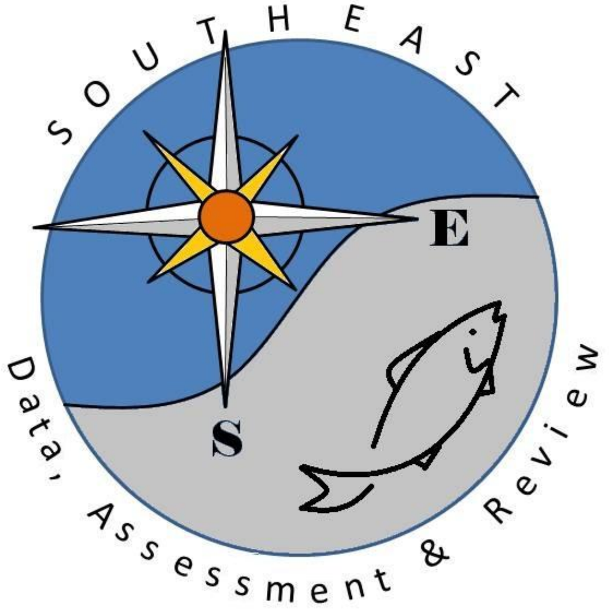
The Artificial Habitat as an Accessory for Improving Estimates of Juvenile Reef Fish Abundance in Fishery Management

Stephen T. Szedlmayer

SEDAR31-RD21

13 August 2012



ARTIFICIAL REEFS IN FISHERIES MANAGEMENT

EDITED BY

STEPHEN A. BORTONE
FREDERICO PEREIRA BRANDINI
GIANNA FABI
SHINYA OTAKE

CRC Press
Taylor & Francis Group
Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

© 2011 by Taylor and Francis Group, LLC
CRC Press is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works

Printed in the United States of America on acid-free paper
10 9 8 7 6 5 4 3 2 1

International Standard Book Number: 978-1-4398-2007-0 (Hardback)

This book contains information obtained from authentic and highly regarded sources. Reasonable efforts have been made to publish reliable data and information, but the author and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The authors and publishers have attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint.

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access www.copyright.com (http://www.copyright.com/) or contact the Copyright Clearance Center, Inc. (CCC), 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

Library of Congress Cataloging-in-Publication Data

Artificial reefs in fisheries management / editors, Stephen A. Bortone … [et al.].
p. cm. -- (Marine biology)
Includes bibliographical references and index.
ISBN 978-1-4398-2007-0 (alk. paper)
1. Artificial reefs. I. Bortone, Stephen A.

SH157.85.A7A774 2011
639.3--dc22 2010048795

Visit the Taylor & Francis Web site at
http://www.taylorandfrancis.com

and the CRC Press Web site at
http://www.crcpress.com

CHAPTER 3

The Artificial Habitat as an Accessory for Improving Estimates of Juvenile Reef Fish Abundance in Fishery Management

Stephen T. Szedlmayer

CONTENTS

ABSTRACT

The juvenile stages of most reef fishes are difficult to sample due to cryptic habitat associations with complex reef habitats. Traditional methods such as trawls are usually inefficient even over reef habitats with relatively small (<1 m) relief. Artificial reefs offer an alternative method for the study of juvenile reef fishes as this information is essential in the effective management of benthic fisheries. If juvenile reef fishes can be attracted to artificial reefs, it is possible to use artificial reefs as part of the sampling method to study these important early stages. For example, the juvenile life stage of the recreationally and commercially important red snapper, *Lutjanus campechanus* (Poey 1860), from the northern Gulf of Mexico has received considerable attention because high mortalities during these stages are associated with later year classes. However, most abundance estimates of age 0–1 red snapper are based on trawl surveys, but as shown here, juvenile red snapper quickly become associated with reef structure during their first month or two of life, suggesting that juvenile abundance estimates using trawls may have both low precision and accuracy. Consistently high densities over several years of new recruits to artificial reefs (even in years of low adult red snapper abundance) and the lack of any increase in new recruit densities (even after significant shrimp trawl bycatch reduction, in recent years) indicates that early postsettlement processes influence subsequent red snapper year class strength. These conclusions are based on diver surveys of artificial

reefs as opposed to traditional trawl sampling. The increased use of sampling juvenile reef fishes with artificial reefs as the “sampling tool” could provide new insight into the ecology and management of important reef fish species.

The various limitations and ecological bottlenecks of marine reef fishes have been extensively studied, with the greatest effort directed at coral reef fishes (e.g., Sale, 1991, 2002). Despite this effort, it is still unclear as to the relative contributions of environmental limitations on early life larval (Doherty, 1991, 2002) or postsettlement juvenile mortality limitations on subsequent adult reef-fish populations (Jones, 1991; Hixon, 1991; Hixon and Webster, 2002). This discussion continues (Armsworth, 2002; Anderson et al., 2007; Caddy, 2008; Oeberst et al., 2009) and is applicable to population regulation questions concerning red snapper stocks in the northern Gulf of Mexico. What has received less attention is the use of artificial reefs in the study of red snapper and their possible utility in defining the functioning mechanisms that affect red snapper stocks (Gallaway et al., 2009; Shipp and Bortone, 2009). Here, the early life history of red snapper is examined with inferences concerning the population dynamics based on artificial reef studies.

INTRODUCTION

Red snapper is an extremely important fish species in the northern Gulf of Mexico. They are harvested by both commercial and sport fishers and impact the economies of coastal communities tremendously. However, fishery assessment models indicate that the stock is considerably overfished (SEDAR7, 2005; SEDAR, 2009). A difficulty with red snapper is that management efforts have continually increased restrictions through bag limits (i.e., number of fish retained per trip), size limits, and total allowable catch over the last 19 years, yet the population models still show a severely overfished stock (SEDAR, 2009). These restrictions have led to extreme reductions in fishing effort, with the 2009 fishing season lasting only 2 months with a total catch near 2.3 million kg.

In contrast, there are several aspects of the red snapper life history and population dynamics that indicate the stock may be in better condition than predicted from previous assessments. First, there is an apparent expansion of the species to new habitats where no records of its previous occupation exist. For example, age-1 red snapper were recently collected 48-km inland within the city limits of Mobile, Alabama, a low-salinity location that has usually been considered outside of the normal red snapper habitat (Dute, 2008). Also, there have been several recent reports of red snapper from the southwest Florida coast, an area with few red snapper in the last 20 years (*Tampa Tribune*, 2009). Another difficulty with the assessment process is the lack of inclusion of larger and older red snapper collected in long-line catches on the outer portion of the continental shelf, which are typically not used in the management of this species (Mitchell et al., 2004). These populations of larger, older fish may represent a reserve population that could buffer extreme effect of fishing mortality. Also, some stock reports are more optimistic than others. Szedlmayer (2007) suggested higher spawning potential ratios compared to past estimates and, over the last 50 years, the construction of extensive artificial reefs along with oil–gas platforms has resulted in harvest levels that have exceeded what past stocks could be expected to sustain (Gallaway et al., 2009; Shipp and Bortone, 2009). One difficulty with the red snapper population assessment is that all models are based on a valid stock–recruit relation. The present fishery is regulated on the premise that sets maximum fishing mortality at some level that would maintain minimum levels of spawning potential ratio (SEDAR, 2009). The implicit assumption is that larger stocks produce larger number of eggs, which then are reflected in larger number of recruits. This stock–recruit relation has not been demonstrated thus far. In fact, the relation shows considerable variation and suggests that fishing mortality may have little effect on new, age-0 recruits (SEDAR, 2009). Without a valid stock–recruit relation, it is probable that other life history stages may be experiencing limiting bottlenecks that may lead to fluctuations in year class strength.

