The Status of Queen Conch, *Strombus gigas*, Research in the Caribbean

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History of Queen Conch Research

Today there are approximately 230 published scientific papers on queen conch, *Strombus gigas*. Publication on this species began in the 1960's and increased rapidly during the 1980's and 1990's (Fig. 1). The increase in publication after 1980 was associated with three particular areas of endeavor. First, many articles were published to document the rapid depletion of conch stocks throughout the Caribbean Sea. Second, substantial progress was made in understanding processes related to growth, mortality, and reproduction in queen conch. Third, because of the apparent and widespread decline in conch, several research laboratories, especially in Florida, Puerto Rico, Venezuela, and the Turks and Caicos Islands began experiments related to hatchery production of juvenile conch. The primary intent was to replenish wild stocks by releasing hatchery-reared animals. Today, hatchery production has been relatively well perfected, and the increase in numbers of scientific papers related specifically to culture has slowed. A thorough review of the history of conch mariculture was provided by Creswell (1994), and Davis (1994) summarized the details of larval culture technique.

In the last decade significant progress has been made in our understanding of the general biology, habitat requirements, distribution, and mortality processes that influence populations of ju-

venile conch. There has also been considerable effort to develop techniques related specifically to stock enhancement through release of hatchery-reared juveniles. Research on stock enhancement is still increasing at a steady rate, primarily in Florida and Mexico.

Little was known about the larval biology of queen conch prior to 1980. And, while culture technique was the primary focus of larval research in the 1980's, larval ecology and fisheries oceanography are the focus of those working with conch larvae in the 1990's. The first formal descriptions of the larvae of several *Strombus* species first appeared in 1993 (Davis et al., 1993), and we can now survey larvae

quantitatively in the field. Publications on larval supply and transport, nutrition and length of life of larval stages, and larval settlement and recruitment are increasing rapidly. Another area of research that is new to the 1990's is related to the role of marine fishery reserves as a management tool for queen conch. All of these issues will be discussed below.

Objectives

An important scientific workshop on queen conch was held in Caracas, Venezuela, in July 1991. This workshop and the proceedings that emerged from it (Appeldoorn and Rodriguez, 1994) provided a good background on the status
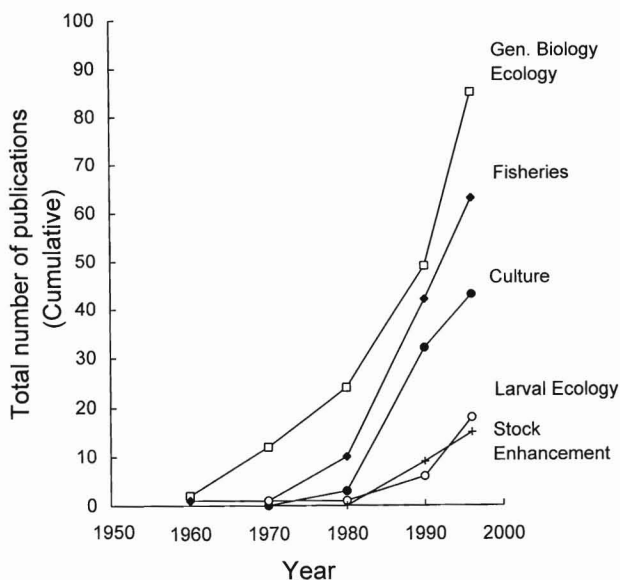
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Figure 1.—Cumulative curves for the total numbers of published scientific articles on queen conch by five subdisciplines.

of research on biology, fisheries, and mariculture of the queen conch. Because the general biology of the queen conch is already relatively well known, the purpose of this paper is to summarize some of the important advances made in the study of queen conch since the 1991 workshop. Emphasis has been placed on topics related to the ecology of queen conch that are most relevant to fisheries management and stock rehabilitation. In the following sections an attempt has been made to draw conclusions about habitat requirements for the species, mortality of juveniles as it relates to stock rehabilitation and enhancement, larval ecology and fisheries oceanography of the species, and the conservation of reproductive stocks.

