American Fisheries Society Symposium 60:285–300, 2007

Indices of Larval Red Snapper Occurrence and Abundance for Use in Stock Assessment

David S. Hanisko[1], Joanne Lyczkowski-Shultz, and G. Walter Ingram
National Marine Fisheries Service
Southeast Fisheries Science Center
Mississippi Laboratories, 3209 Frederic St., Pascagoula, Mississippi 39567 USA

Abstract.—Red snapper *Lutjanus campechanus* larval occurrence and abundance during Southeast Area Monitoring and Assessment Program (SEAMAP) Summer Shrimp/Bottomfish (1982–2003) and Fall Plankton (1986–2003) surveys were examined to identify the time series of ichthyoplankton data that might best reflect trends in the red snapper spawning population in the U.S. Gulf of Mexico (GOM). Since bongo nets were more effective than neuston nets at capturing red snapper larvae only catches from bongo nets were used to estimate annual occurrence and abundance, i.e. the SEAMAP larval red snapper index. The summer survey was conducted during the peak of red snapper spawning in June and July, but limited and inconsistent coverage during this survey did not permit development of a reliable Gulfwide (U.S. continental shelf) index of larval abundance. In contrast, the fall survey conducted near the end of the spawning season in September yielded a 16 year time series over which to examine trends in red snapper abundance throughout the GOM. Although occurrence and abundance of red snapper larvae were lower during September than in June and July, estimates from both summer and fall surveys showed the same inter-annual patterns and were highly correlated. Larvae were eight times more abundant and occurred in five times as many samples in the western than in the eastern GOM. Separate standardized indices of relative abundance were generated for the western and eastern GOM. The standardization procedure accounted for the effects of year, time of day, depth and subregion in the western GOM, but only for subregion in the eastern GOM. Larval indices of red snapper abundance suggest an increased spawning stock in both the western and eastern GOM after 1995.

Introduction

Red snapper *Lutjanus campechanus* are found along the U.S. Atlantic Coast and throughout the Gulf of Mexico (GOM). The U.S. GOM red snapper population supports a popular and economically valuable fishery resource utilized by both recreational and commercial sectors. The fishery is managed by the Gulf of Mexico Fishery Management Council under the Reef Fish Management Plan. The most recent population assessment of red snapper in the GOM resulted in

[1] Corresponding author: david.s.hanisko@noaa.gov.

the stock being classified as overfished and undergoing over fishing (Porch 2007, this volume). Among the fishery independent indices used in this assessment was a larval index based on a 22 year time series of Southeast Area Monitoring and Assessment Program (SEAMAP) resource surveys. A description of these surveys and plankton collection methodologies is presented by Lyczkowski-Shultz and Hanisko (2007, this volume) along with a general summary of information on red snapper larvae taken during SEAMAP surveys. The objective of this companion paper is to present standardized larval indices based on the SEAMAP time series of ichthyoplankton data that might best reflect trends in the red snapper spawning population in the GOM.

Methods

Surveys and Collections:

SEAMAP resource surveys have been conducted in the Gulf of Mexico by the National Marine Fisheries Service since 1982 in cooperation with the states of Florida, Alabama, Mississippi, Louisiana and Texas. Red snapper larvae were captured primarily during two annual SEAMAP surveys that cover the spawning area (continental shelf) and season (summer to early fall) of this species (Lyczkowski-Shultz and Hanisko 2007). The Summer Shrimp/Bottomfish (*SB*) survey, 1982–present, is conducted over the U.S. continental shelf from the U.S./Mexico border to 88° West longitude from mid June through July. The SEAMAP Fall Plankton (*FP*) survey, 1986–present, is conducted over the U.S. continental shelf from the U.S/Mexico border to south Florida from mid August to early October with the majority of samples taken during the month of September. Only data from those two surveys were used to examine the potential of a SEAMAP larval red snapper index.

Plankton sampling on SEAMAP resource surveys is conducted around the clock at predetermined stations arranged in a fixed, systematic grid across the U.S. Exclusive Economic Zone of the GOM. Most systematic grid locations or SEAMAP stations (designated by a unique SEAMAP or 'B' number) are located at ~56 km or 0.5 degree intervals along this grid. Sampling at each location is conducted with paired 61-cm, 0.333 mm mesh bongo nets and/or a single, 2 × 1 m, 0.947-mm mesh neuston net following established SEAMAP collection protocols (SEAMAP 2004). Neuston nets are towed horizontally in the top 0.5 m of the water column, while bongo nets are towed in an oblique manner to within 2–5 m of the bottom or a maximum depth of 200 m. Catches of larvae are standardized to account for sampling effort and expressed as the number of larvae under 10 m^2 of sea surface (larvae/10 m^2) for bongo nets, and as the number of larvae per 10 min tow (larvae/10 min) for neuston nets.

All snapper larvae were examined and identified by ichthyoplankton specialists at the Southeast Fisheries Science Center, Mississippi Laboratories (Lyczkowski-Shultz and Hanisko 2007). Red snapper larvae were identified using descriptions in Drass et al. (2000) and Lindeman et al. (2005). Body length of larvae was measured to the nearest 0.1 mm. Only red snapper larvae greater than 3.8 and less than 6.3 mm were used in our analysis because snapper larvae smaller than 3.8 mm cannot be reliably identified to species, while snapper larvae over 6.0 mm were not effectively captured by bongo and neuston nets presumably due to avoidance (Lyczkowski-Shultz and Hanisko 2007).

Diel period designation for each SEAMAP sample was based on the start time of sample collection. Samples taken after sunrise and before sunset were assigned to the daytime period, and samples after sunset and before sunrise to the nighttime period. Sunrise and sunset for each sample date was calculated using station latitude, longitude and Julian date based on formulae in Seidelmann (1992).

Sample Selection and Data Comparisons:

Plankton data used for this analysis were limited to a single neuston and/or bongo sample from each SEAMAP station taken during the *SB* and *FP* surveys. In cases where more than one sample was taken at a grid location during a survey, the sample taken closest to the targeted location was chosen. When SEAMAP stations were sampled by more than one vessel during the survey, priority was given to samples taken by NMFS vessels as they conduct a majority of surveys each year and therefore provided the most consistent temporal and spatial coverage. Only data from *SB* surveys in 1986, 1987, 1994, 1997, and 2000–2002 that sampled the entire extent of the intended survey area were included in our analysis. Data from all years of the *FP* survey were used with the exception of 1998 when tropical storms severely curtailed sampling. Samples from the *FP* surveys were restricted to those stations sampled during at least 10 years of the survey time series to account for annual variability in spatial coverage (Figure 1).