Another aspect that has probably led to the difficulty in managing red snapper has been the use of indices of abundance for young fishes. These indices have been essentially based on trawl surveys from SEAMAP surveys (Nichols et al., 2005). However, these trawl surveys were typically conducted during the summer (e.g., in June before new recruitment) or fall (e.g., in October when most new recruits have moved to structured habitat). For example, Szedlmayer and Lee (2004) showed that age-0 fish moved to nontrawlable, structured habitat about 4 months after hatching. Thus, fish that were collected in trawl surveys may only be a small percentage of the actual number of new recruits.

It is well established that small changes in mortality rates during early life history stages can have significant effects on subsequent year classes (Houde, 1987; Myers and Cadigan, 1993; Sogard, 1997). In red snapper stock assessments, particular importance is contingent on age-0 and age-1 total (Z) mortality and the partitioning of Z into natural (M) and bycatch (F) mortality. For example, in a 2009 assessment of red snapper (SEDAR, 2009), M values doubled from 0.98 to 2.0 when compared to an earlier assessment (SEADR7, 2005), resulting in a 20% increase in the projected yield from the fishery. Thus, accurate estimates of early life history mortalities are essential and can have significant effects on model predictions and fishery management decisions.

This chapter examines the early life history of red snapper. Specifically, it compares estimates of age-0 to age-1 abundance based on visual SCUBA surveys of red snapper on artificial reefs. From these data, seasonal specific mortality rates for juvenile red snapper from initial settlement (recruitment) through age-1 are then calculated. Seasonally specific mortality rates can subsequently be used to predict possible early life history bottlenecks for red snapper populations.

METHODS

The study sites were located approximately 15–30 km south of Dauphin Island, Alabama (Figure 3.1), in the Gulf of Mexico. The area lacked natural reef structure, was uniform in depth (20 m), and dominated by sand–mud–shell substrates (Schroeder et al., 1995; Dufrene, 2005). Small artificial reefs (1–4 m^2) were placed in the northeast area of the Hugh Swingle reef-building zone. Underwater observers, using SCUBA, counted all fish and assigned them to 25-mm size class intervals based on estimated length.

In July 1998 and 1999, reefs were deployed in 4-m^2 plots (0.1 m height) and made of oyster shell or shell and 10 concrete blocks (20 × 20 × 41 cm, each with two 12 × 14 cm oval holes). All reefs ($N = 60$ each year) were placed at 20 m intervals and alternated from shell to block type. In August 1998, a visual survey was completed on all reefs deployed in 1998, after which these reefs were destroyed by a tropical storm. Three visual surveys were completed on the 1999 reefs in September, October, and November.

In July 2000, 3 × 3 m oyster shell reefs ($N = 10$), and 2 × 2 m shell reefs ($N = 10$) were deployed in the same area. These reefs were placed in a grid pattern, 20 m between reefs, alternating between 2 × 2 and 3 × 3 m sizes. Each reef was visually surveyed three times by divers using SCUBA in early August, late August, and October 2000.

In July and August 2001, artificial reefs (1 m^2 plots) were built that consisted of oyster shell ($N = 20$), shell cage ($N = 20$), shell block (4 blocks; $N = 20$), and shell-block cage ($N = 20$). Reefs were placed in 8 transects with 10 reefs per transect and habitat types alternated at 20 m intervals. A PVC stake (1 m × 12 mm diameter) was placed vertically near each habitat to indicate shrimp trawl effects; that is, the stake would be displaced if the habitat was trawled. Reefs were surveyed in August, September, October, and November 2001 (Piko and Szedlmayer, 2007).

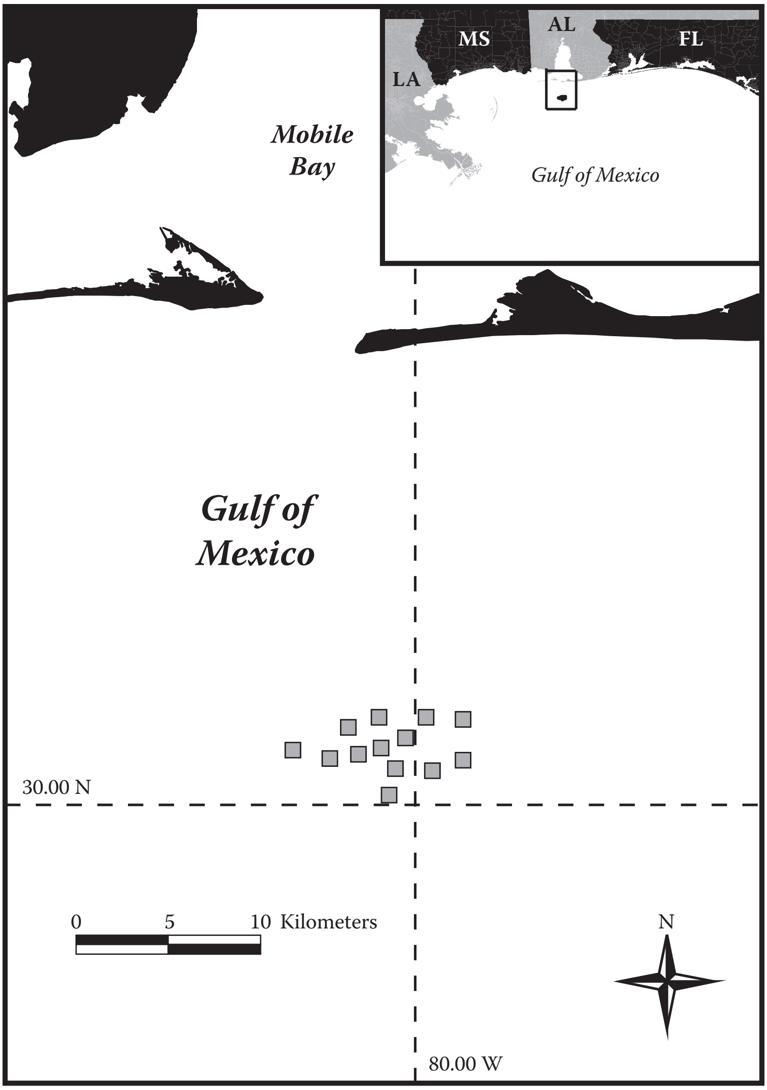


Figure 3.1 Study site locations in the northeast Gulf of Mexico. All artificial reefs over all years were deployed in the Hugh Swingle reef building zone, within 3 km of these sites from 2001.

