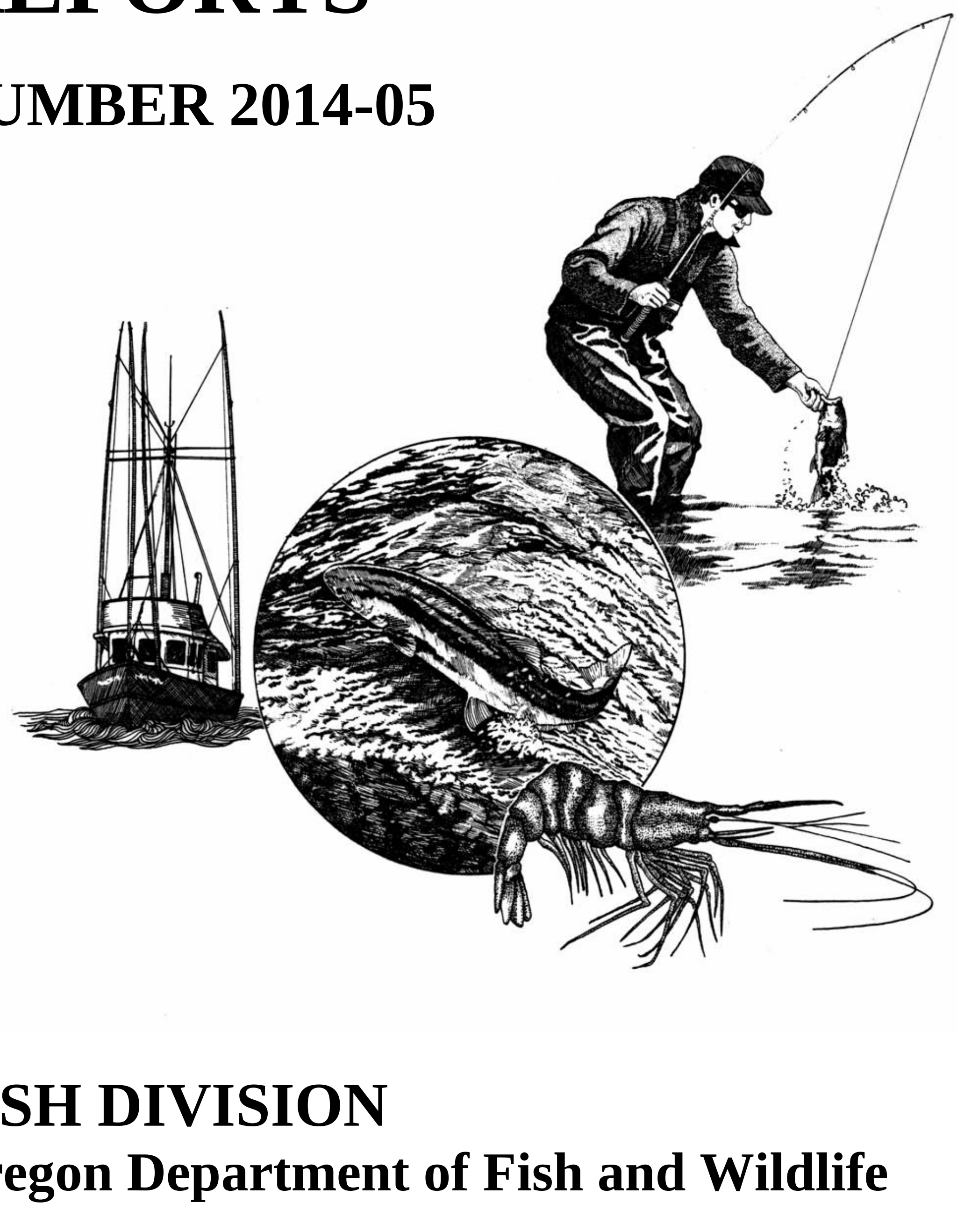

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Effects of climate and fishing on recruitment of ocean shrimp (*Pandalus jordani*): an update of recruitment models through 2013

Effects of climate and fishing on recruitment of ocean shrimp (*Pandalus jordani*): an update of recruitment models through 2013

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Introduction

A key component of Oregon's management strategy for ocean shrimp (*Pandalus jordani*) is an active program for monitoring the status of the stock so that any adverse population-level effects from harvest can be addressed. Oregon's monitoring program has been in place since the early years of the ocean shrimp trawl fishery (Zirges and Robinson 1980) and is ongoing. The basic elements of the monitoring program include fishery landing receipts (fish tickets) and vessel logbooks, from which catch and fishing effort by statistical area (Figure 1) can be derived, and a program to systematically collect biological samples of landed shrimp to determine age and sex composition of the catch and carapace length-at-age (Hannah and Jones 1991).

Ocean shrimp have a life history that makes them resilient to large changes in mortality rates, whether natural or fishery related. They 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). They mate in the fall and the eggs are carried by the females attached to their abdominal appendages over the winter. 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). Female shrimp release larvae in March and April that develop in the plankton for the next 6 months, 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 trawl catches as they recruit to the seafloor in September or October. The fishery captures quantities of ocean shrimp for the following 3 years. Age 1 shrimp typically dominate catches in terms of numbers (Hannah 1999). 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 fall mating at age 2 (Charnov and Hannah 2002).

Studies of the effects of Oregon's large trawl fishery on the ocean shrimp stock have consistently shown that annual recruitment is primarily environmentally driven (Hannah 1993, Hannah 1999, Hannah 2011). Precisely how variation in the ocean environment during the pelagic larval period determines ocean shrimp recruitment remains poorly understood. However, variation in the timing and intensity of the spring transition in coastal currents is believed to strongly influence larval transport and also influences spring sea surface temperatures through upwelling (Huyer et al. 1979, Hannah 1993). However, extremely strong spring upwelling has also been linked to locally depressed recruitment, probably through excessive offshore larval transport (Hannah 2011). The various studies evaluating the effects of fishing on ocean shrimp have consistently shown little evidence for reductions in recruitment due to harvest (Hannah 1993, Hannah 1999). Here, we re-examine that finding by updating the indices of recruitment and spawning stock to include available data through 2013. We also provide a short history of these indices, calculate a new index for the ocean shrimp spawning stock and briefly re-examine the updated relationships between recruitment, spawners and selected environmental variables.