We examined the relative efficiency of neuston and of bongo nets at capturing red snapper larvae by comparing catches in day and night samples. Only *FP* survey samples from stations where both the neuston and bongo samples were taken within the same diel period were considered. Efficiency was measured by comparing the percent occurrence, mean abundance, and the diel percentage of total abundance of red snapper larvae in day and night samples. Diel percentage of total abundance was calculated by dividing the total summed red snapper larval abundance of all day or night samples by the total summed abundance of all samples. Coefficients of variation (CV; standard error/mean) were calculated for each gear and year of the *FP* survey. Average annual CVs were used as an indicator of consistency over the time series. Chi-square tests were used to test for

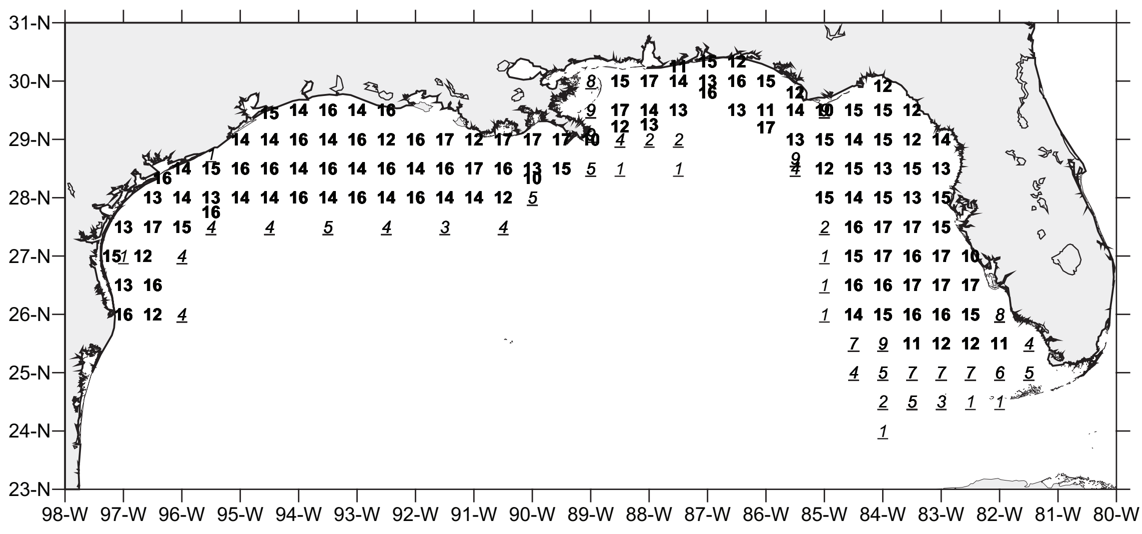

Figure 1. Number of samples taken at each SEAMAP B-number location during all years of the Fall Plankton survey. Bold numbers represent B-number locations which were sampled during at least 10 years of the survey and retained in our analysis, and the underlined italic numbers B-number locations dropped from the analysis.

equal proportion of day and night captures of larvae between the two gear types.

Trends in percent occurrence and abundance of red snapper larvae for the *SB* and *FP* surveys were compared by correlation analysis. All comparisons were carried out using only bongo samples collected west of 087.75°W longitude during the 1986 & 1987, 1994, 1997, and 2000–2002 *SB* and *FP* surveys. The selected years are those where both surveys sampled the full spatial area of the western GOM.

Regional and sub-regional differences in larval red snapper abundance and occurrence were assessed using data from the *FP* surveys. Western and eastern regions were separated at the mouth of the Mississippi River (089.17°W longitude) as delineated by the 2005 red snapper stock assessment (Porch 2007, this volume). The western region was further divide into Texas (TX) and Louisiana (LA) subregions at the TX/LA state line (~093.80°W longitude); and the eastern region into Mississippi/Alabama (MS/AL) and Florida (FL) subregions at the AL/FL state line (~087.25°W longitude). The positions used to separate the subregions are slightly shifted from the actual state lines to accommodate the systematic sampling grid of the plankton surveys. Percent occurrence, mean abundance and the regional or subregional percentage of total abundance were calculated for each region or subregion of the GOM. Regional or subregional percentage of total abundance was calculated by dividing the total summed abundance of all samples in a region or subregion by the total abundance of all samples.

Larval red snapper nominal percent occurrence, nominal mean abundance and model based estimates of standardized relative abundance with associated CVs (standard error/mean) were calculated by year for the western and eastern GOM (as defined above) utilizing the FP survey time series of observations. Standardized indices of relative red snapper abundance based on larval occurrence and abundance were estimated using a delta-lognormal model (Lo et al. 1992). Indices based on this model are a mathematical combination of yearly estimates from two distinct generalized linear models: a binomial model which describes proportion of positive catches (i.e., occurrence) and lognormal model which describes variability in only the nonzero abundance data. A backward selection approach using the GLMMIX and MIXED procedures (Patetta 2002) in SAS (Version 9.1.3 of the SAS System for Windows © 2003, SAS Institute Inc., Cary, North Carolina) was employed to provide yearly index values for both the binomial and lognormal sub-models, respectively. The effects tested for inclusion in each sub-model were year, time of day (day or night), sub-region (TX and LA or MS/AL and FL) and water depth. For the binomial sub-models, a logistic-type generalized linear mixed model was employed, and model fit was evaluated using the fit statistics provided by PROC GLMMIX in SAS. Likewise, for the lognormal sub-model, a generalized linear mixed model was used to describe the nonzero abundance data, and model fit was evaluated using the fit statistics provided by PROC MIXED in SAS. The year effect is integral to the calculation of annual estimates and is forced into the standardization procedure regardless of significance when at least one other parameter is significant. Years when no red snapper larvae were collected were dropped from the analyses since an index developed using delta-lognormal methodology cannot be calculated from data containing only zero catches. Also, when the lognormal submodels did not converge or did not retain any significant effects, only the logistic model describing occurrence was used to develop the indices.

Results

Mean abundance, percent occurrence and the percentage of total abundance of red snapper larvae were higher during *FP* nighttime

Table 1. Mean abundance (Mean) and percent occurrence (%O) with number of samples (*N*), standard error (*SE*), and percentage of total abundance (% Total) of day and night caught red snapper *Lutjanus campechanus* larvae captured in neuston and bongo nets during the Fall Plankton survey.

			Abundance			Occurrence	
Gear	Diel Period	*N*	Mean	*SE*	% Total	%O	*SE*
Neuston	Day	790	0.02	0.01	5.00	1.65	0.45
	Night	729	0.50	0.08	95.00	14.68	1.31
	Day + Night	1519	0.25	0.04	100.00	7.90	0.69
Bongo	Day	790	0.25	0.04	23.00	5.06	0.78
	Night	729	0.92	0.13	77.00	11.93	1.20
	Day + Night	1519	0.57	0.07	100.00	8.36	0.71

Table 2. Percent coefficient of variation (standard error/mean) of annual abundance (*A*) and percent occurrence (%O) of red snapper *Lutjanus campechanus* larvae captured in neuston and bongo nets during the Fall Plankton survey.