Habitat Requirements and Nursery Grounds

While adult queen conch are now relatively uncommon in the shallowest regions of many Caribbean banks and island shelves, the most productive nurseries for the species tend to occur in shallow (<5–6 m deep) seagrass meadows. There are, however, certain exceptions, such as in Florida, where many juveniles are associated with shallow algal flats, and on certain deep banks such as Pedro Bank, south of Jamaica. Some juveniles are found in deeper shelf locations (>10 m depth), but these constitute a large proportion of the total juvenile source only in areas where shallow-water populations are very heavily impacted by fishing or habitat destruction.

Generally, larvae are transported by surface currents from spawning grounds onto shallow banks where the larvae settle and spend their first 2–3 years of life. Long-term studies near Lee Stocking Island in the Exuma Cays, Bahamas (Stoner et al., 1994, 1996a), and in the Florida Keys (Glazer[1]) have shown that aggregations of juveniles occur in the same locations year after year. Despite expansive distribution of seagrass beds in both the Bahamas and Florida, the conch nurseries occur in very specific locations within those meadows, and vast areas of seemingly appropriate seagrass beds are never occupied by conch. Near Lee Stocking Island, 90–95% of the vast seagrass meadow appears to be unsuitable for juvenile conch. Several factors appear to be important in providing environmental conditions appropriate for juveniles in the central Bahamas, and these principles appear to be relatively universal. Most nurseries are located in areas with an intermediate density of seagrass (usually 30–80 g dry wt/m^2) and in depths of 2–4 m. On the Great Bahama Bank, the largest, most productive nurseries for queen conch are located directly in the paths of strong tidal currents, and are flushed with clear oceanic water on every tide. Recent GIS (geographic information system) models of conch distribution (Jones, 1996) show that the locations of conch nurseries can be predicted with some degree of accuracy using a combination of seagrass biomass, water depth, and tidal circulation patterns.

The association of conch aggregations with particular locations may also be related to patterns of larval settlement. Recent laboratory experiments have shown that a wide variety of biological substrata affects settlement and metamorphosis in queen conch larvae; however, substrata such as seagrass detritus and sediment taken directly from nursery grounds induce settlement at a much higher frequency than the same materials taken from non-nursery locations (Davis and Stoner, 1994). Distributional pattern in early post-settlement conch also indicates that most settlement occurs in the immediate vicinity of the long-term nursery grounds (Stoner et al.[2]). Conch larvae are known to detect and settle in response to biological cues that are associated with subsequent high growth rates in the postlarvae (Stoner et al., 1996b), and juvenile conch are known to occupy areas that have exceptionally high algal productivity. It is also possible that conch larvae are concentrated in nursery areas before settlement. This will be discussed later in the section on Larval Ecology.

The uniqueness of queen conch nursery habitats has important implications for both fisheries management and stock enhancement of this seriously overfished resource. Despite the presence of very large seagrass meadows in certain conch-producing areas such as the Bahamas, Belize, Mexico, and Florida, only relatively small sectors of the meadows may actually have production potential for queen conch, either because they lack larval recruitment features or suitability as benthic habitat. Transplant experiments indicate that most seagrass beds, in fact, cannot support juvenile conch. The most productive nursery habitats appear to be determined by complex interactions of physical oceanographic features, seagrass and algal communities, and larval recruitment. These critical habitats need to be identified, understood, and protected to insure continued queen conch population stability.

Juvenile Mortality and Stock Enhancement

For at least 20 years it has been proposed that releases of hatchery-reared queen conch could be used to enhance or rehabilitate depleted populations (Berg, 1976). Mariculture technique for conch is relatively well perfected (Davis, 1994), and there are now hatcheries in the Caribbean region, most notably the Caicos Conch Farm[3] on the island of Providenciales, capable of producing millions of juveniles each year. However, high mortality has plagued conch planting efforts since the first releases were made in the early 1980's in Venezuela, the Bahamas, and Puerto Rico (Creswell, 1994).