In June and July 2002, a new set of reefs were deployed (*N* = 80) using the same design as employed in 2001. One visual survey was completed on all reefs in September 2002, after which all reefs were destroyed by a tropical storm. After the storm, the visual surveys confirmed that the PVC stakes were still intact, yet the reefs had become silted over (Lingo and Szedlmayer, 2006).

In September 2003, the artificial habitats deployed were constructed from plastic-coated wire (1.2 × 1.2 × 0.6 m; 3.6-cm mesh; *N* = 16). Each habitat contained two concrete blocks (20 × 20 × 41 cm) and ten sections of PVC pipe (31 cm long, 10 cm diameter) for added structure. Reefs were placed 24 m apart, at a depth of 23 m. A second reef design was also deployed at a depth of 20 m in October 2003 (steel cages 2.5 × 1.3 × 1.2 m; *N* = 16). These steel cages were placed 57 m apart. All reefs were surveyed in October, November 2003, April, and June 2004 (Chapin et al., 2009).

A third artificial reef design was deployed in June 2003 (2 × 2 × 0.2 m; *N* = 40). Each reef consisted of ten concrete blocks (each block = 20 × 20 × 41 cm) placed on a polyethylene mat

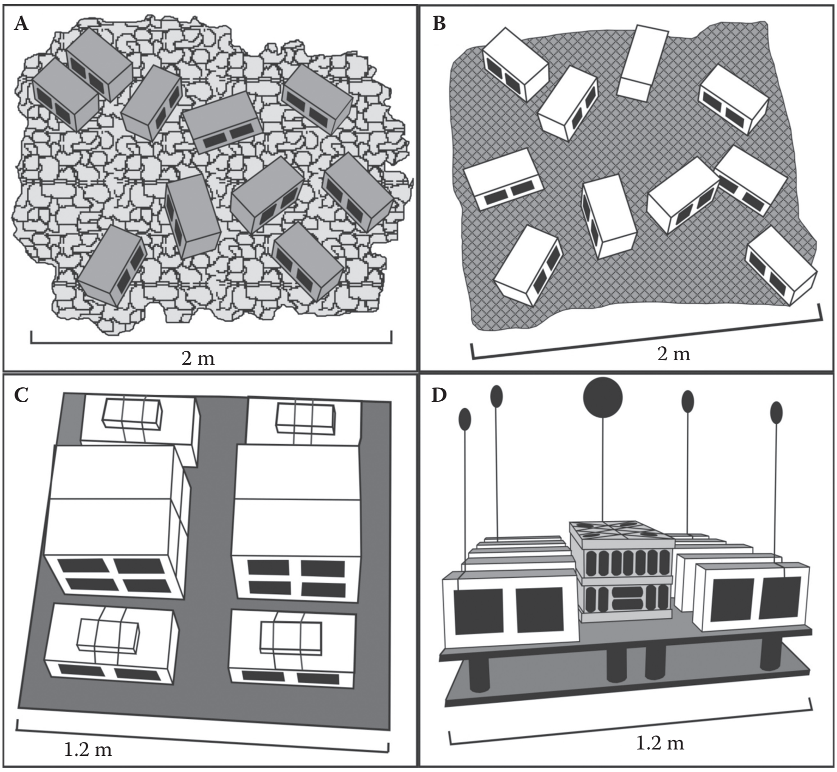


Figure 3.2 Artificial reef design of (A) 1998–1999, (B) 2003, (C) 2005 and 2006 habitats, and (D) 2007.

($4\ m^2$, 0.64-cm mesh; Figure 3.2A). Reefs were placed at 30 m intervals within each transect, with transects approximately 0.5 km apart. These reefs were visually surveyed in October, November 2003, and May 2004 (Redman and Szedlmayer, 2009).

In October and November 2004, wire reefs (1.2 × 1.2 × 1.2 m; $N = 22$) made of plastic-coated galvanized wire (5.1-cm mesh) containing four concrete blocks, each were deployed in 20 m of water. Reefs were surveyed in May and June 2005, before a tropical storm destroyed all reefs. A visual survey on 13 June 2005 indicated that the remaining wire reefs were displaced approximately 24 m from their original position and were in poor (i.e., broken and displaced) condition.

In October 2005, artificial reefs ($N = 20$) were deployed that consisted of 12 concrete blocks (20 × 20 × 41 cm) attached with cable ties to a plywood base (0.005 × 1.2 × 1.2 m). Two sets of four concrete blocks each were stacked and attached in the center of the board with the four remaining concrete blocks secured on either side (Figure 3.2B). Each reef was surveyed in October, December 2005, May, August, and December 2006. In July 2006, reefs ($N = 40$) with the 2005 design were deployed and surveyed in June 2006.

An additional reef design (1.22 × 1.22 × 0.42 m) was deployed ($N = 30$) in August 2007. Each of the reefs deployed in 2007 were comprised of concrete half-blocks (41 × 10 × 20 cm). Each half-block was attached to a polypropylene double pallet (1.22 × 1.02 × 0.14 m) with four cable ties (123 cm, 79 kg breaking strength). Five half-blocks were arranged in rows on each side of the pallet, and a plastic crate (61 × 30.5 × 28 cm) was placed in the middle. The plastic crate had various-sized holes (12.1 × 3.2, 14 × 3.8, 7.6 × 3.2 cm) on the top and the sides. One float (13 × 5 cm) was attached with 0.64 cm diameter line to each corner half-block of the pallet ($N = 4$), and floated 1 m above the habitat. A large circular float (15 cm diameter) was also tied in the center of the plastic pallet 1 m above the half-blocks (Figure 3.2C). All reefs were attached to a 1.8 m ground anchor with a 1.3 cm

Table 3.1 Reef-type Surveyed, Deployment Date, Dimensions, Number of Reefs Deployed, and Total Volume Per Individual Reef for Artificial Reefs Surveyed for Juvenile Red Snapper