		Nueston		Bongo	
Year	*N*	*A*	%O	*A*	%O
1986	107	65.74	49.29	44.94	43.87
1987	110	62.64	49.31	60.84	43.89
1988	51	100.00	100.00	100.00	100.00
1989	51	70.74	70.00	58.42	56.57
1990	62	67.22	48.75	53.05	48.75
1991	58	100.00	100.00	44.77	43.12
1992	106	31.98	25.02	38.72	36.70
1993	110	38.99	28.73	38.65	36.74
1994	118	42.04	39.94	67.81	43.95
1995	114	56.64	32.13	35.09	25.14
1996	112	44.88	27.40	35.83	32.11
1997	115	40.12	32.14	29.60	24.18
1999	108	33.10	26.13	42.97	36.72
2000	105	46.47	27.30	27.96	21.56
2001	106	47.24	43.86	43.21	32.04
2002	86	40.08	25.70	32.48	25.70

sampling for both neuston and bongo nets (Table 1). No difference between gears (α = 0.05, P = 0.1415) was observed in the occurrence of larvae during nighttime hours. However, the occurrence of red snapper larvae in bongo net samples was found to be significantly higher than nueston samples (α = 0.05, P = <0.0001) during the day. The diel percentage of total red snapper larval abundance was skewed in favor of nighttime catches for both gears. However, the percentages of diel total abundance were more equitably distributed between day and night samples for the bongo than for the neuston (Table 1). Sampling variability over the time series was less variable for the bongo than the neuston. Annual CV on mean abundance for the neuston averaged 56%, and annual CV on percent occurrence averaged 45%. While annual CV on mean abundance for the bongo averaged 47%, and annual CV on percent occurrence averaged 41% (Table 2). Overall, the bongo was more effective at catching larvae over the 24 h time period than the neuston with less year to year sampling variability. Therefore all further analyses of red snapper larvae in SEAMAP collections were solely based on bongo net samples.

Day and night occurrence, mean abundance and diel percentage of total abundance from selected years of the *SB* and *FP* surveys west of 087.75°W longitude differed between the surveys (Table 3). Mean abundance and occurrence during the *FP* survey were considerably higher at night than during the day. However, mean abundance and occurrence during the *SB* survey were similar between day and night. The number of night samples available from the *SB* survey was less than half the number of day samples. Whereas, the number of day and night samples available from the *FP* survey were about the same. The difference in the observed diel pattern between the two surveys was likely caused by disparity in the number of night and day samples collected during the *SB* survey. Therefore comparison between the two surveys was confined to daytime samples only.

Mean abundance during the *SB* survey was two times greater than during the *FP* survey. Occurrence was also higher during the *SB* survey (13%) than during the *FP* survey (9%) (Table 3). Annual ratios (*SB*/*FP*) of mean abundance ranged from 1.14 to 2.97, and annual ratios (*SB*/*FP*) of occurrence between the two surveys ranged from 0.73 to 1.92 (Table 4). Mean abundance and occurrence between the *SB* and *FP* surveys were highly correlated within years. The correlation was 80% ($n = 7$, $r = 0.795$) between *SB* and *FP* annual abundance and 75% ($n = 7$, $r = 0.747$) between *SB* and *FP* annual occurrence.

Larval red snapper occurrence and abundance during the *FP* survey were an order of magnitude higher in the western than in the eastern GOM (Figure 2). Larvae were nine times more abundant and occurred in five times as many samples in the western than in the eastern GOM. The western GOM accounted for 88% of the total GOM larval abundance from the 16 years of *FP* surveys. In contrast, the eastern GOM accounted for only 12% of the total GOM larval abundance. Larval abundance, occurrence and percentage of total GOM abundance were similar between the TX and LA sub-regions. However, the MS/AL and FL sub-regions in the eastern GOM were quite different. Larvae were four times more abundant and occurred in four times as many samples in the MS/AL sub-region than in the FL sub-region. The disproportionately smaller MS/AL subregion also accounted for nearly half of the 12% of total abundance in the eastern GOM.

Table 3. Mean abundance (Mean) and percent occurrence (%*O*) with number of samples (*N*), standard error (*SE*), and percentage of total abundance (% Total) of day and night caught red snapper larvae captured in bongo nets during the 1986, 1987, 1994, 1997, and 2000–2002 Summer Shrimp/Bottomfish (*SB*) and Fall Plankton (*FP*) surveys in the western Gulf of Mexico.

			Abundance			Occurrence	
Survey	Diel Period	*N*	Mean	*SE*	% Total	%O	*SE*
SB	Day	222	0.96	0.20	72.68	13.06	2.27
	Night	102	0.78	0.24	27.32	13.73	3.42
	All	324	0.90	0.16	100.00	13.27	1.89
FP	Day	224	0.46	0.11	21.95	8.93	1.91
	Night	193	1.88	0.38	78.05	20.73	2.93
	All	417	1.12	0.19	100.00	14.39	1.72

Table 4. Daytime abundance (A) and percent occurrence (B) of red snapper larvae captured in bongo nets during the 1986, 1987, 1994, 1997, and 2000–2002 Summer Shrimp/Bottomfish (*SB*) and Fall Plankton (*FP*) surveys in the western Gulf of Mexico with associated standard errors (*SE*) and number of samples (*N*). *SB/FP* ratios are the annual abundance or percent occurrence (% Occurrence) of the *SB* survey divided by the *FP* survey. Correlation is the Pearson correlation coefficient of annual abundance or percent occurrence for all years listed.

(A)

Year	*N*	*SB* Abundance	*SE*	*N*	*FP* Abundance	*SE*	*SB/FP* Ratio	Correlation
1986	41	0.48	0.28	30	0.42	0.24	1.14	$r = 0.80$
1987	29	0.42	0.31	32	0.14	0.14	2.97	
1994	28	0.79	0.62	34	0.00	0.00		
1997	34	1.25	0.70	35	0.65	0.28	1.93	
2000	34	1.51	0.60	28	0.96	0.47	1.57	
2001	26	1.16	0.52	30	0.59	0.41	1.97	
2002	30	1.17	0.57	35	0.51	0.28	2.30	

(B)

Year	*N*	*SB* % Occurrence	*SE*	*N*	*FP* % Occurrence	*SE*	*SB/FP* Ratio	Correlation
1986	41	7.32	4.12	30	10.00	5.57	0.73	$r = 0.75$
1987	29	6.90	4.79	32	3.13	3.13	2.21	
1994	28	7.14	4.96	34	0.00	0.00		
1997	34	14.71	6.17	35	14.29	6.00	1.03	
2000	34	20.59	7.04	28	14.29	6.73	1.44	
2001	26	19.23	7.88	30	10.00	5.57	1.92	
2002	30	16.67	6.92	35	11.43	5.46	1.46	

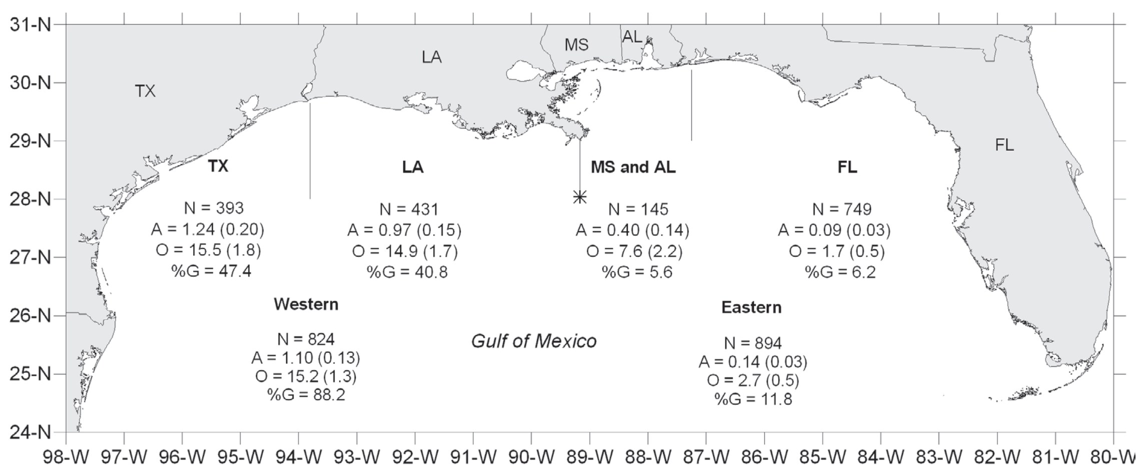

Figure 2. Mean abundance (A), percent occurrence (O) and percentage of Gulf of Mexico total abundance (%G) of red snapper *Lutjanus campechanus* larvae from the western and eastern Gulf of Mexico, and the Texas (TX), Louisiana (LA), Mississippi/Alabama (MS and AL) and Florida subregions collected during the Fall Plankton survey. Values in parenthesis are standard errors of abundance and percent occurrence. Western and eastern Gulf of Mexico regions are separated at the mouth of the Mississippi River (*) and the subregions by the plotted demarcation lines.