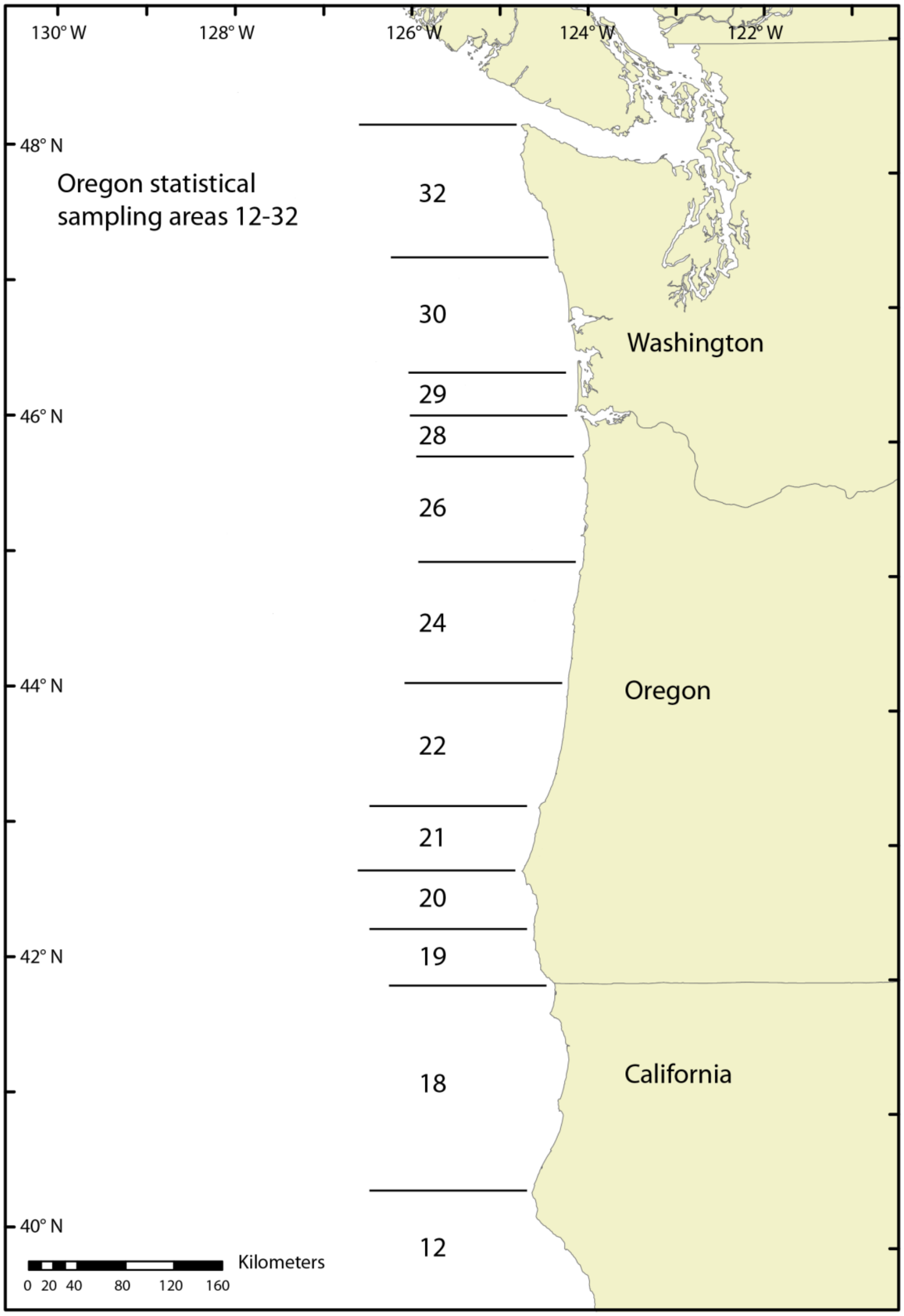

Figure 1. Map showing Oregon's statistical sampling areas 12-32 for the ocean shrimp fishery.

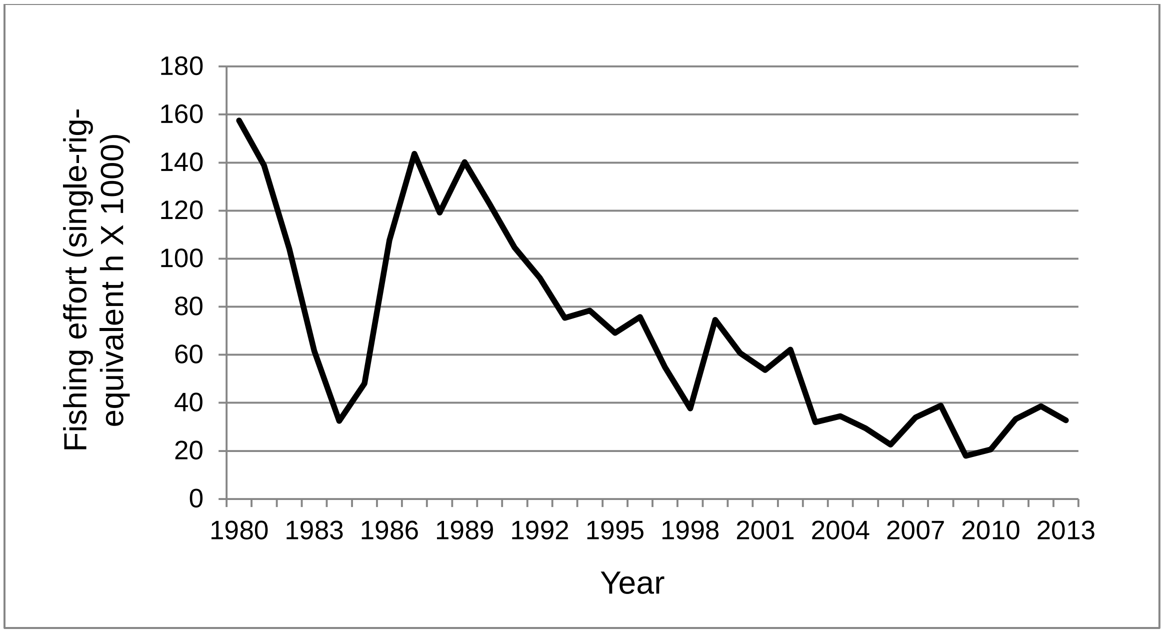

Figure 2. Fishing effort, in thousands of single-rig equivalent hours, for ocean shrimp landed into Oregon ports from all areas (Figure 1), 1980-2013.