Reef Type	Time Built	Length (m)	Width (m)	Height (m)	*N*	Volume (m^3)
Shell/block	April 24–July 8, 1998	2.0	2.0	0.3	30	1.20
Shell	April 24–July 8, 1998	2.0	2.0	0.1	29	0.40
Shell/block	July 7–August 3, 1999	2.0	2.0	0.3	30	1.20
Shell	July 7–August 3, 1999	2.0	2.0	0.1	30	0.40
Shell small	July 11–26, 2000	2.0	2.0	0.1	10	0.40
Shell large	July 11–26, 2000	3.0	3.0	0.1	10	0.90
Shell/block	July 24–August 28, 2001	1.0	1.0	0.3	60	0.30
Shell	July 24–August 28, 2001	1.0	1.0	0.1	20	0.10
Shell/block	June 12–July 31, 2002	1.0	1.0	0.3	60	0.30
Shell	June 12–July 31, 2002	1.0	1.0	0.1	20	0.10
Small cage	September 10, 2003	1.2	1.2	0.6	16	0.86
Large cage	October 7, 2003	2.5	1.3	1.2	16	3.90
Block/mat	June 15–25, 2003	2.0	2.0	0.2	40	0.80
Wire cage	October 28–November 22, 2004	1.2	1.2	1.2	22	1.73
Block/wood	October 10–12, 2005	1.2	1.2	0.4	20	0.58
Block/wood	July 17–26, 2006	1.2	1.2	0.4	40	0.58
Block/pallet	August 1–9, 2007	1.2	1.0	1.1	30	1.42
Block/pallet	July 9–10, 2009	1.22	1.02	1.14	20	1.42

diameter rope. Habitats were placed in six rows with five habitats per row, at 500 m intervals. Reefs were surveyed in May and June 2008.

Artificial reefs with the same design as those deployed in 2007 reefs were deployed in July 2009 ($N = 20$). All reefs were secured to the substrate with a 1.8 m ground anchor. Reefs were surveyed in August and September 2009.

The reef type used, time built, dimensions, number of reefs, and total volume are shown in Table 3.1. For each year, the mean number of age-0 and age-1 red snapper was estimated per reef volume for each survey. The highest mean number of individuals from each year was used to make comparisons across years. Also, after fish attained maximum abundance, the subsequent decline in age-0 and age-1 red snapper was used to estimate a mortality rate over all years.

RESULTS

All reefs over all years attracted high numbers of age-0 red snapper (Figure 3.3). The highest mean number was observed in 2000 with age-0 red snapper attaining a density of 451 fish per m^3 (Figure 3.4). Mean numbers of new recruits varied in other years, ranging from 58 in 1998 to 202 per m^3 in 1999. More recent estimates of red snapper recruitment in 2009 also indicated similar abundance at 77 per m^3, compared to 1998 and 2002 (Figure 3.4). The mean abundance of age-1 red snapper was an order of magnitude lower compared to age-0 fish, and ranged from 4 to 40 per m^3 over different years. There was an increase in abundance of age-1 red snapper in more recent years at 10 to 40 per m^3 from 2006 to 2009, compared to <6 fish per m^3 from 1998 to 2000 (Figure 3.4).

Over several years, it was possible to compare the initial abundance of age-0 to age-1 red snapper the following year to estimate instantaneous annual mortality (Z = natural log of survival). Mortality ranged from 2.2 (2001–2002) to 2.7 (2002–2003). A higher number of initial recruits of age-0 red snapper appeared to result in more age-1 fish the following year. This pattern was apparent for 1998, 2000, 2001, and 2000 cohorts (Figure 3.4).

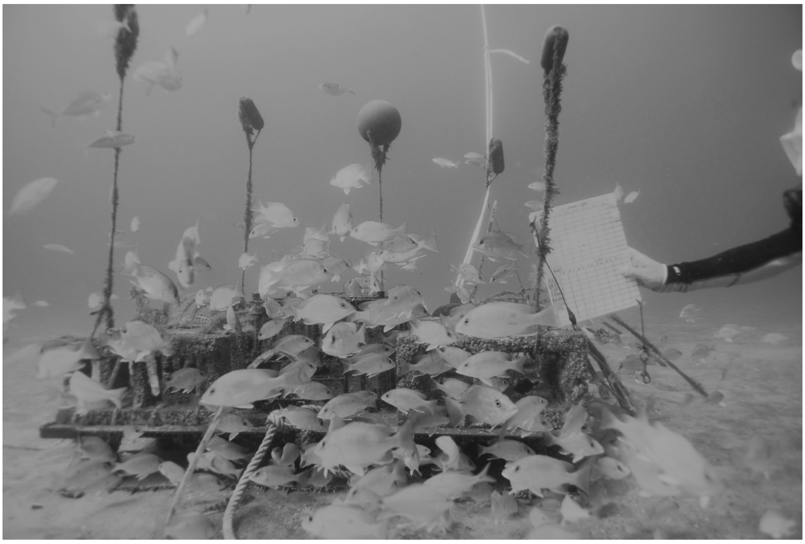


Figure 3.3 ***See color insert.*** The “pallet” reef type with age-0 red snapper September 9, 2009.

The maximum densities of new recruits occurred in August (Figure 3.5). Mean abundance of age-0 and age-1 red snapper from each survey period were plotted for all years, which enabled a seasonal estimate of mortality over all years for age-0 and age-1 red snapper. There was a substantial change in the mortality rate over the first year. Almost all of the total annual mortality occurred during the first 3 months (August, September, and October) after the initial recruitment of red snapper to reef structure. Separated into time periods, mortality was 2.7 from August to October, after which mortality decreased to 0.7 over the next 9 months from November to July the following year. Thus, once fish survived the first 3 months after recruitment to reef structure, they most likely would survive to the following year. Then mortality increased for these age-1 fish to 2.0 from August to December (Figures 3.5 and 3.6).

DISCUSSION

Early Recruitment to Structured Habitat

Age-0 red snapper moved to reef structure early in their life history at the smallest-size classes (approximately 30 mm TL) just after metamorphoses. Here, the first juvenile settlers to benthic substrate are defined as new recruits (Armsworth, 2002). Previous studies indicated a longer occupancy of open-habitat types by new red snapper recruits before movement to more structured reef habitat. These previous studies also reported substantial differences in the length of time over open habitat; for example, a delay of approximately 4 months was shown by Szedlmayer and Lee (2004), while much longer delays were suggested with young fish staying over open habitat over their first year (Rooker et al., 2004; Wells et al., 2008). The longer occupancy of red snapper over open habitat through age-1 was considered part of the “normal” early life history of red snapper in stock assessments as estimates M for age-1 fish were based on the ability to capture age-1 red snapper with trawl gear (Nichols et al., 2005; SEDAR, 2009). The multiple year survey of small artificial reefs of the present study clearly showed peak recruitment of age-0 red snapper to structured habitat in August of their first year, at much earlier stages compared to all past studies. If densities are compared between the present artificial reefs surveys and past trawl surveys, it is apparent that trawl