Model based standardized indices of relative abundance were generated using the delta-lognormal procedure for both the western and eastern GOM utilizing samples collected during the Fall Plankton survey. The modeling exercise for the western GOM index identified the following significant effects: year (P = 0.0138) and time of day (P = <0.0001) for the binomial submodel; and time of day (P = 0.0075), subregion (P = 0.0159) and water depth (P = 0.0150) for the lognormal submodel. The year effect (P = 0.0935) was not significant but was retained in the lognormal sub-model. For the eastern GOM index the modeling exercise identified subregion (P = 0.0002) as the only significant effect in the binomial submodel. The year effect (P = 0.9086) was not significant but was retained in the binomial sub-model. No significant factors were identified in the lognormal sub-model. Therefore, the eastern standardized index of relative abundance is based solely on the binomial submodel describing the occurrence of larvae.

The western standardized index indicated a substantial increase in red snapper larvae after 1994 (Tables 5 and Figure 3). In the western GOM CVs of the standardized index of annual abundance ranged from 29% to 75% and in general were below 40% after 1994. Nominal indices based on larval occurrence and abundance in the western GOM showed similar trends in abundance at similar levels of precision. A standardized index of relative abundance based on the binomial sub-model (occurrence) was calculated for the eastern GOM (Table 5 and Figure 3). Both the standardized and nominal indices for the eastern GOM indicated very low levels of red snapper abundance with an increase after 1995. CVs of the eastern abundance indices in almost all years were greater than 50%.

Discussion

Lyczkowski-Shultz and Hanisko (2007) review the early life history of red snapper in the Gulf of Mexico based on over 7,900 neuston and 7,000 bongo collections from SEAMAP plankton surveys 1982–2003. The objective of this companion study was to develop standardized larval indices of relative red snapper abundance generated from those collections that might best reflect trends in the size of the red snapper spawning populations in the western and eastern U.S. GOM. After examination of the survey data we have concluded that the most reliable and spatially consistent index is the one based on abundance and occurrence of red snapper larvae estimated from bongo net samples taken during the Fall Plankton survey of shelf waters from Brownsville, TX to south Florida.

Use of Fall Plankton survey data as a basis for an index of the spawning population size is complicated by the timing of this survey (~September to early October) which is near the end of the red snapper spawning season (Futch and Bruger 1976; Collins et al. 1996, 2001; Woods 2003; Fitzhugh et al. 2004). However, occurrence and abundance of red snapper larvae were lower in September than during the SEAMAP Summer Shrimp/Bottomfish survey in June and July (the nominal time of peak spawning) annual estimates of occurrence and abundance for the two survey types (*SB* and *FP*) were highly correlated, and the ratios of annual mean abundance and occurrence between the two were fairly consistent from year to year. Thus we conclude that larval red snapper abundance as measured during the fall plankton survey effectively approximates reproductive output of the red snapper population at least in the western GOM.

The timing of the Fall Plankton survey may have biased our estimates of the spawning population of red snapper among the various regions and subregions of the GOM. Sampling during the Fall Plankton survey typically begins in early September off south Texas and continues eastward to south Florida through the end of September and occasion-

Table 5. Nominal abundance (*NA*), nominal percent occurrence (%*O*), and standardized relative abundance (*SRA*) of red snapper *Lutjanus campechanus* larvae collected during the Fall Plankton survey with associated percent coefficient of variation (%CV, (standard error/mean) and number of samples (*N*) by year for the western (A) and eastern (B) Gulf of Mexico.

(A)

		Nominal Abundance		Nominal Occurrence		Standardized Relative Abundance	
Year	*N*	*NA*	%CV	%O	%CV	*SRA*	%CV
1986	50	0.31	49.54	8.00	48.45	0.33	51.93
1987	56	0.95	69.46	5.36	56.68	0.78	71.99
1988	28	0.00		0.00		.	
1989	29	0.59	57.55	10.34	55.63	0.74	63.20
1990	32	0.97	45.34	15.63	41.74	0.88	49.22
1991	32	0.62	49.23	12.50	47.52	0.56	52.04
1992	56	0.53	37.77	12.50	35.68	0.47	38.82
1993	56	0.55	37.65	12.50	35.68	0.48	38.50
1994	56	0.91	72.14	7.14	48.62	0.77	75.43
1995	56	1.99	35.78	21.43	25.82	1.78	36.25
1996	56	1.12	34.70	16.07	30.81	1.04	36.13
1997	55	1.65	28.71	25.45	23.29	1.71	28.94
1998						.	
1999	52	0.42	44.72	9.62	42.93	0.43	47.06
2000	55	2.01	31.97	25.45	23.29	1.80	29.80
2001	47	1.25	48.49	12.77	38.54	1.19	50.43
2002	54	1.43	32.86	22.22	25.70	1.47	32.64
2003	54	2.33	31.48	29.63	21.17	2.19	29.20

(B)

		Nominal Abundance		Nominal Occurrence		Standardized Relative Abundance	
Year	*N*	*NA*	%CV	%O	%CV	*SRA*	%CV
1986	62	0.08	100.00	1.61	100.00	0.02	100.11
1987	60	0.14	70.30	3.33	70.11	0.03	70.17
1988	27	0.21	100.00	3.70	100.00	0.04	99.04
1989	29	0.00		0.00			
1990	36	0.00		0.00			
1991	35	0.10	100.00	2.86	100.00	0.03	99.48
1992	53	0.00		0.00			
1993	59	0.00		0.00			
1994	65	0.06	100.00	1.54	100.00	0.02	100.15
1995	61	0.10	70.13	3.28	70.12	0.03	70.19
1996	62	0.00		0.00		.	
1997	63	0.03	100.00	1.59	100.00	0.02	100.13
1998						.	
1999	61	0.33	69.11	4.92	56.76	0.05	56.82
2000	58	0.51	53.19	6.90	48.67	0.07	48.69
2001	62	0.15	58.14	4.84	56.78	0.05	56.84
2002	39	0.09	100.00	2.56	100.00	0.03	99.63
2003	62	0.40	52.49	6.45	48.75	0.06	48.81

ally into mid October. Lyczkowski-Shultz and Hanisko (2007) report a sharp decline in the occurrence and abundance of red snapper larvae from September to October. The decline may be indicative of the abrupt termination of spawning in this species as was suggested by Woods (2003) based on the low incidence during the spawning season of red snapper ovaries exhibiting over 50% atresia. Declining reproductive output from September to mid October and the west to east progression of the Fall Plankton survey may lead to an underestimation of larval occurrence and abundance in the eastern region of the survey area.