Methods

Indices

A variety of methods have been used to index ocean shrimp spawning stock and recruitment (Hannah 1993, Hannah 1999, Hannah 2011). All of the methods used have relied on fishery-dependent data, as no fishery-independent data (e.g. trawl surveys) are available, and have typically utilized catch and effort data from areas 18-28 (Figure 1, Hannah 1993) or areas 19-28 (Hannah 1999, Hannah 2011). Stock and recruitment indices based on fishery-dependent data suffer from a variety of flaws, but have been used with success for ocean shrimp because recruitment varies so widely, creating a high “signal to noise” ratio and also because the fishery for ocean shrimp is very intensive (Hannah 1993). The earliest stock and recruitment indices for ocean shrimp were based primarily on age-specific fishery CPUE (catch per unit effort, Hannah 1993) and were later replaced with indices that explicitly included estimates of geographic stock area (GSA, the spatial area occupied by the stock or by a cohort), which varies widely for ocean shrimp (Hannah 1999). Estimates of GSA were derived from fishery logbook data and depended on the fishery strongly targeting age 1 shrimp each year (Hannah 1999). As fishing effort declined steadily in recent years (Figure 2), this assumption has become less tenable. Also, when different ex-vessel prices for different sizes of shrimp (split pricing) became standard practice after 1999, fishery targeting of age 1 shrimp declined, also undermining this assumption. As a result, GSA estimates from logbook data, following the methods of Hannah (1999), can no longer be used to calculate stock and recruitment indices.

To work around this problem and effectively index recruitment, Hannah (2011) used a simple “virtual population estimate” (VPE) as an index for the years 1980-2006 (year of catch at age 1).

VPE is just a sum of catch-at-age across each cohort. One advantage of a VPE is that it is very simple to calculate for the northern and southern portions of Oregon's shrimp stock separately and thus allows examination of relative trends in recruitment by area (Hannah 2011). More recently, a separable virtual population analysis (SVPA) model has been successfully fitted to ocean shrimp fishery catch-at-age data (areas 19-28, Figure 1) to generate another index of age 1 recruitment (ODFW unpublished data). VPE and SVPA are very similar approaches and yield strongly correlated indices of age 1 recruitment. In this report, we update only the simple VPE approach for indexing recruitment for northern and southern Oregon waters, following Hannah (2011), as well as a combined index for both areas.

A spawning stock index that does not depend on annual estimates of GSA has not been developed for ocean shrimp. In this report, we construct a new index for the ocean shrimp spawning stock and compare it with the GSA-based index calculated following Hannah (1999) for the available data years. To index the fall spawning stock in numbers, we calculated a VPE-based spawner index as:

$$S_t = C_{2,\,t+1} + C_{3,t+2} + C_{3,t+1}, \text{ where,}$$

C_a is the catch in numbers of shrimp of age a,

t = year of age 1 recruitment and fall spawning.

This is essentially a minimum estimate of the age 1 and age 2 ocean shrimp that must have been alive in the fall of year t, because they were captured by the fishery as older shrimp in either of the following two fishing seasons. This simple approach was used, rather than a method indexing spawning biomass or egg production, based on an earlier study that had shown no benefit of using these more complex indices (Hannah 1999). We calculated the spawning stock index for northern and southern Oregon waters, as well as a combined index for both areas.

Regression analysis

We conducted a multiple regression analysis to determine how the relationships between recruitment, spawning stock and selected marine environmental variables from the larval period have been altered by the addition of several years of additional data. Our primary purpose was to better understand how variation in the spawning stock influences subsequent recruitment. Thus, we fit a variety of models similar to the ones previously evaluated by Hannah (1999, 2011), both with and without the spawning stock indices. This analysis utilized log-transformed values of the recruitment and spawning stock indices and assumed a log-normal error structure. To evaluate this assumption, the residuals from the best fitting model were tested for normality with a goodness of fit test. The marine environmental variables we included were those from the pelagic larval period that have previously been shown to be related to ocean shrimp recruitment, specifically April sea level height (SLH) at Crescent City, California, and for southern Oregon ocean shrimp, the April-July upwelling index at 42° N. latitude (Hannah 2011). It should be noted that many different marine environmental variables are strongly cross-correlated and most are also serially autocorrelated, making the selection of a single "best" variable or time period for understanding environmental forcing of ocean shrimp recruitment problematic. However, we did include an additional environmental variable designed to reflect a longer term average of surface transport and sea surface temperature conditions during the ocean shrimp pre-recruit time period. Specifically, we evaluated the 10-month (April-January) average SLH at Crescent City California as a predictor of ocean shrimp recruitment. We chose this time period based on results from the exploratory analysis of correlations between ocean shrimp recruitment and marine environmental variables in Hannah (1993) that showed significant correlations between recruitment and various environmental variables up to a year following larval release.

Sensitivity of recruitment to variation in the spawning stock

We also evaluated the relative effects of variation in the ocean shrimp spawning stock and the ocean environment on age 1 recruitment. We first selected a multivariate regression model that included both the spawner index and environmental variables and then profiled predicted recruitment across varied levels of these variables. We modeled the effect of spawning stock on recruitment using the mean, and 10^{th} and 90^{th} percentiles of the spawning stock index to represent average, low and high spawner abundance, respectively. Using the same values for the environmental variables, we evaluated the effect of variation in spawner abundance on predicted recruitment under average, favorable and unfavorable conditions for larval survival.

Results

Indices

The updated VPE-based recruitment index (year t) for northern and southern Oregon (Table 1, Figure 3) showed a large increase in recruitment in southern Oregon waters after 2008. This represents a reversal of the situation seen from 1999-2003 in which northern Oregon recruitment was strong while recruitment off southern Oregon was much weaker (Hannah 2011).

The VPE-based spawner index (Table 2, Figure 4) showed that the reversal of north-south shrimp recruitment distribution in recent years very quickly altered the abundance and distribution of spawners. Several large, southerly-distributed recruitment events, in combination with reduced total fishery effort, created a large increase in spawner abundance on the southern Oregon coast (Figures 3 and 4). The VPE-based spawner index we developed was well correlated ($P<0.0001$, $r^2=0.6447$, Figure 5) with the GSA-based spawner index from Hannah (1999), but did differ markedly in some years. Graphs of recruitment in northern and southern Oregon waters versus the respective spawning stock indices for the parent year do not show strong evidence for a meaningful stock-recruitment relationship in either area (Figure 6).

Table 1. VPE-based recruitment index (numbers of shrimp) for northern and southern Oregon ocean shrimp (see text) for age 1 recruitment years 1980-2011.

