California Fish and Game 102(4):175-182; 2016

Year-class strength predicts commercial catch 11 years later for white seabass, *Atractoscion nobilis*, off southern California

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Key Words: white seabass, *Atractoscion nobili*, Marine Resources Protection Act of 1994, year-class strength, abundance, survivorship, recruitment, commercial catch, otoliths

Fisheries in the past have undergone collapse due to over-exploitation of a target species beyond natural replenishment. White seabass (*Atractoscion nobilis*) has been a commercial fishery species in Southern California since the late 1800s and a popular recreational species since the mid-20th century (Hervas et al. 2010). A decline in their numbers was seen in the early 1900s and by 1982 caused the commercial white seabass fishery to move operations offshore and abide by management regulations. The change in white seabass recreational catch was dramatic and attributed to overfishing, declining from a peak of 64,000 individuals in 1949 to 284 in 1978 (Vojkovich and Reed 1983, Vojkovich & Crooke 2001).

Over the last two decades, the population of white seabass along the coast of California appears to be rising. The Marine Resource Protection Act in 1994 imposed restrictions by limiting fishing depth along the California coast and Channel Islands in addition to the state wide ban in the use of gill and trammel nets, resulting in a significant increase in white seabass numbers between 1995-2004 (Pondella and Allen 2008). White seabass commercial take was low in 1997 with 26 t and in 1998 greatly increased to 70 t (California Cooperative Fisheries Investigations [CalCOFI] 1999). Recent reports indicate that the combined commercial and recreational catch during 2008 was 342 t (CalCOFI 2009), and increased slightly to 364 t in 2010 (CalCOFI 2011).

Year-class strength is an index that uses measures of abundance, survivorship, or recruitment rates to summarize the success of a species for a given year (Landsman et al. 2011, Neuheimer and Gronkjaer 2012). Population structure can experience distinctive phases year to year, shifting in relation to increases or decreases in sea surface temperature (Tolonen et al. 2003, Lappalainen et al. 2009). Larval and juvenile stages are arguably more susceptible to variations in the environment (Tolonen et al. 2003, Raventos 2009). By organizing individuals into cohorts, it has been revealed that specific age groups benefit the most from variation in environmental conditions, contributing the most to the overall fitness of the population through increased growth and survival (Martinson et al. 2012). For species that are heavily exploited, life history information is sometimes sparse, but it is essential to the development of effective management plans and aiding stock assessments (Campana and Thorrold 2001, Fairclough et al. 2011).

The objective of this paper is to report a significant relationship between the year-class strength and commercial catch in white seabass over the last two decades. Valero and Waterhouse (2016) recently concluded that the fishing effort for white seabass has remained constant over the observed time period of catches used in this study.

We aged individuals using otoliths to determine year-class strength, thus providing insight into the population structure. Otoliths used were collected as part of an independent assessment of the abundance of juvenile white seabass off Southern California (Allen et al. 2007). Sagittal otoliths that were in good condition and intact were used for aging. One hundred otoliths were randomly sampled from each collection year, starting from 1997 to 2008 (n=1200). Length, width, and depth of each otolith were measured using Mitutoyo digital calipers (±0.01 mm) with weight recorded using an Ohaus Voyager Pro analytical balance (±0.001 g). Otoliths were mounted on wooden blocks using commercially available cyanoacrylate adhesive in preparation for cross-section. A Buehler Isomet low-speed saw equipped with two 0.3 mm diamond-edge blades was used to create 0.5 mm thick cross-sections. Each section was mounted onto glass slides using Crystalbond 509 mounting adhesive and polished for clarity by alternating between 400 and 600 fine grit sandpaper.

Cross-sections were digitally photographed using an Olympus SZX7 zoom stereo microscope with a QImaging QICAM digital camera attachment. Aging of otoliths (to the year) was based on two blind reads, i.e. having no prior knowledge of the fish itself, to prevent biased estimates of age. If the initial and second read did not agree, a third read was made to reach an agreement on age. Final age was taken as an average if an agreement was not met after three reads. Reasonable assumption of annual bands will follow an understanding of age validation reported in Williams et al. (2007) and Romo-Curiel et al. (2014).