Given the likelihood of underestimating larval occurrence and abundance in the eastern GOM the larval data still seems to reflect the !relative regional and subregional differences in GOM red snapper population. Based on larval occurrence and abundance the relative red snapper population was four to eight times greater in the western than the eastern GOM. The current stock assessment for red snapper estimated the unfished abundance of the western population to be three times greater than the eastern population (Porch 2007, this volume). At the subregional level, larval occurrence and abundance indicated a decreasing trend in the red snapper abundance from Texas to Florida. The percentage of the total number of age-0 and age-1 red snapper caught off TX (69%), LA (23%) and MS/AL (7%) during 1988 to 2006 SEAMAP Fall Groundfish trawl surveys show a similar pattern (Nichols, NMFS, personal communication). Gold and Saillant (2007, this volume) and Saillant and Gold (2004) estimated the population of red snapper off TX, LA and MS/AL based on genetic variance effective size. Population estimates for TX and MS/AL were similar, but the estimate for LA was at least an order of magnitude higher than for TX and MS/AL. Larval occurrence and abundance also suggest a higher abundance of red snapper off LA than MS/AL, but in contrast to the variance effective size estimates suggested that red snapper abundance off TX and LA were similar. The only estimate of relative population size between subregions in the eastern GOM was the larval data. Although the MS/AL and FL subregions each contributed about the same percent (5.6 and 6.2) to total Gulfwide abundance of larval snapper the mean abundance of larvae off MS/AL was four times greater than off FL. The greater concentration of larvae off MS/AL may be attributed to production from the adult spawning stock associated with the high concentration of artificial reefs in the area (Szedlmayer and Shipp 1994; Minton and Heath 1998; Shipp 1999; Patterson and Cowen 2003).

The standardized larval indices of abundance presented here for the western and eastern GOM differed from the larval indices used in the most recent red snapper stock assessment (SEDAR7 2005; Porch 2007, this volume). The initial indices were based on the size adjusted abundance of 3.8–8.3 mm larvae taken in bongo nets during both the SEAMAP Summer Shrimp/Bottomfish and Fall Plankton surveys, and only the year effect was accounted for in the delta-lognormal model (Hanisko et al. 2004; Lyczkowski-Shultz et al. 2004).. In contrast, the current indices were based on the abundance of 3.8–6.3 mm larvae in bongo nets taken during the Fall Plankton survey, and were unadjusted for size. The model generating these indices attempted to account for the effects of year, time of day and subregion. The different formulations of the larval indices revealed similar trends in relative red snapper abundance over time. Both versions suggested an increased adult spawning stock in the eastern GOM, as did the 2005 assessment (Porch 2007). However, the eastern GOM indices were of limited value in resolving annual changes in population size due to their low precision. The 2005 stock assessment in the western GOM indicated little or no increase

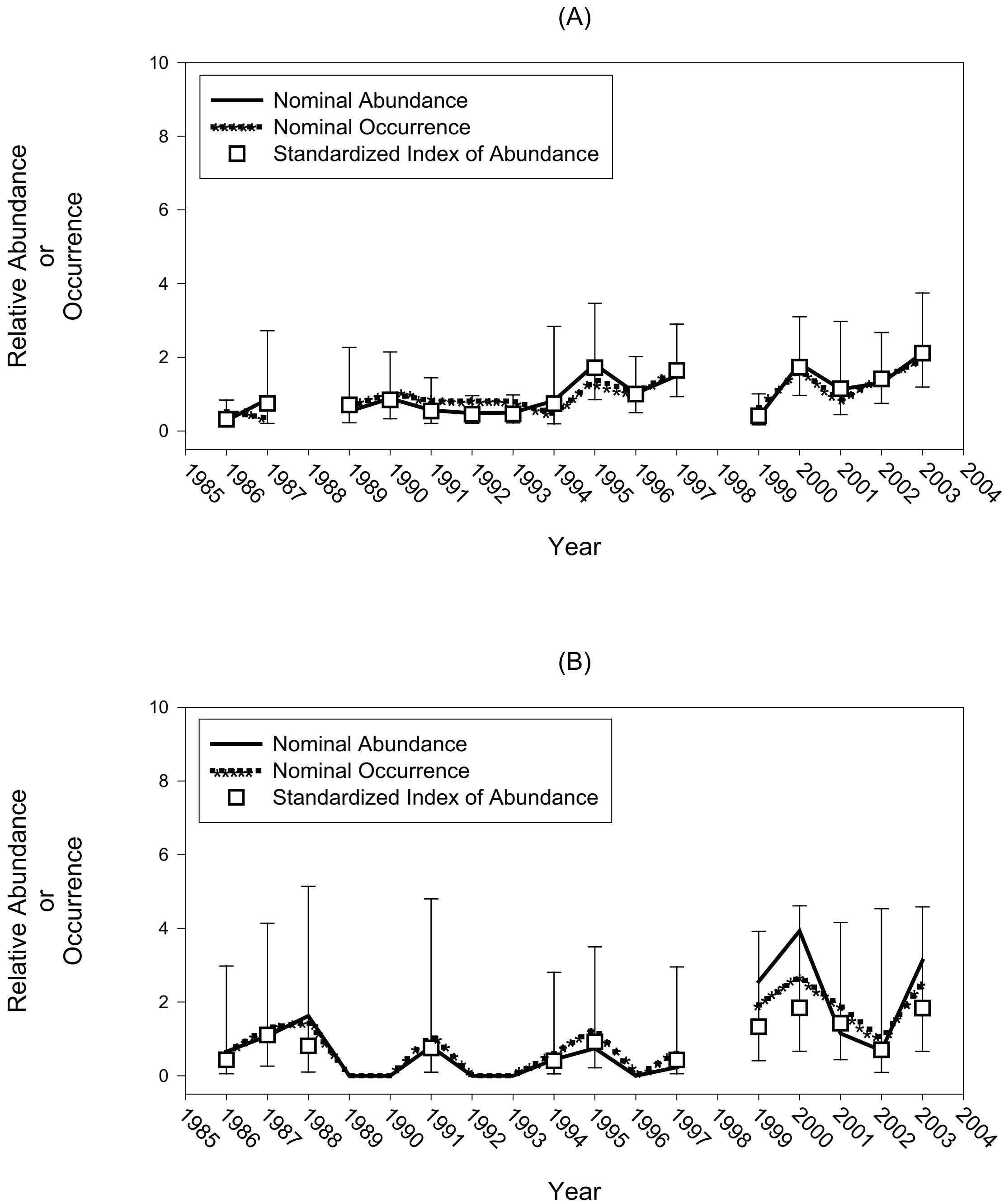

Figure 3. Nominal abundance, nominal percent occurrence, and standardized relative abundance of red snapper *Lutjanus campechanus* larvae collected during the Fall Plankton survey by year for the western (A) and eastern (B) Gulf of Mexico. Error bars associated with the standardized index are asymmetrical 95% confidence intervals. Annual values of nominal abundance, nominal percent occurrence, and standardized relative abundance are scaled by their respective means.

in the population of red snapper, while both (current and initial) indicated an increased spawning stock.