Year	Northern Oregon recruit index	Southern Oregon recruit index	Combined index
1980	728,616,363	2,019,024,896	2,747,641,259
1981	405,882,000	1,159,289,000	1,565,171,000
1982	360,356,000	1,401,452,000	1,761,808,000
1983	85,954,000	107,994,000	193,948,000
1984	422,350,000	411,394,000	833,744,000
1985	1,207,136,000	544,513,000	1,751,649,000
1986	1,210,598,000	1,164,884,000	2,375,482,000
1987	3,459,191,000	1,352,859,000	4,812,050,000
1988	2,969,139,000	2,568,127,000	5,537,266,000
1989	1,997,855,000	2,986,657,000	4,984,512,000
1990	322,311,000	263,278,000	585,589,000
1991	814,968,000	1,449,799,000	2,264,767,000
1992	1,103,498,000	4,088,133,000	5,191,631,000
1993	123,130,000	403,052,000	526,182,000
1994	438,091,496	1,261,901,052	1,699,992,548
1995	296,599,432	338,872,938	635,472,370
1996	485,416,725	1,106,990,917	1,592,407,642
1997	376,535,724	1,475,139,756	1,851,675,480
1998	294,338,065	198,348,198	492,686,263
1999	2,006,092,327	1,115,996,493	3,122,088,820
2000	2,412,733,990	644,085,999	3,056,819,989
2001	1,502,743,294	672,373,104	2,175,116,398
2002	4,056,114,228	492,166,634	4,548,280,862
2003	2,547,679,356	99,802,655	2,647,482,011
2004	401,818,540	79,094,079	480,912,619
2005	2,249,139,156	701,863,226	2,951,002,382
2006	196,403,843	209,927,836	406,331,679
2007	2,096,425,166	1,687,833,415	3,784,258,581
2008	309,505,532	980,923,212	1,290,428,744
2009	832,893,452	2,569,655,714	3,402,549,166
2010	932,201,506	3,547,139,865	4,479,341,370
2011	859,111,929	3,595,117,951	4,454,229,880

Table 2. VPE-based spawner index (numbers of shrimp) for northern and southern Oregon ocean shrimp (see text) for fall spawning years 1981-2011.

Year	Northern Oregon spawner index	Southern Oregon spawner index	Combined spawner index
1981	188,170,000	226,602,000	414,772,000
1982	50,392,000	215,823,000	266,215,000
1983	22,953,000	51,855,000	74,808,000
1984	356,766,000	144,190,000	500,956,000
1985	922,524,000	297,198,000	1,219,722,000
1986	722,498,000	344,031,000	1,066,529,000
1987	505,496,000	376,698,000	882,194,000
1988	938,984,000	1,021,971,000	1,960,955,000
1989	827,756,000	1,077,499,000	1,905,255,000
1990	221,313,000	238,875,000	460,188,000
1991	312,064,000	473,292,000	785,356,000
1992	445,053,000	512,118,000	957,171,000
1993	96,678,000	156,991,000	253,669,000
1994	164,232,496	394,888,052	559,120,548
1995	116,133,928	184,533,990	300,667,918
1996	231,805,096	179,616,795	411,421,891
1997	267,939,673	94,185,783	362,125,456
1998	147,667,705	123,827,880	271,495,585
1999	586,190,800	158,222,804	744,413,604
2000	1,104,875,975	152,063,065	1,256,939,040
2001	677,281,471	137,715,692	814,997,163
2002	917,327,895	27,523,752	944,851,647
2003	1,076,233,654	56,868,459	1,133,102,113
2004	260,371,914	68,488,966	328,860,880
2005	761,457,715	436,528,597	1,197,986,312
2006	303,244,166	207,657,531	510,901,697
2007	978,246,483	642,792,536	1,621,039,019
2008	240,005,163	402,224,048	642,229,211
2009	475,128,479	1,210,638,823	1,685,767,302
2010	472,807,710	2,310,419,672	2,783,227,382
2011	749,927,385	2,856,106,997	3,606,034,382

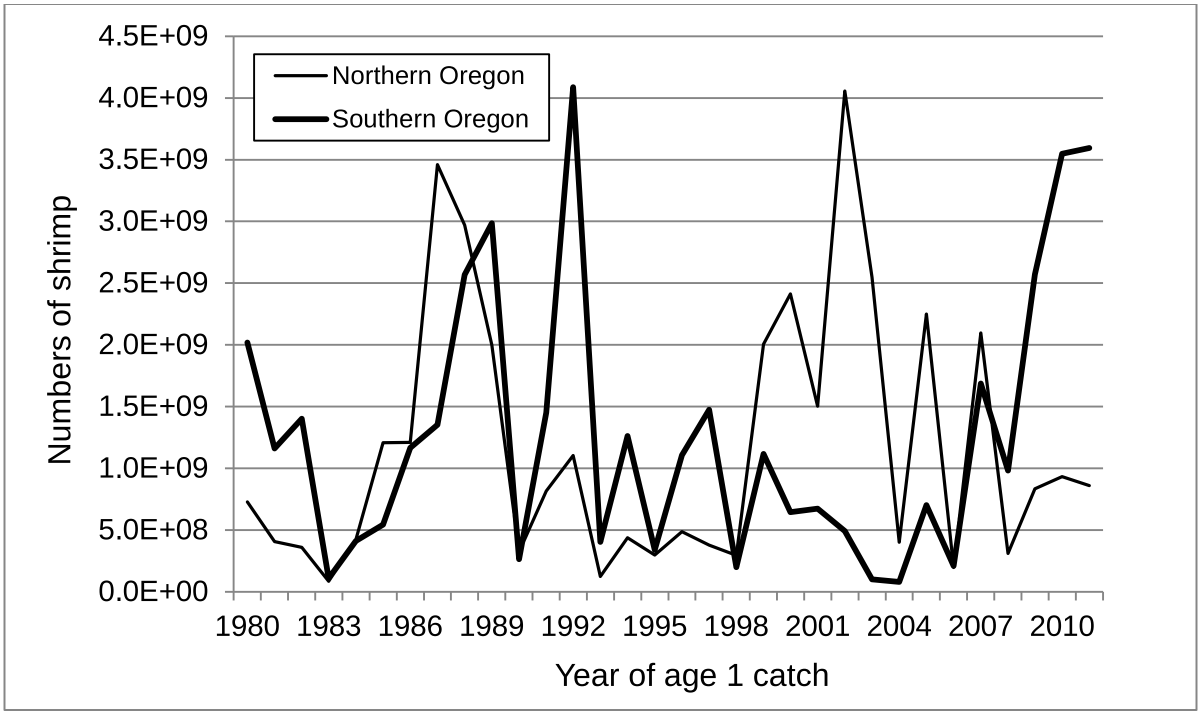

Figure 3. Ocean shrimp VPE-based recruitment index (see text) for northern (areas 24-28, Figure 1) and southern (areas 19-22, Figure 1) Oregon waters, for age 1 recruitment years 1980-2011.