Aged individuals were organized into cohorts to represent the age structure of the population based on birth years, which were determined by subtracting how old each individual was when caught from the year it was caught. Due to sampling method, which was size and age selective, only juvenile fish that were five years of age and younger were used in the analysis.

Using a traditional catch-curve regression (Ricker 1975), we conservatively estimated annual mortality and survivorship for white seabass. Counts for each cohort were then adjusted for annual mortality using a modified equation for mortality and survivorship from Allen et al. (1995): where N_0= number of fish in a year-class at t=0, N_t= estimated number of recruits at t years in the past, corrected for mortality, and S= annual estimated survivorship (complement of mortality).

Year-class strength (annual recruitment index) was estimated by taking the average number of individuals across age groups within each represented birth year. Only fish born after 1996 and before 2007 were used in the analysis, as this time period had the highest resolution due to large numbers of fish in the samples that were born in those years. Time-lag comparisons were made to assess if there was a relationship between year-class strength and commercial catch of white seabass. All statistical analysis was conducted using SYSTAT 13.1.

Fifteen individuals from the original 1200 were excluded from the analysis due to damaged otoliths. Sagittal otoliths from the remaining 1185 individuals revealed a population structure of fish primarily ages 1 to 5, with the oldest individual aged at 11 years (Figure 1). During the 1997–2008 sampling period, the peak number of fish spawned occurred in 1997, 2000, and 2004 (Table 1). Annual mortality (M, 0.6), survivorship (S, 0.4), and instantaneous annual mortality (-Z, 0.991) for white seabass was estimated conservatively by catch-curve regression.