In addition to the initial larval indices, three other indices were used by the recent stock assessment to identify trends in the adult spawning stock: a SEAMAP reef fish video survey index (VIDEO; Gledhill and Ingram 2004), an index of commercial hand line catches (CHL; McCarthy and Cass-Calay 2004) and an index of recreational catch reported from Marine Recreational Fisheries Statistics Survey Data (MRFSS; Cass-Calay 2004). The trends indicated by the larval, VIDEO, CHL and MRFSS indices were in general agreement for the eastern GOM. In the western GOM, the 2005 assessment was not able to reconcile the increasing trend of the initial larval index with the flat or declining trends indicated by the other indices of adult abundance (Porch 2007, this volume). The current larval index indicated a less dramatic increase over the time series with little or no increase from 1995 to 2003, but still indicated higher abundances of red snapper after 1995 than the other indices. Confidence intervals estimated for the current larval index and the VIDEO, MRFSS and CHL indices suggested that the difference among the trends in the indices may not be statistically significant (Cass-Calay 2004; Gledhill and Ingram 2004; McCarthy and Cass-Calay 2004).

Potential explanations for the discrepancy among the trends suggested by the VIDEO, MRFSS and CHL and larval indices in the western GOM may be linked to differences in sampled habitat, subregional coverage and age selectivity. The SEAMAP VIDEO survey provides data on the adult population from natural reef and hard bottom habitats but does not index the spawning stock from artificial reefs in the western GOM. Artificial reefs, predominantly offshore oil and gas platforms, harbor large numbers of red snapper and are a major destination of commercial and recreational fisherman targeting the species (Witzig 1986; Reggio 1987; Stanley and Wilson 2000, 2003; Nieland and Wilson 2003). Data in the MRFSS index was limited to catches reported solely from the state of LA, as data available from the Texas Department of Parks and Wildlife was incompatible with MRFSS and was not included (Cass-Calay 2004). The MRFSS and CHL indices select predominantly for age 2 to age 4 and age 3 to age 5 fish respectively, and may not adequately represent older fish. Allman et al. (this volume) compared age compositions between the recreational, commercial handline and longline sectors and found that age 2 to age 4 fish accounted for 90% of the recreational sector with less with 0.3% of all fish greater than age 10, where as age 3 to age 5 fish dominated CHL catches with 1% of fish greater than age 10. The age distribution from commercial longline catches underscores the age selectivity of the MRFSS and CHL indices. Red snapper by age 5 were fully recruited to the commercial long-line fishery with over 22% of fish greater than age 10 (Allman et al. 2007, this volume). In contrast to the VIDEO, MRFSS and CHL indices, the larval index references the majority of the spawning area in the western GOM, and the reproductive output of the adult spawning stock regardless of habitat and age.

In general, the eastern and western larval indices indicated two distinct periods of larval abundance and occurrence: 1986–1994 when larval occurrence and abundance was extremely low, and 1995–2003 when occurrence and abundance were two times greater than the earlier period. The inception of the *FP* survey in 1986 coincided with the decline of the red snapper fishery in the mid to late 1980s. During this time, the total catch of red snapper fell from 4.7 million kg (10.3 million pounds) in 1982 to 1.8 million kg (4.0 million pounds) in 1990, and the fishery was supported primarily by age 1 to age 3 fish (Hood and Steele 2004). The depletion of the adult spawning stock during this period may be reflected in the low levels of larval red snapper occurrence and abundance indicated by the larval indices from 1986 to 1994. Increased occurrence and abundance after 1995 may reflect higher recruitment from above average year classes during the period from 1989 to 1991 which coincided with the lower total catches in the early 1990s, and recruitment from strong year classes during the mid 1990s (Allman et al. this volume; Nichols 2004; Turner and Porch 2004; SEDAR7 2005). Most female red snapper mature by age 2 and nearly all (95%) by age 5 (Fitzhugh et al. 2004). Therefore, fish recruited to the population in the late 1980s and early 1990s would begin contributing to larval production between 1991 and 1996, and the 1994 to 1996 recruits between 1996 and 2001. This corresponds well with increased larval occurrence and abundance during SEAMAP Fall Plankton surveys after 1995.

The red snapper spawning stock in the GOM was estimated to be much lower than it had been historically, but estimated recruitment for both the western and eastern components of the stock have been above the long term average. Porch (2007) indicates that the recruitment estimates are well above those for an unfished population despite the indicated decrease in the spawning potential of the current stock, and suggests as a possible interpretation that red snapper stocks may have become more productive over the last two decades. Under this hypothesis, the increase in red snapper larval occurrence and abundance may reflect an increase in the reproductive output of red snapper and not an increase in the size of the spawning population.

The idea that the size or biomass of a fish stock can be estimated from egg or larva abundance data as measured during field surveys has been around since the end of the 19th century (Heath 1992). Use of ichthyoplankton data to estimate the biomass of fish populations over time, either in absolute or relative terms, is based on the assumption that population parameters such as fecundity, spawning frequency, hatching success, development, growth and mortality are unvarying from spawning season to spawning season (i.e., year to year) or even within a spawning season (Heath 1992; Hunter and Lo 1993). More often than not this assumption is difficult, if not impossible, to verify due to the lack of specific information on early life stage vital rates or the cost of obtaining such information. Despite the shortcomings, ichthyoplankton abundance and presence/absence data continues to be used in contemporary, age structured stock assessment models both in the U.S. and worldwide. These models are enhanced by inputs of fishery-independent indices of relative stock abundance which are considered to be without bias (as opposed to fishery-dependent data sources and indices) because they are based on statistical sampling design. Lack of fishery-independent data are considered to a great impediment to fishery assessments (NMFS 2001). As a result of this ichthyoplankton surveys continue to become an increasingly important source of fishery-independent data for fish stocks such as Pacific sardine (Lo and Macewicz 2006), bocaccio rockfish (Ralston and Ianelli 1998), cowcod rockfish (Butler et al. 2002), and Atlantic bluefin tuna (Scott et al. 1993; Scott and Turner 2002; Ingram et al. 2006).

The value of larval data in red snapper assessments remains problematic as our results have shown. Inclusion of data on the abundance of smaller (<4 mm) red snapper larvae in SEAMAP collections that now can be identified only to family or genus (*Lutjanus* sp.) may improve not only the precision of the larval index but its value as a practical gauge of spawning biomass as well. Use of molecular genetic techniques to identify the smallest field collected snapper larvae to species holds great promise. There are plans at SEFSC/NMFS Mississippi Laboratories to begin identifying small snapper larvae in SEAMAP samples using genetic techniques in the near future. Modeling the effects of environmental factors influencing larval occurrence and abundance may also improve the precision of the larval indices and provide a better understanding of their distribution. Environmental effects were not investigated for the current indices as considerable work still needs to be completed regarding the identification of corresponding environmental data within the SEAMAP ichthyoplankton database. More consistent plankton sampling during SEAMAP summer trawl surveys in coming years, i.e. during peak months of red snapper spawning, may also enhance the contribution of the red snapper larval index in future population assessments.