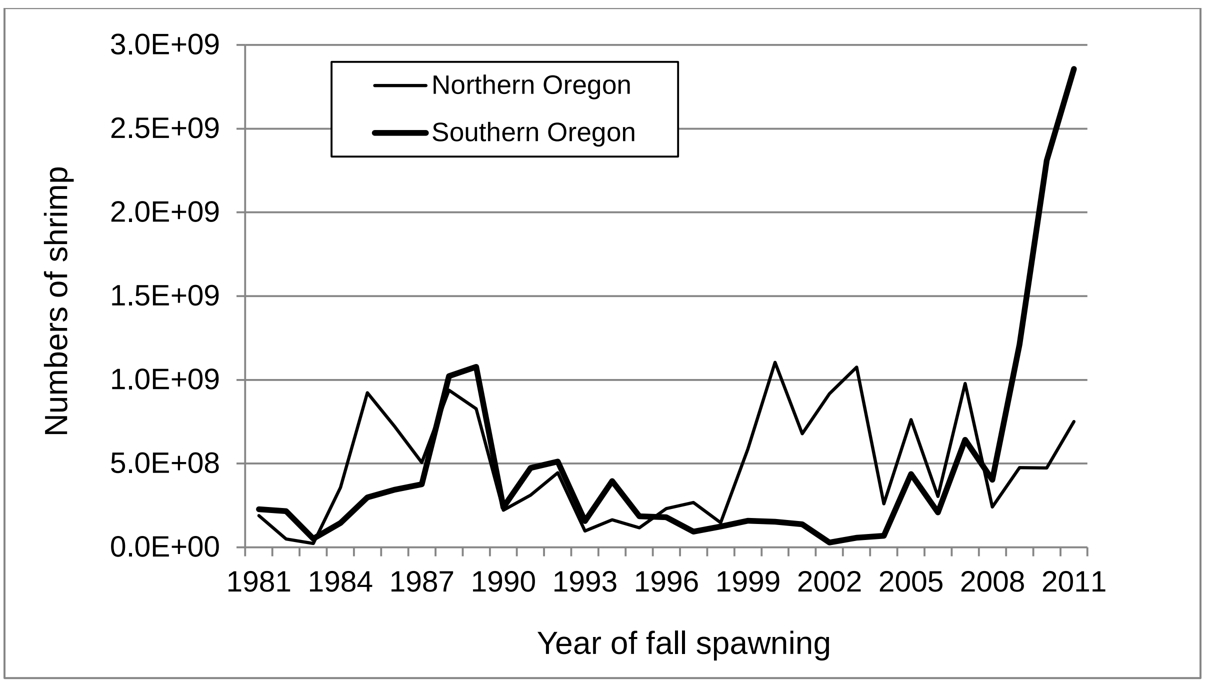

Figure 4. Ocean shrimp VPE-based spawner index (see text) for northern (areas 24-28, Figure 1) and southern (areas 19-22, Figure 1) Oregon waters, for spawning years 1981-2011.

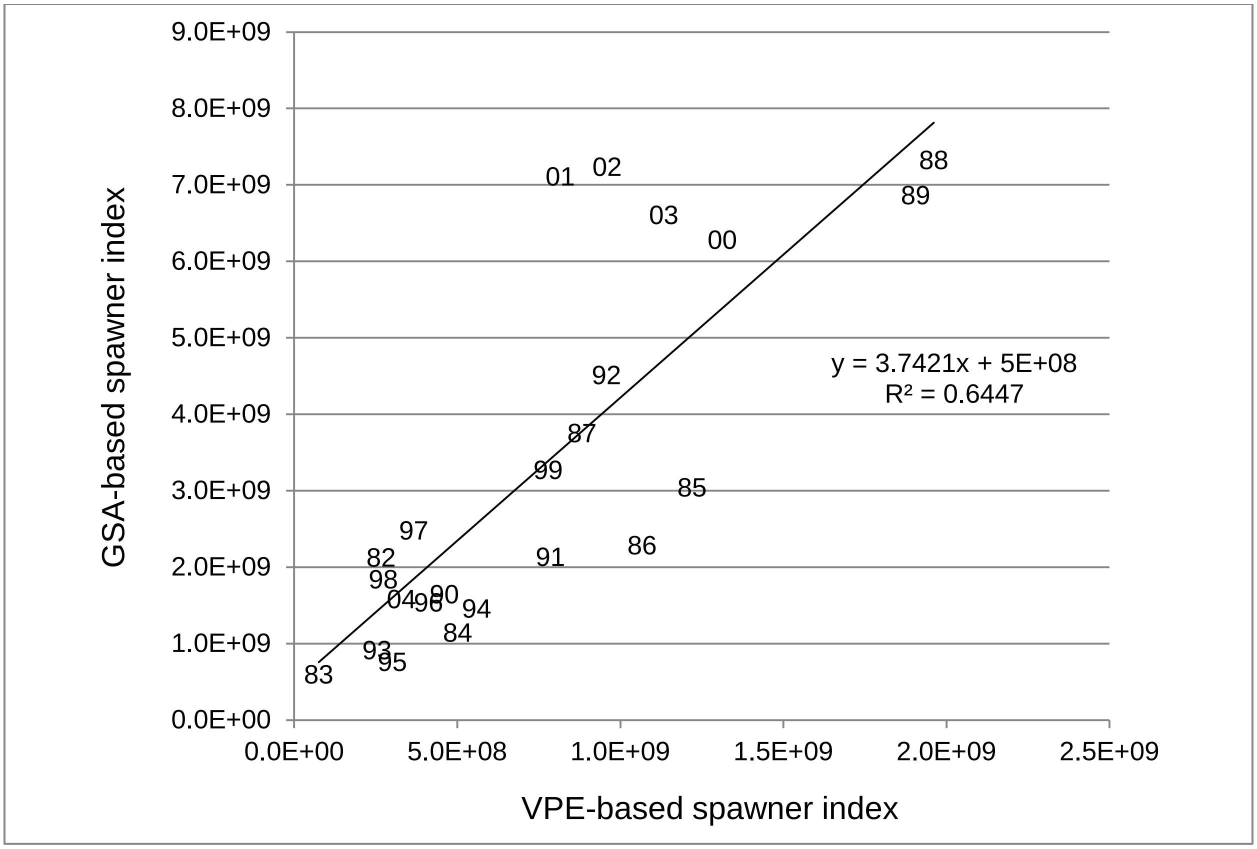

Figure 5. Comparison of a new, VPE-based spawning index for ocean shrimp with a GSA-based index (following Hannah 1999), for spawning years 1982-2004.