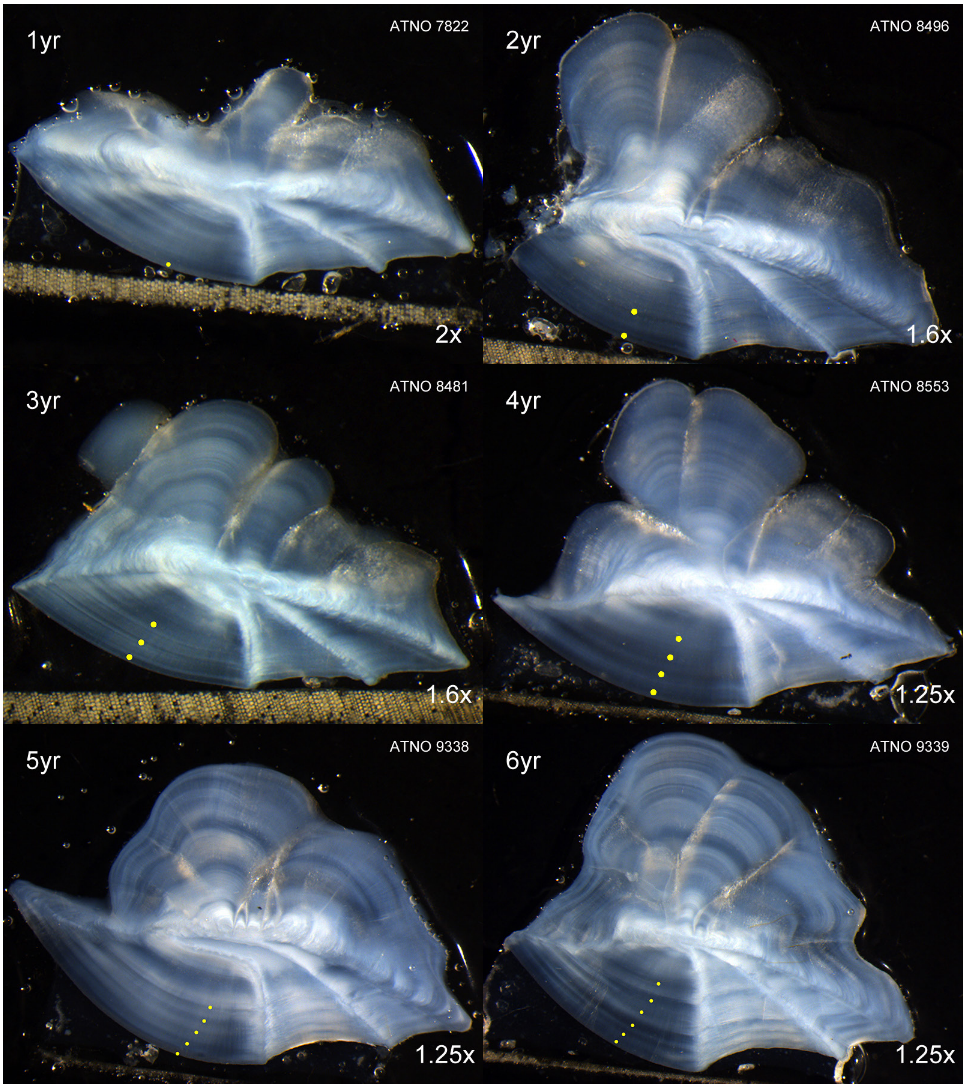

Figure 1.—Cross-sectioned sagittal otoliths of juvenile white seabass (*Atractoscion nobilis*) representing ages 1-6 years. White dots denote annual rings.

Table 1.—Cohort structure of white seabass (*Atractoscion nobilis*) for the 1996-2007 sampling period based on n = 1149 individuals representing ages 1-5 years.

Age	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
1	88	80	39	51	52	30	10	50	46	16	47	24
2	10	42	29	16	55	46	35	32	69	38	42	
3	11	16	16	10	34	12	17	13	12	15		
4	4	11	2	7	1	3	2		3			
5	3	1	3	2	1		1	2				
Total	116	150	89	86	143	91	65	97	130	69	89	24

Year-class strength estimates in 1996 and 1997 had the highest values, partly coinciding with the strong 1997-1998 El Niño (Figure 2). However, year-class strength overall was not significantly correlated with mean yearly summer sea-surface temperature (r^2=0.065 p=0.42), multivariate ENSO index (r^2=0.004, p=0.85), Pacific Decadal Oscillation (r^2=0.048, p=0.49), nor North Pacific Gyre Oscillation (r^2=0.025, p=0.62).

On-the-other-hand, commercial catch of white seabass was positively correlated with year-class strength in the presence of a time lag (Figure 3). Specifically, cross correlation

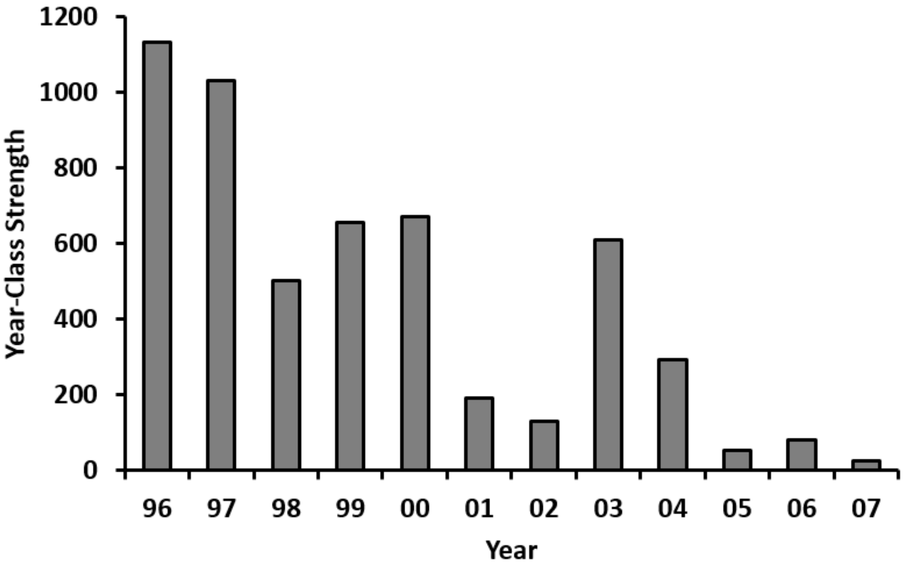

Figure 2.—Estimated year-class strength (corrected for mortality) of *Atractoscion nobilis*, 1996-2007,

analysis revealed a significant time lag of 11 years in the time series (Figure 4). This 11-year time lag resulted in a significant relationship between 2008-2015 commercial landings and 1996-2007 year-class strength (n=9, r^2=0.48, p=0.038, Figure 5).