Acknowledgments

The following individuals are gratefully acknowledged for their significant contributions to this work: Pam Bond, Connie Cowan, Denice Drass, Gelenn Zapfe, Lanora Lange and Rosanne Brasher, NOAA/NMFS Mississippi Laboratories, Pascagoula, MS; Malgorzata Konieczna, Hanna Skolska and the Ichthyoplankton Group, Sea Fisheries Institute, Plankton Sorting and Identifications Center, Szczecin and Gdynia, Poland; Kim Williams at the SEAMAP Archiving Center, Fish and Wildlife Resaearch Institute, St. Petersburg, FL; and Cindy Gavins, Gulf Coast Research laboratory/USM, Ocean Springs, MS. We would also like to recognize the enduring efforts of the crews of the NOAA Ships Chapman, Oregon II and Gordon Gunter; and the dedication of the biologists of the NMFS, Gulf States resource agencies, Johnson Controls International and IAP World Services that participate on SEAMAP cruises making this historical data series possible. I also thank Will Patterson and two anonymous reviewers for their helpful comments on the manuscript.

References

Allman, R. J., and G. R. Fitzhugh. 2007. Temporal age progressions and relative year-class strength of Gulf of Mexico red snapper. Pages 311–328 *in* W. F. Patterson, III, J. H. Cowan, Jr., G. R. Fitzhugh, and D. L. Nieland, editors. Red snapper ecology and fisheries in the U.S. Gulf of Mexico. American Fisheries Society, Symposium 60, Bethesda, Maryland.

Butler, J. L., L. D. Jacobson, J. T. Barnes, and H. G. Moser. 2002. Biology and population dynamics of the cowcod (*Sebastes levis*) in the southern California Bight. Fishery Bulletin 101:260–280.

Cass-Calay, S. L. 2004. Revised catch rate indices of red snapper (*Lutjanus campechanus*) landed during 1981–2003 by the U.S. Gulf of Mexico recreational fishery. Southeast Data, Assessment and Review 7: Gulf of Mexico red snapper. Available: http://www.sefsc.noaa.gov/sedar/download/SEDAR7-AW-04v2.pdf?id=DOCUMENT. (March 2007).

Collins, L. A., G. R. Fitzhugh, L. Mourand, L. A. Lombardi, W. T. Walling, Jr., W. A. Fable, M. R. Burnett, and R. J. Allman. 2001. Preliminary results from a continuing study of spawning and fecundity in the red snapper (Lutjanidae: *Lutjanus campechanus*) from the Gulf of Mexico, 1998–1999. In L. R. Creswell, editor. Proceedings of the 52nd Annual Gulf and Caribbean Fisheries Institute 52:34–47.

Collins, L. A., A. G. Johnson, and C. P. Keim. 1996. Spawning and annual fecundity of the red snapper (*Lutjanus campechanus*) from the northeastern Gulf of Mexico. Pages 174–188 *in* F. Arreguin-Sanchez, J. L. Munro, M. C. Balgos, and D. Pauly editors, Biology, fisheries and culture of tropical groupers and snappers. ICLARM Conference Proceedings 48.

Drass, D. M., K. L. Bootes, J. Lyczkowski-Shultz, B. H. Comyns, G. J. Holt, C. M. Riley, and R. P. Phelps. 2000. Larval development of red snapper, *Lutjanus campechanus*, with comparisons to co-occurring snapper species. Fishery Bulletin. 98:507–527.

Fitzhugh, G. R., M. S. Duncan, L. A. Collins, W. T. Walling and D. W. Oliver. 2004. Characterization of red snapper (*Lutjanus campechanus*) reproduction: for the 2004 Gulf of Mexico SEDAR. Southeast Data, Assessment and Review 7: Gulf of Mexico red snapper. Available: http://www.sefsc.noaa.gov/seda/download/SEDAR7_DW35.pdf?id=DOCUMENT. (March 2007).

Futch, R. B., and G. E. Bruger. 1976. Age, growth, and reproduction of red snapper in Florida waters. Pages 165–183 *in* H. R. Bullis and A. C. Jones editors. Proceedings: Colloquium on snapper-grouper fishery resources for the western central Atlantic Ocean. Florida Seagrant College Report 17:165–185.

Gledhill, C. T., and W. Ingram. 2004. SEAMAP reef fish survey of offshore banks. Southeast Data, Assessment and Review 7: Gulf of Mexico red snapper. Available: http://www.sefsc.noaa.gov/sedar/download/SEDAR7_DW15.pdf?id=DOCUMENT. (March 2007).

Gold, J. R., and E. Saillant. 2007. Population structure of red snapper in the northern Gulf of Mexico. Pages 201–216 *in* W. F. Patterson, III, J. H. Cowan, Jr., G. R. Fitzhugh, and D. L. Nieland, editors. Red snapper ecology and fisheries in the U.S. Gulf of Mexico. American Fisheries Society, Symposium 60, Bethesda, Maryland.

Hanisko, D. S., J. Lyczkowski-Shultz, and G. W. Ingram, Jr. 2004. Alternate fishery independent larval indices of abundance for red snapper. Southeast Data, Assessment and Review 7: Gulf of Mexico red snapper. Available: http://www.sefsc.noaa.gov/sedar/download/SEDAR7-RW%2007.pdf?id=DOCUMENT. (March 2007).

Heath, M. R. 1992. Field investigations of the early life stages of marine fish. Advances in Marine Biology 28:1–174.

Hood, P., and P. Steele. 2004. History of red snapper management in federal waters of the U.S. Gulf of Mexico, 1982 to 2004. Southeast Data, Assessment and Review 7: Gulf of Mexico red snapper. Available: http://www.sefsc.noaa.gov/sedar/download/SEDAR7_DW40.pdf?id=DOCUMENT. (March 2007).

Hunter, J. R., and N. C.-H. Lo. 1993. Ichthyoplankton methods for estimating fish biomass introduction and terminology. Bulletin of Marine Science 53(2): 723–727.

Ingram, G. W., Jr., W. J. Richards, G. P. Scott, and S. C. Turner. 2006. Development of indices of bluefin tuna (*Thunnus thynnus*) spawning biomass in the Gulf of Mexico using delta-lognormal models. ICCAT Working Document. SCRS/06/082.

Lindeman, K. C., W. J. Richards, J. Lyczkowski-Shultz, D. M. Drass, C. B. Paris, J. M. Leis, M. Lara, and B. H. Comyns. 2005. Lutjanidae: snappers. Pages 1549–1595 *in* W. J. Richards, editor. Early stages of Atlantic fishes: an identification guide for the western central North Atlantic. CRC Press, Boca Raton, Florida.

Lo, N. C. -H., L. D. Jacobson, and J. L. Squire. 1992. Indices of relative abundance from fish spotter data based on delta-lognormal models. Canadian Journal of Fisheries and Aquatic Sciences 49:2515–1526.