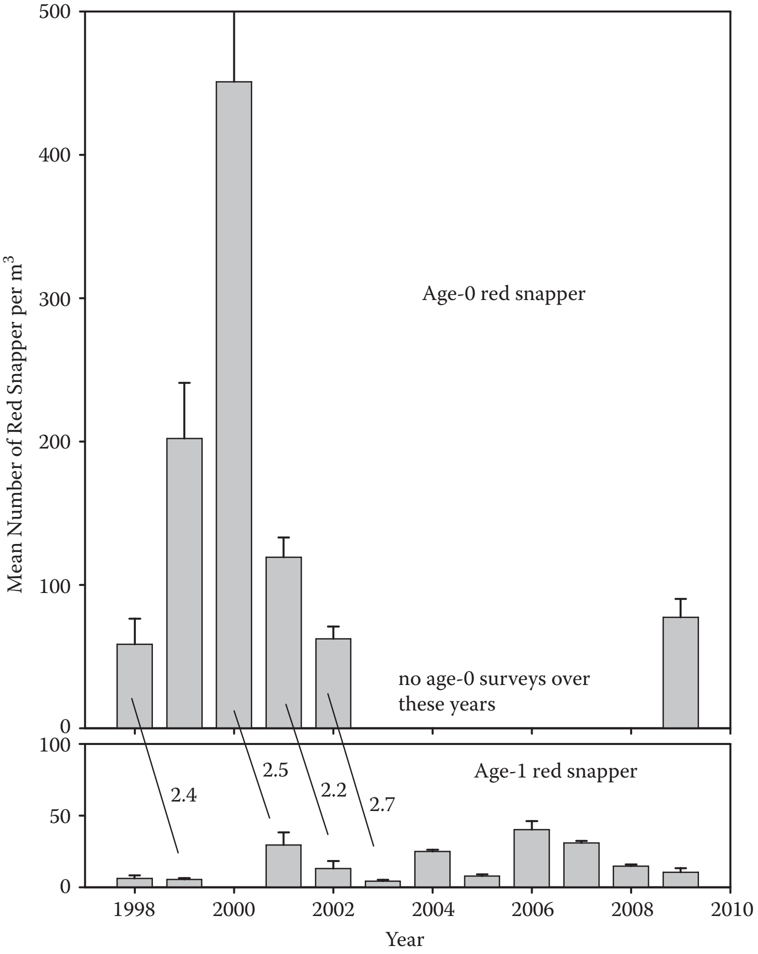


Figure 3.4 Age-0 and age-1 red snapper peak mean abundance per m^3 for each year. Diagonal lines show mortality (Z) estimates for years with surveys of age-0 fish in the first year, followed by estimates of age-1 fish in the following year.

surveys did not sample most of the new red snapper recruits; that is, they were simply sampling in the wrong place and time period. For example, the maximum mean number of age-0 red snapper from trawl surveys were approximately 10 fish ha^{-1} (Wells et al., 2008), 100 fish ha^{-1} (Rooker et al., 2004), and 1557 fish ha^{-1} (Szedlmayer and Conti, 1999). When the lowest density estimate over all years from the present study (1998) is converted to number ha^{-1} for comparisons to trawl densities, the artificial reef estimated densities are three orders of magnitude greater, that is, 500,000 fish ha^{-1}. Thus, using visual sampling techniques on artificial reefs to address management questions probably results in a different depiction of red snapper early life history when compared to trawl surveys. Here, the pattern of early recruitment to structured habitat was consistent over many years (1998–2009), indicating that previous estimates of abundance, movements, mortalities, and habitat value based on fish sampled using trawl surveys are inadequate. This study suggests that previous trawl studies were only comparing the leftover or remaining surplus production of fish that were unable to compete for the structured habitat and would not ordinarily survive due to increased predation and reduced prey resources (Piko and Szedlmayer, 2007; Gazey et al., 2008; Caddy, 2008; Redman and Szedlmayer 2009).

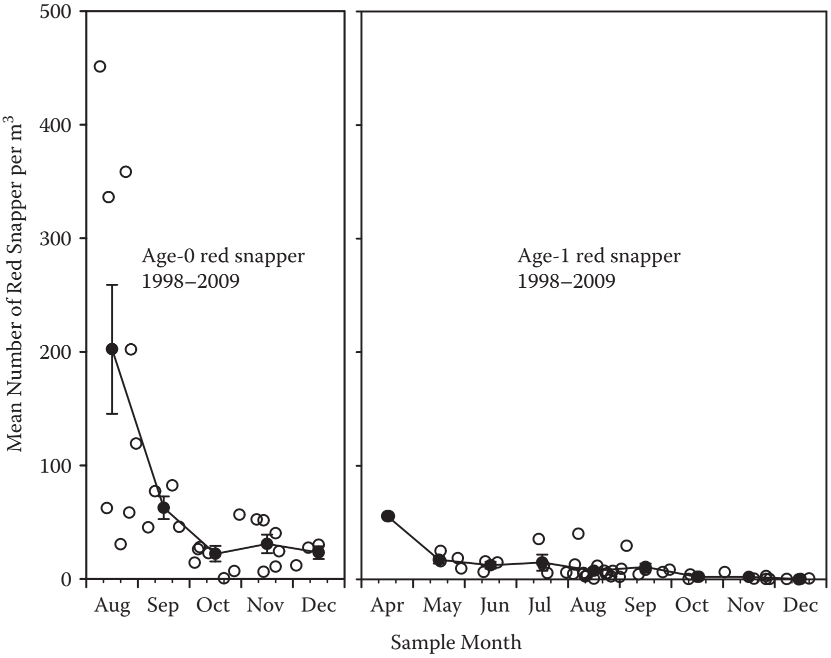


Figure 3.5 Age-0 and age-1 red snapper mean abundance per m³ pooled over all years by survey period.

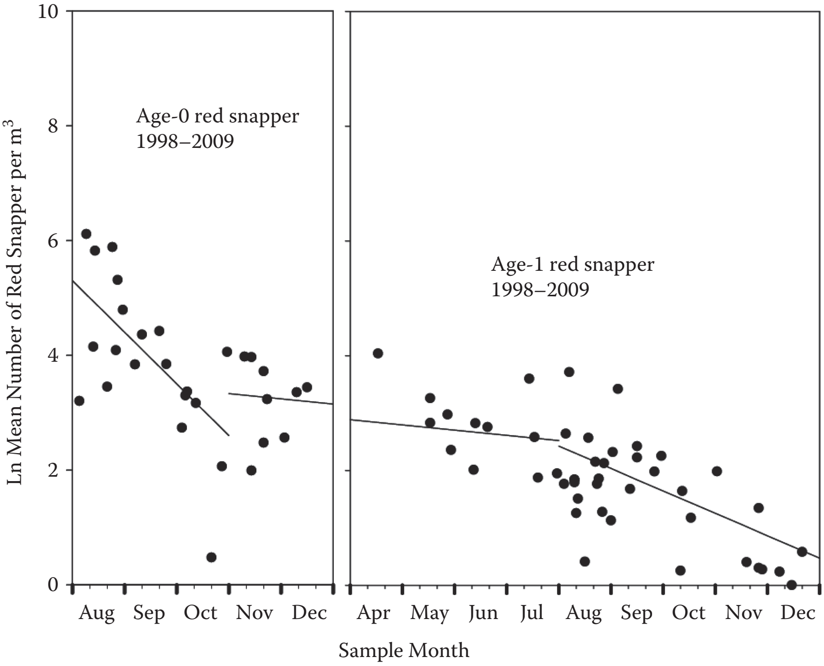


Figure 3.6 Natural logarithm of age-0 and age-1 red snapper mean abundance per m³ pooled over all years by survey periods. Different lines show mortality estimates for different time periods. Not shown are January, February, and March, because surveys were not taken.