White seabass have undergone an increase in Catch Per Unit Effort (CPUE) and juvenile abundance that could be attributed to the strong 1997 El Niño event in Southern California (Allen et al. 2007, Williams et al. 2007). Our results also suggested that the year-class strength for white seabass was the greatest in 1996 and 1997. There remains concern that the increase in white seabass abundance may not persist as the positive influence from the 1997-1998 El Niño year classes may begin to diminish. The strong year-class strength of white seabass from the 1997 El Niño has been reflected in the gradual increase in commercial landings, where the commercial catch of white seabass is made up primarily of individuals at least 10 years of age. The 2011-2012 annual review of the white seabass management plan reports that half of the fish sampled commercially were likely older than 12.5 years and likely older than 9 years from the recreational fishery (Department of Fish and Wildlife 2013).

The linear model predicting the relationship between commercial catch and year class strength was found to be y=137.4x+107072 (Figure 5). This model can be used to predict present and future commercial catches of white seabass for years in which year class strength (x) has been estimated (1996-2007). This model currently predicts that catch

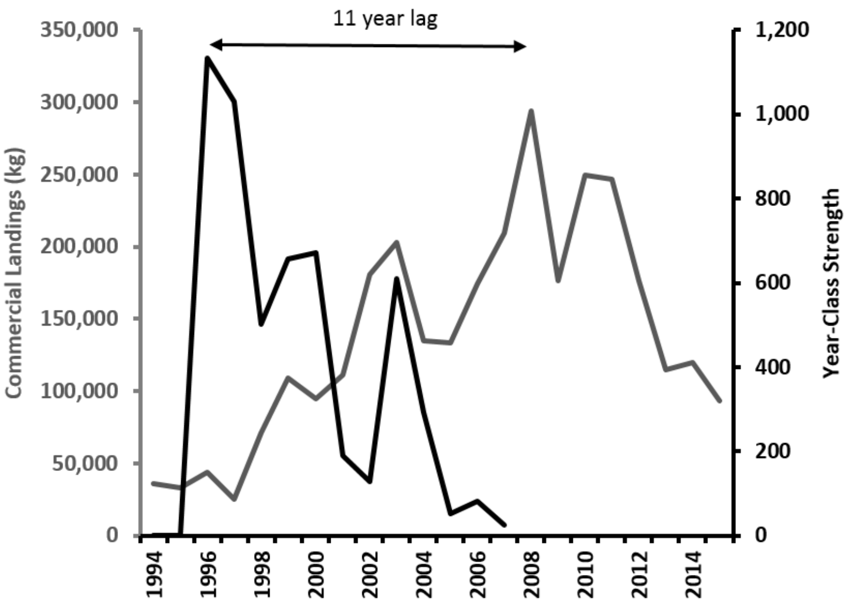

Figure 3.—Comparison between 1994-2015 commercial landings (gray) and 1996-2007 year-class strength (black) for white seabass, with a time lag of 11 years indicated by the arrowed line.