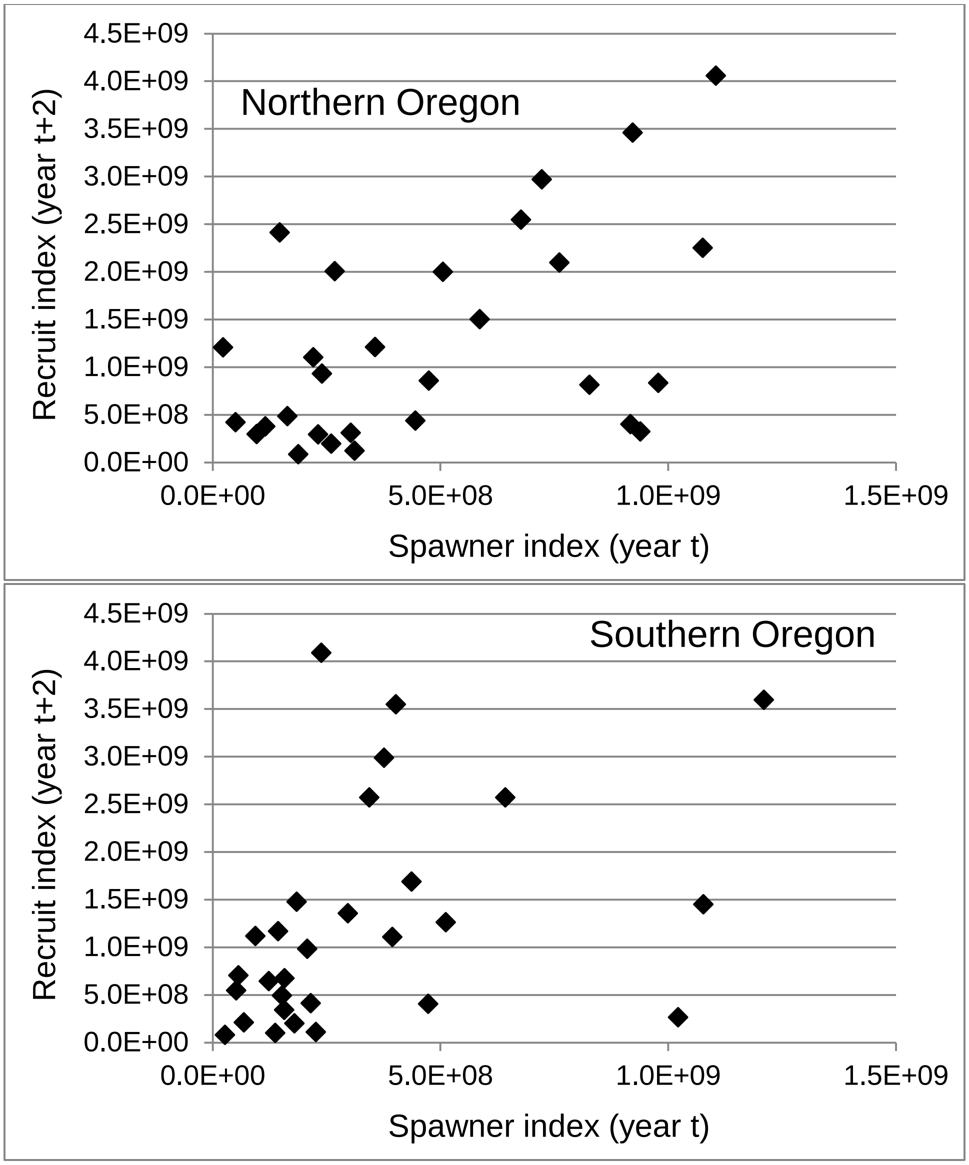

Figure 6. Comparison of spawning stock (fall of year t) and age 1 recruitment indices (year t+2) for ocean shrimp from areas off of northern and southern Oregon.

Regression analysis

Regression analysis showed that for ocean shrimp in northern Oregon waters, a simple model incorporating just April-January SLH (year t-1) was best at predicting variation in the log of the age 1 recruitment index (model 3, Table 3) and performed better than one based on April SLH (year t-1, model 2, Table 3). A simple regression of the log of the recruitment index on the log of the spawning stock index was marginally non-significant (model 1, Table 3), but a more complex model showed that the spawning stock index had little additional explanatory power after April-January SLH was included as an independent variable (model 4, Table 3). The residuals from the best fitting model (model 3) were normally distributed ($P>0.05$).

For southern Oregon waters, a simple regression of the log of the age 1 recruitment index on the log of the spawning stock index explained about 26% of the observed variation (P=0.0048, model 1, Table 4). The slope of this relationship was also positive, as would be expected. Similar to the results for northern Oregon, the model incorporating April-January SLH and April-July upwelling (year t-1, model 3, Table 4, r-squared = 0.4174) was much better at predicting the log of the recruitment index than a model incorporating April SLH and April-July upwelling (model 2, Table 4, r-squared = 0.1861). The most complex model fitted, incorporating April-January SLH, April-July upwelling and the log of the spawning stock index, explained 51% of the variation in log recruits (model 4, Table 4), again suggesting a positive effect on recruitment from a larger spawning stock. The residuals from this model were also normally distributed (P>0.05).

For the combined northern and southern recruitment and spawning stock indices, increased recruitment was not associated with a larger spawning stock index and April-July upwelling also lacked explanatory power (models 1, 4 and 5, Table 5). Again, April-January SLH was a better predictor of log recruitment than April SLH, and was the best predictive model of recruitment, on a stock-wide basis (r-squared=0.4418, model 3 Table 5). The residuals from this final model were also normally distributed (P>0.05).

Table 3. Results of multiple regression analysis of the log-transformed northern Oregon ocean shrimp recruitment index (year t) on the log-transformed spawner index (year t-2) and selected environmental variables during the pre-recruit period (year t-1), for age 1 recruitment years 1980-2009.

Model-Dependent variable	Parameters/variables	Coefficients	Standard error	R^2	P>F
1-Log northern recruit index (t)	Intercept	13.0982	3.8141		
	Log spawner index (t-2)	0.3767	0.1939		
	Full model			0.1227	0.0625
2-Log northern recruit index (t)	Intercept	33.6968	4.9437		
	April SLH (t-1)	-1.8617	0.6945		
	Full model			0.1932	0.0118
3-Log northern recruit index (t)	Intercept	56.1579	9.3649		
	April-Jan SLH (t-1)	-4.8583	1.1379		
	Full model			0.3779	0.0002
4-Log northern recruit index (t)	Intercept	51.9404	11.3588		
	Log spawner index (t-2)	0.1148	0.1779		0.5242
	April-Jan SLH (t-1)	-4.5840	1.2867		0.0014
	Full model			0.4105	0.0010

Table 4. Results of multiple regression analysis of the log-transformed southern Oregon ocean shrimp recruitment index (year t) on the log-transformed spawner index (year t-2) and selected environmental variables during the pre-recruit period (year t-1), for age 1 recruitment years 1980-2009.