Postrecruitment Population Regulation

There has been a long-standing debate concerning the relative contributions of pelagic larval stage population regulation and postrecruitment juvenile-stage population regulation (Doherty, 1991; Jones, 1991; Hixon, 1991; Doherty, 2002; Armsworth, 2002; Hixon and Webster, 2002; Anderson et al., 2007; Oeberst et al., 2009). In a traditional view, many researchers have considered the early life history in marine fishes of little consequence and that stock–recruit relations were the driving force behind population fluctuations and all that matters are the sizes of the adult spawning stocks, which then regulate the subsequent year class strength (see a discussion of paradox: Rothschild, 1986). The present study indicates that, in fact, early life history stages are important and support postrecruit population regulation for red snapper. All data supporting this contention were based on the study of red snapper with artificial reefs. Probably, the most important factor that points in this direction were the very high natural mortalities ($M = 2.7$) of age-0 red snapper in the first 3 months after recruitment to reef structure. Over all years combined, 79% of the total first year mortality occurred during the first 3 months. Thus, it appears that if fish survive the first 3 months, they are likely to survive the first year. Most, if not all, mortality was considered M, because there were no indications of any reefs being subject to impacts by trawl gear. One criticism of estimating M from visual surveys on small artificial reefs is that estimates in M may be the result of emigration rather than natural mortality, and fish were simply leaving structured habitat and suffered bycatch or fishing mortality (F) over open habitat. If this were the case, it would be expected that age-0 and age-1 red snapper bycatch and SEAMAP trawl survey estimates would be correlated to present visual surveys; that is, higher reef densities would lead to more spill over to open habitat, thus leaving more fish susceptible to trawl gear. However, a comparison of densities from the artificial reefs in the present study to bycatch and CPUE from SEAMAP trawl studies over the same years (SEDAR, 2009) showed little correlation for either age-0 or age-1 red snapper (Figures 3.7 and 3.8). Also, there has been a drastic reduction in shrimp trawl effort over the last several years (SEDAR, 2009), and this reduction seems to have had no effect on densities of fish of age-0 over these same years in the present study. There was also a third period of differential mortality that showed substantial increase after fish were >1 year old (i.e., 13–18 months old). However, the decline in red snapper after age-1 from the "small" artificial reefs in the present study was probably owing to movement to larger reef structure rather than mortality. Fish of this size (i.e., >13 months) have been observed to move to larger structured habitat as red snapper grow (Gallaway et al., 2009).

Also, the continuous high abundances of age-0 recruits on the small artificial reefs over the time period (1998–2009) observed in the present study provide support for a postrecruit population bottleneck. Over this same time period, stock assessments suggested a severely overfished red snapper stock (SEDAR7, 2005; SEDAR, 2009). Lorenzen (2008) indicated that many fish populations show density-dependent regulation in the postrecruit stage, but that heavily exploited populations were regulated by stock–recruit relations. Apparently, red snapper do not fit this model as the stock is heavily exploited yet most mortality occurs just after settlement and there has been little evidence of any stock-recruit relation. Presently, according to the most recent assessment, the stock is displaying signs of recovery (SEDAR, 2009), but this recovery is not reflected in increased age-0 fish densities on reef structures in more recent years (2007–2009), again indicating a lack of a stock–recruit relation. Also, even at the low population estimates of 1998 to 2002, the highest recruitment of age-0 fish to small artificial reefs was observed. The contention that some fish populations are not regulated from the top but rather the population size results from postrecruitment processes in the early life history has been described for several fisheries (Caddy, 2008; Gazey et al., 2008; Lorenzen 2008). In the present study, red snapper stocks in the northern Gulf of Mexico appear to follow this type of population regulation. Moreover, two factors (i.e., prey resources and shelter from predation) are probably both enhanced from structured habitat. Additionally, the high recruitment and

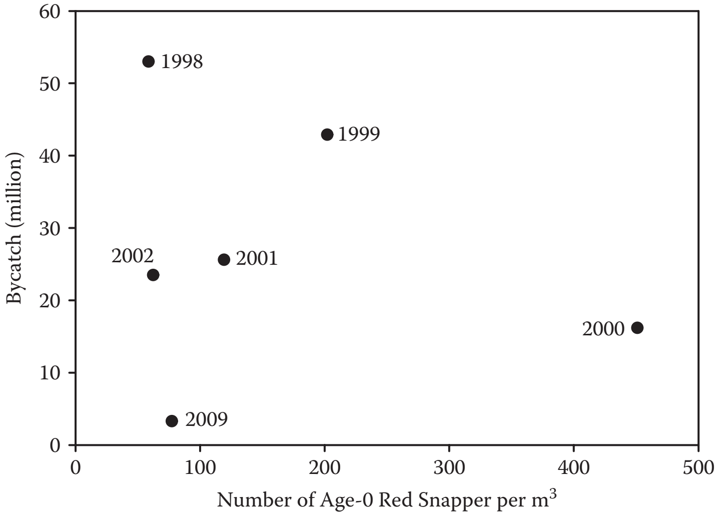


Figure 3.7 Age-0 red snapper mean abundance per m^3 from visual surveys compared to bycatch mortality estimates from SEDAR (2009).

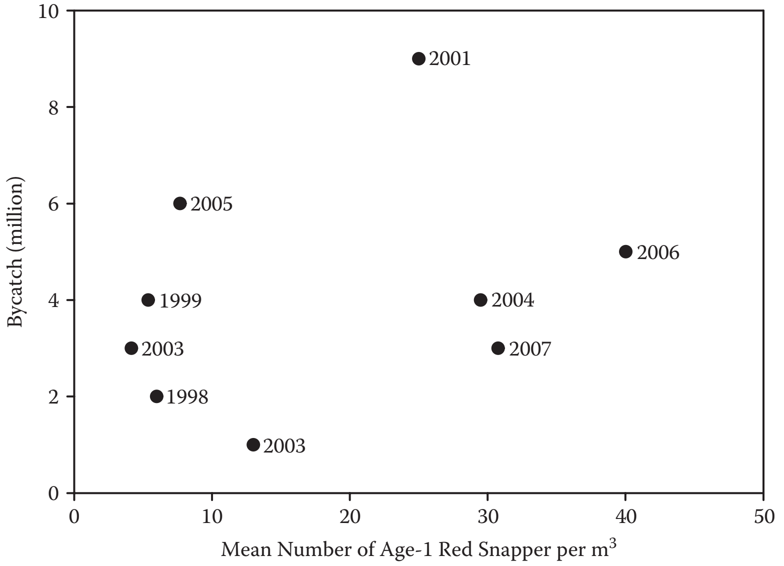


Figure 3.8 Age-1 red snapper mean abundance per m^3 from visual surveys compared to bycatch mortality estimates from SEDAR (2009).

subsequent densities on artificial reefs suggests that such habitat is limited (Szedlmayer and Lee, 2004; Piko and Szedlmayer, 2007; Redman and Szedlmayer, 2009).