Lo, N. C. -H., and B. J. Macewicz. 2006. Spawning biomass of Pacific sardine (*Sardinops sagax*) off California in 2005. NOAA Technical Memorandum NMFS. NOAA-TM-NMFS-SWFSC-387

Lyczkowski-Shultz, J., and D. S. Hanisko. 2007. A time series of observations on red snapper larvae from SEAMAP surveys, 1982–2003: seasonal occurrence, distribution, abundance and size. Pages 3–23 *in* W. F. Patterson, III, J. H. Cowan, Jr., G. R. Fitzhugh, and D. L. Nieland, editors. Red snapper ecology and fisheries in the U.S. Gulf of Mexico. American Fisheries Society, Symposium 60, Bethesda, Maryland.

Lyczkowski-Shultz, J., D. S. Hanisko, and G. W. Ingram, Jr. 2004. The potential for incorporating a larval index of abundance for stock assessment of red snapper, *Lutjanus campechanus*. Southeast Data, Assessment and Review 7: Gulf of Mexico red snapper. Available: http://www.sefsc.noaa.gov/sedar/download/SEDAR7_DW14.pdf?id=DOCUMENT. (March 2007).

McCarthy K. J., and S. L. Cass-Calay. 2004. Standardized catch rates of red snapper (*Lutjanus campechanus*) from the United States commercial handline fishery in the Gulf of Mexico during the 1996–2003: additional indices. Southeast Data, Assessment and Review 7: Gulf of Mexico red snapper. Available: http://www.sefsc.noaa.gov/sedar/download/SEDAR7-AW-09.pdf?id=DOCUMENT. (March 2007).

Minton, V., and S. R. Heath. 1998. Alabama's artificial reef program: building oases in the desert. Gulf of Mexico Science 16:105–106.

Nichols. S. 2004. Calibration among the separate trawl survey programs to extend the time series for juvenile snapper indexes. Southeast Data, Assessment and Review 7: Gulf of Mexico red snapper. Available: http://www.sefsc.noaa.gov/sedar/download/SEDAR7_DW2.pdf?id=DOCUMENT. (March 2007).

Nieland, D. L., and C. A. Wilson. 2003. Red snapper recruitment to and disappearance from oil and gas platforms in the northern Gulf of Mexico. Pages 73–81 *in* D. R. Stanley and A. Scarborough-Bull, editors. Fisheries, reefs, and offshore development. American Fisheries Society, Symposium 36, Bethesda, Maryland.

NMFS (National Marine Fisheries Service). 2001. Marine Fisheries Stock Assessment Improvement Plan. Report of the National Marine Fisheries Service National Task Force for Improving Fish

Stock Assessments. U.S. Department of Commerce, NOAA Technical Memorandum. NMFS-F/SPO-56.

Patetta, M. 2002. Longitudinal Data Analysis with Discrete and Continuous Responses Course Notes. SAS Institute Inc., Cary, North Carolina.

Patterson, W. F., III, and J. H. Cowan, Jr. 2003. Site fidelity and dispersion of red snapper associated with artificial reefs in the northern Gulf of Mexico. Pages 181–193 *in* D. R. Stanley and A. Scarborough-Bull, editors. Fisheries, reefs, and offshore development. American Fisheries Society, Symposium 36, Bethesda, Maryland.

Porch, C. E. 2007. An assessment of the red snapper fishery in the U.S. Gulf of Mexico using a spatially-explicit age-structured model. Pages 355–384 *in* W. F. Patterson, III, J. H. Cowan, Jr., G. R. Fitzhugh, and D. L. Nieland, editors. Red snapper ecology and fisheries in the U.S. Gulf of Mexico. American Fisheries Society, Symposium 60, Bethesda, Maryland.

Ralston, S., and J. N. Ianelli. 1998. When lengths are better than ages: the complex case of bocaccio. Pages 451–468 in F. Funk, T. J. Quinn II, J. Heifetz, J. N. Ianelli, J. E. Powers, J. F. Schweigert, P. J. Sullivan, and C.-I. Zhang, editors. Fishery stock assessment models. Alaska Sea Grant College Program Report No. AK-SG-98–01, University of Alaska Fairbanks, Alaska.

Reggio, V. C., Jr. 1987. Rigs-to-reefs: the use of obsolete petroleum structures as artificial reefs. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, OCS Report MMS87–0015, New Orleans, Louisiana.

Saillant, E., and J. R. Gold. 2004. Population structure and variance effective size of red snapper (*Lutjanus campechanus*) in the northern Gulf of Mexico. Fishery Bulletin 104:136–148.

Scott, G. P., and S. C. Turner. 2002. Updated index of bluefin tuna (*Thunnus thynnus*) spawning biomass from Gulf of Mexico ichthyoplankton surveys. International Commission for the Conservation of Atlantic Tunas, Working Document SCRS/02/91.

Scott, G. P., S. C. Turner, C. B. Grimes, W. J. Richards, and E. B. Brothers. 1993. Indices of larval bluefin tuna, *Thunnus thynnus*, abundance in the Gulf of Mexico: modeling variability in growth, mortality and gear selectivity. Bulletin of Marine Science 53(2):912–929.

SEAMAP (Southeast Area Monitoring and Assessment Program). 2004. Environmental and biological atlas of the Gulf of Mexico 2001, Number 118. Gulf States Marine Fisheries Commission, Ocean Springs, Mississippi.

SEDAR (Southeast Data, Assessment, and Review). 2005. Stock assessment report of SEDAR 7–10 Gulf of Mexico Red Snapper. SEDAR Assessment Report 1.

Seidelmann, P. Kenneth editor. 1992. Explanatory Supplement to the Astronomical Almanac. University Science Books, Sausalito, California.

Shipp, R. L. 1999. The artificial reef debate: are we asking the right questions? Gulf of Mexico Science 17:51–55.

Stanley, D. R., and C. A. Wilson. 2000. Variation in the density and species composition of fishes associated with three petroleum platforms using dual beam hydroacoustics. Fisheries Research 47:161–172.

Stanley, D. R., and C. A. Wilson. 2003. Seasonal and spatial variation in the biomass and size frequency distribution of fish associated with oil and gas platforms in the northern Gulf of Mexico. Pages 123–153 *in* D.R. Stanley and A. Scarborough-Bull, editors. Fisheries, reefs, and offshore development. American Fisheries Society, Symposium 36, Bethesda, Maryland.

Szedlmayer, S. T., and R. L. Shipp. 1994. Movement and growth of red snapper, *Lutjanus campechanus*, from an artificial reef area in the northeastern Gulf of Mexico. Bulletin of Marine Science 55:887–896.

Turner, S. C., and C. E. Porch. 2004. Alternate indices of abundance of juvenile red snapper from the Gulf of Mexico from SEAMAP surveys 1972–2003. Southeast Data, Assessment and Review 7: Gulf of Mexico red snapper. Available: http://www.sefsc.noaa.gov/sedar/download/SEDAR7-AW-25.pdf?id=DOCUMENT. (March 2007).

Witzig, J. 1986. Rig fishing in the Gulf of Mexico 1984: marine recreational fishing results. Pages 103–105 *in* Proceedings, Sixth Annual Gulf of Mexico Information Transfer Meeting. U.S. Department of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, OCS Study/MMS86–0073. New Orleans, Louisiana.

Woods, M. K. 2003. Demographic differences in reproductive biology of female red snapper (*Lutjanus campechanus*) in the northern Gulf of Mexico. Master's thesis, University of South Alabama, Mobile, Alabama.