Model -Dependent variable	Parameters/variables	Coefficients	Standard error	R^2	P>F
1-Log southern recruit index (t)	Intercept	8.5708	3.8685		
	Log spawner index (t-2)	0.6175	0.2008		
	Full model			0.2593	0.0048
2-Log southern recruit index (t)	Intercept	31.3186	5.5322		
	April SLH (t-1)	-1.3912	0.7683		0.0806
	April-July upwelling index	-0.0095	0.0048		0.0552
	Full model			0.1861	0.0505
3-Log southern recruit index (t)	Intercept	59.070	9.4134		
	April-Jan SLH (t-1)	-5.0691	1.2636		0.0004
	April-July upwelling index at 42° N. Lat.	-0.0137	0.0042		0.0029
	Full model			0.4174	0.0004
4-Log southern recruit index (t)	Intercept	45.7117	10.8133		
	Log southern spawner index (t-2)	0.4139	0.1880		0.0371
	April-Jan SLH (t-1)	-4.4014	1.2530		0.0017
	April-July upwelling index at 42° N. Lat.	-0.0091	0.0045		0.0543
	Full model			0.5130	0.0004

Table 5. Results of multiple regression analysis of the log-transformed combined Oregon ocean shrimp recruitment index (year t) on the log-transformed combined spawner index (year t-2) and selected environmental variables during the pre-recruit period (year t-1), for age 1 recruitment years 1980-2009.

Model-Dependent variable	Parameters/variables	Coefficients	Standard error	R^2	P>F
1-Log combined recruit index (t)	Intercept	13.7241	4.6450		
	Log combined spawner index (t-2)	0.3739	0.2288		
	Full model			0.0899	0.1138
2-Log combined recruit index (t)	Intercept	33.6392	4.3429		
	April SLH (t-1)	-1.7318	0.6101		
	Full model			0.2117	0.0081
3-Log combined recruit index (t)	Intercept	55.6255	7.0423		
	April-Jan SLH (t-1)	-4.6680	0.9580		
	Full model			0.4418	0.0001
4-Log combined recruit index (t)	Intercept	51.7079	9.8218		
	Log combined spawner index (t-2)	0.1193	0.1906		0.5368
	April-Jan SLH (t-1)	-4.4646	1.0711		0.0003
	Full model			0.4545	0.0004
5-Log combined recruit index (t)	Intercept	57.5845	7.5187		
	April-Jan SLH (t-1)	-4.9005	1.009		0.0001
	April-July upwelling index at 42° N. Lat.	-0.00262	0.0034		0.4409
	Full model			0.4533	0.0002

Sensitivity of recruitment to variation in the spawning stock

Profiling across larval environmental conditions and variation in the spawning stock index using model 4 in Table 4 and the input values shown in Table 6, shows that environmental variation during the larval period has a much greater influence on ocean shrimp recruitment than variation in the spawning stock index (Figure 8). For each line shown in Figure 8, increasing the spawning stock index from the 10th to the 90th percentile increases the recruitment index by a factor of about 3.5 (Figure 8). In contrast, increasing both environmental variables from the 10th percentile to the 90th percentile values, at any fixed level of the spawning stock index, increases the predicted recruitment index by a factor of about 18 (Figure 8).

Table 6. Input values used with model 4 in Table 4 for predicting southern Oregon age 1 shrimp recruitment across a range of spawning stock levels and environmental conditions during the larval period.

Dependent variable	Selection criteria	Larval conditions	Input value
Spawning stock index	Mean		478,163,928
	10th percentile		58,030,510
	90th percentile		1,197,000,000
April-January SLH (larval period)	Average	Average	7.335
	10th percentile	Unfavorable	7.585
	90th percentile	Favorable	7.159
April- July Upwelling (larval period)	Mean	Average	96.21
	10th percentile	Unfavorable	54.38
	90th percentile	Favorable	165.5

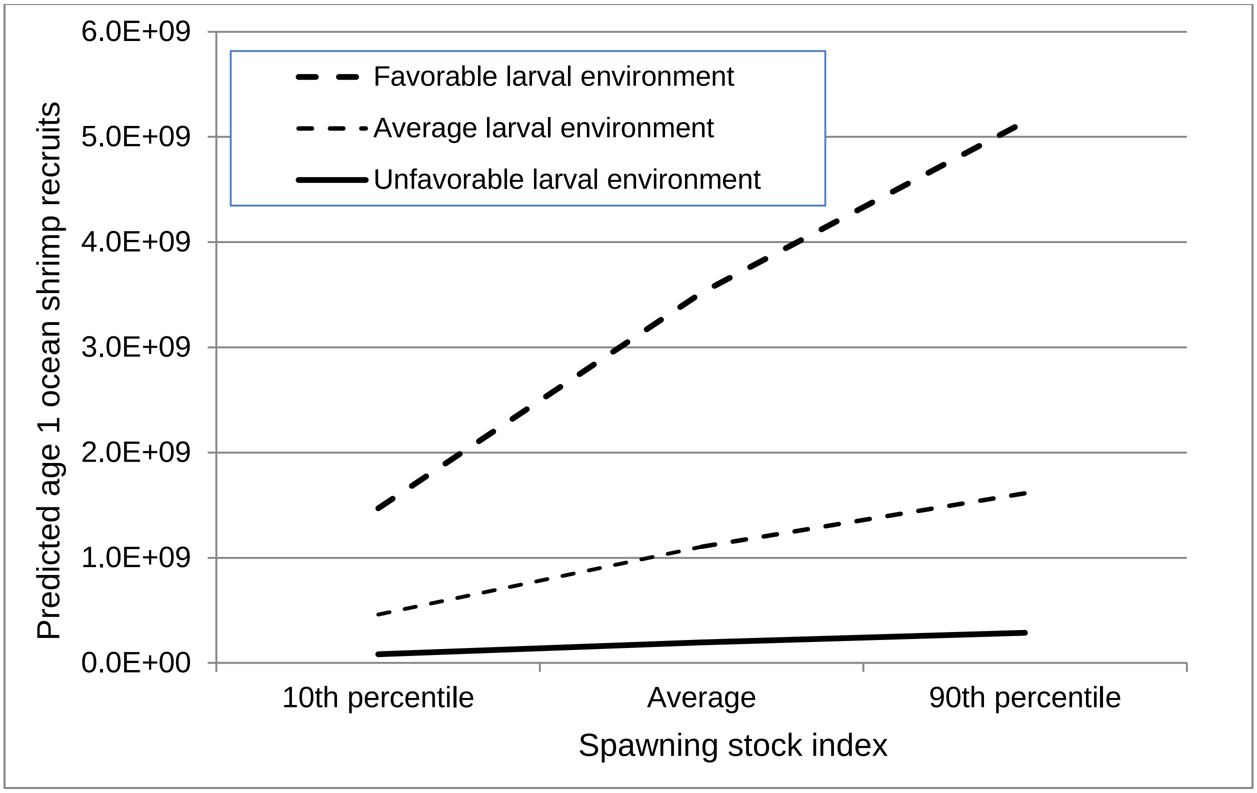

Figure 8. Predicted southern Oregon age 1 ocean shrimp recruitment using model 4 in Table 4, profiled across a range of spawning stock indices and larval environmental conditions (Table 6).