Future Use of Artificial Reefs in Fishery Management Questions

Future studies on early life history of red snapper will be advanced with the use of artificial reefs. Clearly, artificial reefs do not function in a vacuum, and adjacent habitats probably have a substantial effect (Lindberg et al., 1990; Frazer and Lindberg, 1994; Strelcheck et al., 2005). Presently, it is difficult to make inferences about such adjacent habitats on the differential habitat value of various substrate types for juvenile stages of red snapper. For the most part, this lack of understanding is due to cryptic habitat use patterns of red snapper where fish move to structured habitat just after settlement, making quantitative sampling with typical trawl gear difficult at best. A new approach of involving artificial reefs as the sampling "tool" could overcome many of the past sampling problems encountered in evaluating habitat value for this important species. The latest version of this small artificial reef design could be used to facilitate comparisons of different benthic habitats in the northern Gulf of Mexico. This reef type has several advantages: (1) it has the appropriate combination of weight and surface area to overcome many of the physical problems of past reef designs, that is, movement or burial; (2) the proper dimensions and structure to promote attraction of young red snapper and other reef fishes; (3) can be constructed and deployed from a relatively small vessel; (4) can be anchored to reduce storm effects; (5) it is small enough to allow for complete visual and camera surveys; and (6) it has concrete surfaces that increase benthic epifaunal growth (Miller and Szedlmayer, unpublished data).

Another aspect of early life history features of red snapper that could be enhanced through the use of artificial reef deployments is the relative effects of predation. If predation is a major ecological forcing function for populations of reef fishes, it would be expected that proximity to potential predators would also affect habitat selection by young new recruits. Thus, a prediction would be that small reefs (e.g., pallet reefs in the present study) that are near (approximately 15 m) large reefs (e.g., gas platforms, approximately 2000 m^3) would have reduced numbers of new recruits (age-0 and age-1) compared to small reefs that are further away (e.g., 500 m) from the large reefs. These distances are based on previous studies of movements and residency of red snapper on artificial reefs (Szedlmayer and Schroepfer, 2005; Schroepfer and Szedlmayer, 2006; Chapin et al., 2009), but may also function for other marine predators and prey. Reefs could then be surveyed for abundance and size estimates of associated reef fish communities with visual and video surveys.

In conclusion, in the northern Gulf of Mexico, young red snapper are present at higher densities 3 to 4 orders of magnitude greater at small artificial reefs than estimates of abundance of these fish from trawl surveys over open habitat. The high densities of the earliest settlers suggest that "optimal" habitat is limiting for their early life stages. These high densities quickly decline in the first few months after settlement, but then remain relatively stable for the remainder of the first year. There is little evidence for a stock–recruit relation, based on the consistent high recruitment of young red snapper to artificial reefs even in years that had low adult stock abundance estimates. Also, these high recruit densities on artificial reefs are not affected by a reduction in shrimp trawling, suggesting that an important, limiting bottleneck occurs in the postsettlement stages of red snapper. This lack of a stock–recruit relation has little to do with questions of red snapper adult stock condition (i.e., overfished or not overfished), only that the population has not attained such a severely depleted condition that the stock–recruit relations becomes important. Significant regulation at present stock levels is occurring at the juvenile stage and is, for the most part, natural mortality.

ACKNOWLEDGMENTS

I thank S. Beyer, A. Chapin, D. Miller, C. Furman, C. Gurshin, G. Lipkey, D. Moss, P. Mudrak, D. Nadeau, A. Piko, M. Piraino, A. Purcell, R. Redman, C. Simmons, T. Syc, M. Topolski, D. Topping, B. Wildberger, and R. Wingate for help building and surveying artificial reefs. This project was funded by the Mississippi-Alabama Sea Grant Consortium (MASGC R/SP-14) NOAA award number NA06OAR4170078 and Marine Resources Division, Alabama Department of Conservation and

Natural Resources. This study is a contribution of the Alabama Agricultural Extension Station and Department of Fisheries and Allied Aquacultures, Auburn University.

REFERENCES

Anderson, T. W., M. H. Carr, and M. A. Hixon. 2007. Patterns and mechanisms of variable settlement and recruitment of a coral reef damselfish, *Chromis cyanea*. *Mar. Ecol. Prog. Ser*. 350:109–116.

Armsworth, P. R. 2002. Recruitment limitation, population regulation, and larval connectivity in reef fish metapopulations. *Ecology* 83: 1092–1104.

Caddy, J. F. 2008. The Importance of "cover" in the life histories of demersal and benthic marine resources: A neglected issue in fisheries assessment and management. *Bull. Mar. Sci*. 83: 7–52.

Chapin, A. M., S. T. Szedlmayer, and R. P. Phelps. 2009. Survival and movement of hatchery-reared red snapper on artificial habitats in the northern Gulf of Mexico. *Fish. Manage. Ecol*. 16: 28–36.

Doherty, P. J. 1991. Spatial and temporal patterns in recruitment. Pages 261–293 in P. F. Sale, Ed. *The Ecology of Fishes on Coral Reefs*. Academic Press, San Diego, CA.

Doherty, P. J. 2002. Variable replenishment and the dynamics of reef fish populations. Pages 327–355 in P. F. Sale, Ed. *Coral Reef Fishes: Dynamics and Diversity in a Complex Ecosystem*. Academic Press, San Diego, CA.

Dufrene, T. A. 2005. Geological Variability and Holocene Sedimentary Record on the Northern Gulf of Mexico Inner to Mid-Continental Shelf. M.S. thesis, Louisiana State University, Baton Rouge, LA. 100 pp.

Dute, J. 2008. Yankee Red Snapper of Mobile Bay. July 6, 2008. Press-register, Mobile, AL.

Frazer, T. K. and W. J. Lindberg. 1994. Refuge spacing similarly affects reef-associated species from three phyla. *Bull. Mar. Sci*. 55: 388–400.

Gallaway, B. J., S. T. Szedlmayer, and W. J. Gazey. 2009. A life history for red snapper in the Gulf of Mexico with an evaluation of the importance of petroleum platforms and other artificial reefs. *Rev. Fish. Sci*. 17: 48–67.