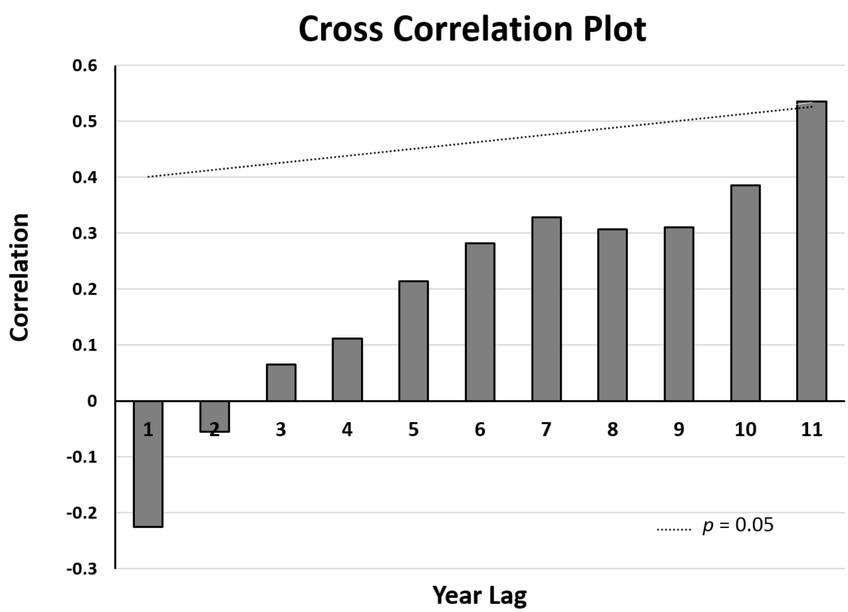

Figure 4.—Plot of Cross Correlation analysis between commercial landings and year-class strength for white seabass with time lag of up to 11 years. Dotted line represents the p=0.05 significance-level.

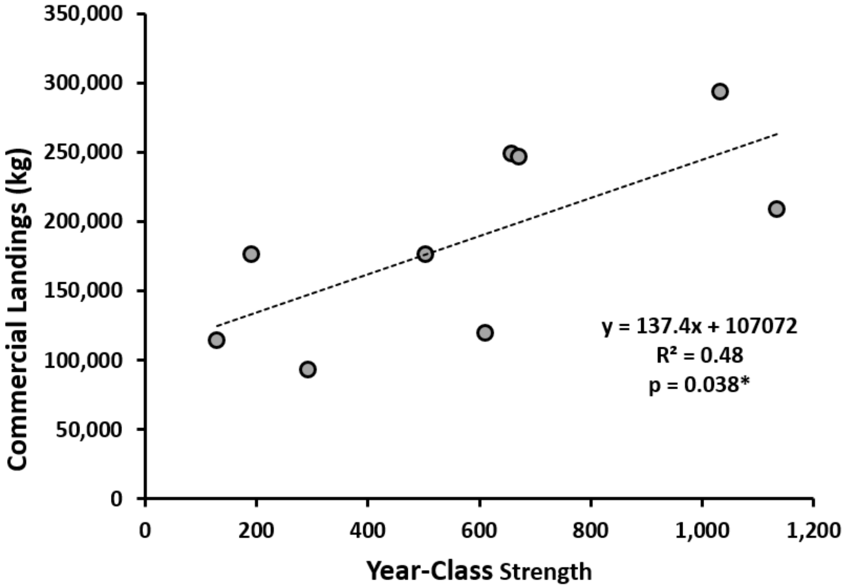

Figure 5.—Relationship between 2008-2015 commercial landings (y) and 1996-2007 year-class strength (x) for white seabass with time lag of 11 years (n=9, r^2=0.48, p=0.038). Trend line is dotted and represents the proposed linear model of y=137.4x+107072.

in 2016, once reported, should be about 114,200 kg, 118,300 kg in 2017, and 110,400 kg in 2018 (all estimates are $\pm$759 SD) based on the year class strength data presented here.

In summary, the present study determined the population structure of white seabass over an 11-year period (1997-2008) and revealed that year-class strength was the greatest in 1996 and 1997. Year-class strength was strongest during the 1997 El Niño, though was not significantly correlated with sea surface temperature or any climate index. Commercial landings for the species have shown a steady increase following the strong 1997 El Niño event, resulting in a significant relationship between year-class strength and commercial landings with an eleven-year time lag. We conclude that year-class strength estimation is an informative tool in assessing population structure of this managed species over time and may be used as a general predictor of catch over a decade later (11-years). Thus the information provided in our study can inform the white seabass fishery, update management approaches, and help ensure the persistence of white seabass into the future.

Acknowledgments

We thank Drs. Mark A. Steele and Michael P. Franklin for their intellectual support and review of various phases of this project. We also thank Celeste Gottschalk for her support with data collection. This project would not have been possible without the otoliths that were collected and archived by the efforts of past members of the Nearshore Marine Fish Research Program and support from the Southern California Marine Institute. Financial support was provided by the California State University, Northridge Research and Graduate Studies through their thesis support program and the Association of Retired Faculty memorial scholarship program.

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Submitted 20 July 2016
Accepted 03 October 2016
Associate Editor was P. Kalvass