Discussion

The updated spawning stock and recruitment indices show that the ocean shrimp stock remains highly resilient to both fishery impacts and large, naturally caused variations in distribution and abundance. The stock in southern Oregon waters rebounded rapidly from very depressed recruitment in 2003 and 2004, reaching new record levels of spawner abundance in about 5 years, despite continued fishing (Figures 3 and 4). The simplest explanation for the rapid rebound in abundance is that environmental conditions during the larval period, as reflected in April-January mean SLH, were much better than average for several age 1 recruitment years after 2006 (Figure 7).

The multiple regression analysis showed that April-January mean SLH in the pre-recruit year was consistently more strongly negatively correlated with the various ocean shrimp recruitment indices than mean April SLH in the pre-recruit year (Tables 3-5). In prior studies with shorter time series of data, mean April SLH was found to be strongly correlated with age 1 ocean shrimp recruitment, and it was suggested that April might be a critical time period in which the ocean envirionment strongly influenced shrimp larval survival or transport (Hannah 1993, Hannah 1999, Hannah 2011). The reduced correlation of April SLH with recruitment in this study arises primarily from a single age 1 recruitment year, 2007, in which recruitment was slightly above average despite a higher than average April SLH the year prior, suggesting a weak or late spring transition (Figures 3 and 7). April-January SLH for the same year suggests that conditions during the remainder of the pre-recruit year were better than average (Figure 7). With the 2007 age 1 year excluded, the fit of April SLH to the models shown in Tables 3-5 is greatly improved. However, it may also be the case that averaging sea level height over a longer portion of the pre-recruit year may actually capture more of the relevant variation in environmental conditions that influence year class success. This is supported by indications that the onset of a strong warm-phase El Niño event as late as the winter just prior to age 1 recruitment can sometimes adversely influence shrimp recruitment (Hannah 1993). More typically, recruitment success is determined prior to the fall, when age zero shrimp begin appearing in trawl catches. Catches of age zero shrimp have been shown to have some predictive value with regard to the age 1 ocean shrimp recruitment indices (Hannah 2010).

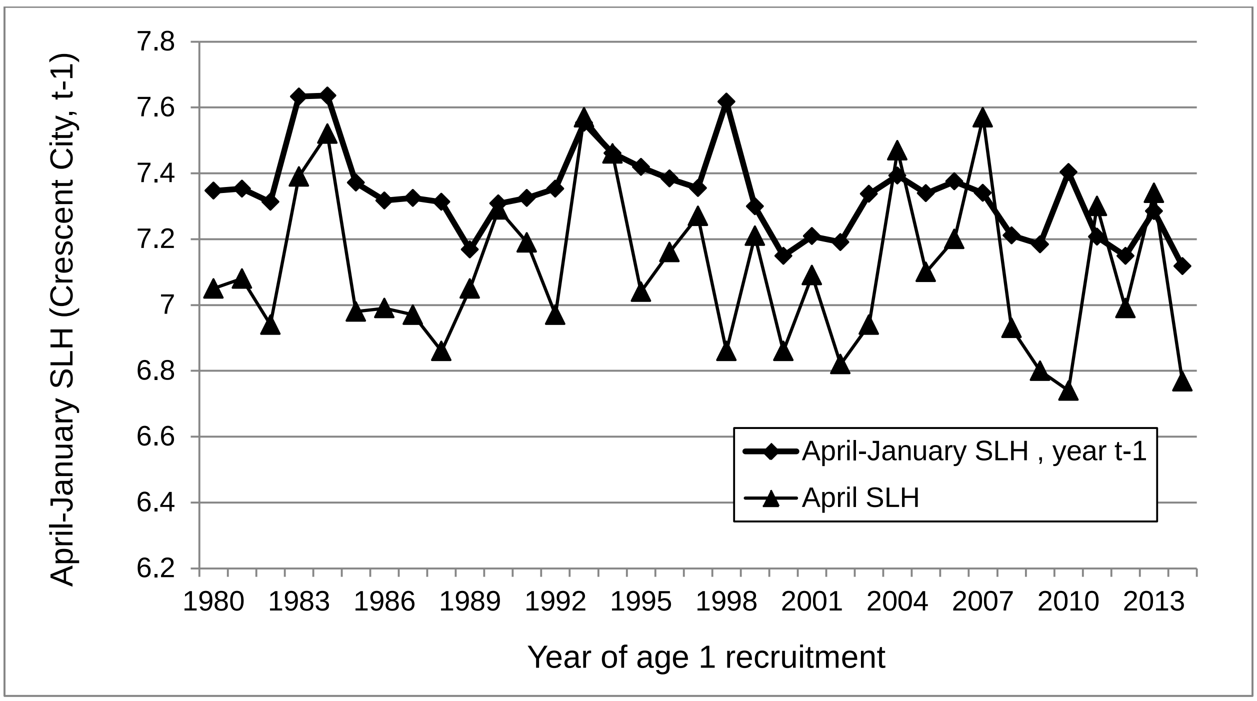

Figure 7. Time series of April and April-January mean sea level height at Crescent City, California in the year prior to the year of age 1 ocean shrimp recruitment.

Generally, the regression analysis did not indicate the spawner index to be a strong driver of ocean shrimp recruitment, similar to the findings of previous studies (Hannah 1993, Hannah 1999). The finding that the spawner index seems to be a legitimate predictor variable for southern Oregon ocean shrimp recruitment is novel and interesting, but may also be an artifact. Garcia (1983) has pointed out that many apparent stock-recruitment relationships in short-lived shrimps may actually result from strong environmental forcing of recruitment in combination with the natural serial autocorrelation present in marine environmental variables. Even if our data are considered as evidence of a statistical relationship between the ocean shrimp stock and recruitment indices in southern Oregon waters, simple inspection of Figures 3, 4 and 6 shows that recruitment varies too widely year-to-year for the spawning stock to be the primary driver of annual recruitment, as also illustrated in Figure 8. The dominant effect of environmental variation in determining ocean shrimp recruitment (Figure 8) and the strong dependence of spawner abundance on that same year's age 1 recruitment suggest that it may not even be possible to maintain a high level of shrimp spawning stock in all years. Although a somewhat higher average spawning stock could be maintained by reduced fishing, our analysis shows that this will not guarantee large recruitments (Figure 8), but would sacrifice a high proportion of the available fishery yield. The available information continues to support the concept of managing ocean shrimp by maintaining the spawning stock above some low threshold that will still allow a strong year class to form during favorable environmental conditions.

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