Gazey, W. J, B. J. Gallaway, J. G. Cole, and D. A. Fournier. 2008. Age composition, growth, and density dependent mortality in juvenile red snapper estimated from observer data from the Gulf of Mexico penaeid shrimp fishery. *N. Am. J. Fish. Manage*. 28: 1828–1842.

Hixon, M. A. 1991. Predation as a process structuring coral reef fish communities. Pages 476–508 in P. F. Sale, Ed. *The Ecology of Fishes on Coral Reefs*, Academic Press, San Diego, CA.

Hixon, M. A. and M. S. Webster. 2002. Density dependence in reef fish populations. Pages 303–325 in P. F. Sale, Ed. *The Ecology of Fishes on Coral Reefs*, Academic Press, San Diego, CA.

Houde, E. D. 1987. Fish early life dynamics and recruitment variability. *Amer. Fish. Soc. Symp*. 2: 17–29.

Jones, G. P. 1991. Postrecruitment processes in the ecology of coral reef fish populations: A multifactorial perspective. Pages 294–328 in P. F. Sale, Ed. *The Ecology of Fishes on Coral Reefs*, Academic Press, San Diego. CA.

Lindberg, W. J., T. K. Frazer, and G. R. Stanton. 1990. Population effects of refuge dispersion for adult stone crabs (Xanthidae, *Menippe*). *Mar. Ecol. Prog. Ser.* 66: 239–249.

Lingo, M. E. and S. T. Szedlmayer. 2006. The influence of habitat complexity on reef fish communities in the northeastern Gulf of Mexico. *Environ. Biol. Fishes* 76: 71–80.

Lorenzen, K. 2008. Fish population regulation beyond "stock and recruitment": The role of density-dependent growth in the recruited stock. *Bull. Mar. Sci.* 83: 181–196.

Mitchell, K. M., T. Henwood, G. R. Fitzhugh, and R. J. Allman. 2004. Distribution, abundance, and age structure of red snapper (*Lutjanus campechanus*) caught on research longlines in U.S. Gulf of Mexico. *Gulf Mex. Sci.* 22: 164–172.

Myers, R. A. and N. G. Cadigan. 1993. Density-dependent juvenile mortality in marine demersal fish. *Can. J. Fish. Aquat. Sci.* 50: 1576–1590.

Nichols, S., G. Pellegrin, Jr., and G. W. Ingram, Jr. 2005. Estimation of juvenile M for red snapper based on SEAMAP survey data. Nat. Mar. Fish. Serv., SEDAR7-AW-15, Miami, FL.

Oeberst, R., B. Klenz, T. Gröhsler, M. Dickey-Collas, R. D. M. Nash, and C. Zimmermann. 2009. When is year-class strength determined in western Baltic herring? *ICES J. Mar. Sci*. 66: 1667–1672.

Piko, A. A. and S. T. Szedlmayer. 2007. Effects of habitat complexity and predator exclusion on the abundance of juvenile red snapper. *J. Fish Biol.* 70: 758–769.

Redman, R. A. and S. T. Szedlmayer. 2009. The effects of epibenthic communities on reef fishes in the northern Gulf of Mexico. *Fish. Manage. Ecol*. 16: 360–367.

Rooker, J. R., A. M. Landry, Jr., B. W. Geary, and J. A. Harper. 2004. Assessment of a shell bank and associated substrates as nursery habitat of post-settlement red snapper. *Estuar. Coast. Shelf Sci*. 59: 653–661.

Rothschild, B. J. 1986. *Dynamics of Marine Fish Populations*. Harvard University Press, Cambridge, MA. 277 pp.

Sale, P. F., Ed. 1991. *The Ecology of Fishes on Coral Reefs*, Academic Press, San Diego, CA. 754 pp.

Sale, P. F., Ed. 2002. Coral reef fishes: Dynamics and diversity in a complex ecosystem. Academic Press, San Diego, CA. 549 pp.

Schroeder, W. W., A. W. Shultz, and O. H. Pilkey. 1995. Late Quaternary oyster shells and sea-level history, inner shelf, northeast Gulf of Mexico. *J. Coast. Res.* 11: 241–258.

Schroepfer, R. L. and S. T. Szedlmayer. 2006. Estimates of residence and site fidelity for red snapper *Lutjanus campechanus* on artificial reefs in the northeastern Gulf of Mexico. *Bull. Mar. Sci*. 78: 93–101.

SEDAR7. 2005. Stock assessment report of SEDAR 7, Gulf of Mexico Red Snapper. NMFS, SEFSC, NOAA, Charleston, SC, 480 pp. Available from http://www.sefsc.noaa.gov via the Internet. Accessed January 28, 2009.

SEDAR. 2009. Stock Assessment of Red Snapper in the Gulf of Mexico: SEDAR Update Assessment. NMFS, SEFSC, NOAA, Miami, FL, 111 pp. Available from http://www.sefsc.noaa.gov via the Internet. Accessed January 28, 2009.

Shipp, R. L. and S. A. Bortone. 2009. A perspective of the importance of artificial habitat on the management of red snapper in the Gulf of Mexico. *Rev. Fish. Sci*. 17: 41–47.

Sogard, S. M. 1997. Size-selective mortality in the juvenile stage of teleost fishes: A review. *Bull. Mar. Sci*. 60: 1129–1157.

Strelcheck, A., J. H. Cowan, Jr., and A. Shah. 2005. Influence of reef location on artificial-reef fish assemblages in the north central Gulf of Mexico. *Bull. Mar. Sci.* 77: 225–440.

Szedlmayer, S. T. 2007. An evaluation of the benefits of artificial habitats for red snapper, *Lutjanus campechanus*, in the northeast Gulf of Mexico. *Proc. Gulf Caribb. Fish. Inst*. 59: 223–230.

Szedlmayer, S. T. and J. J. Conti. 1999. Nursery habitats, growth rates, and seasonality of age-0 red snapper, *Lutjanus campechanus*, in the northeast Gulf of Mexico. *Fish. Bull*. 97: 626–635.

Szedlmayer, S. T. and J. D. Lee. 2004. Diet shifts of red snapper, *Lutjanus campechanus*, with changes in habitat and fish size. *Fish. Bull*. 102: 366–375.

Szedlmayer, S. T. and R. L. Schroepfer. 2005. Long-term residence of red snapper on artificial reefs in the northeastern Gulf of Mexico. *Trans. Am. Fish. Soc*. 134: 315–325.

Tampa Tribune. 2009. Red Snapper Bite in the Gulf of Mexico is Red Hot. July 15, 2009, *Tampa Tribune*, Tampa FL.

Wells, R. J., J. H. Cowan, Jr., W. F. Patterson, III, and C. J. Walters. 2008. Effect of trawling on juvenile red snapper (*Lutjanus campechanus*) habitat selection and life history parameters. *Can. J. Fish. Aquat. Sci*. 65: 2399–2411.