In recent years many investigators have examined the various factors that influence mortality rates in juvenile conch. These factors include conch size, season, abundance of predators, density

[2] Stoner, A. W., M. Ray, and S. O'Connell. In Review. Settlement and recruitment of queen conch (*Strombus gigas*) in seagrass meadows: associations with habitat and micropredators.

of conch, structural complexity of the habitat (e.g. biomass of seagrass), and artifacts associated with hatchery rearing. Stoner and Glazer (In Press) recently combined the results of their respective long-term experiments in the Bahamas and Florida to provide a new synthesis of mortality data for queen conch. Although increasing survivorship of juvenile conch is ordinarily assumed to be directly related to conch size and age, with some degree of refuge in size occurring between 60 and 100 mm shell length (Jory and Iversen, 1983; Ray et al., 1994), Stoner and Glazer (In Press) learned that factors such as season, year, location, and conch density can have effects on survivorship as important as size. Recently, Ray et al. (In Press) learned that there is a large suite of very small predators that consume conch in the first weeks after settlement. In Bahamian nursery grounds, the most important of these, by virtue of their abundance, were xanthid crabs less than 5 mm in carapace width.

Instantaneous rates of natural mortality (M), even in large juveniles, can vary by a factor of at least 10, from well below 1.0 to over 12.0 (Fig. 2). Because M is calculated as a logarithmic function, the probability of a conch surviving 1 year of life may vary by ten orders of magnitude, depending upon the time and location. It is clear that mortality rates of conch in natural populations can be extremely high. For example, instantaneous rates of natural mortality for small juveniles are commonly as high as 8.0–9.0. This means that an individual conch will have about a 1 in 10,000 chance of surviving over the next year.

Although hatchery production of juvenile conch is now relatively routine, hatchery-reared conch can have certain morphological, physiological, and behavioral deficiencies that increase their mortality in the field when compared with natural stocks. Stoner and Davis (1994) found that hatchery-reared queen conch grew more slowly than wild conch, had lower rates of burial, and they had shorter apical spines on the shells. All of these factors could negatively influence long-term survival of the hatchery-reared conch (Stoner,
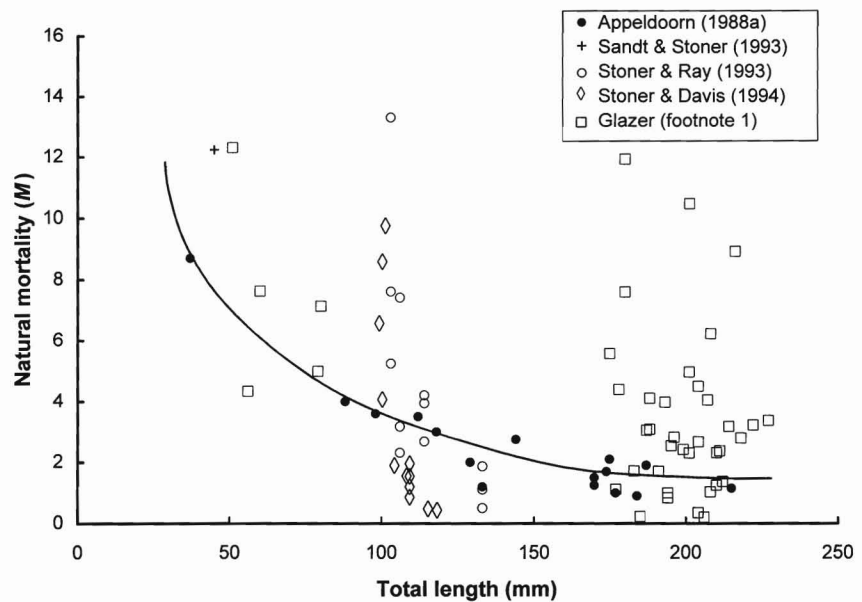

Figure 2.—Variation in instantaneous rates of natural mortality (M) for free-ranging juvenile queen conch. The curve shown was adapted from data provided by Appeldoorn (1988a) and is not intended to represent the points that are plotted for more recent investigations. Source: Stoner and Glazer (In Press).

1994). On the basis of their review, Stoner and Glazer (In Press) concluded that stock enhancement or rehabilitation that is dependent upon hatchery-reared conch has a relatively low probability of success because natural mortality rates in juvenile queen conch are high, growth rates are low, and hatchery-reared conch have numerous deficiencies. The problem is exacerbated by the continuing high cost of hatchery rearing.

It is possible that conch stocks in some locations are now so low that they cannot recover naturally. Larval recruitment data indicate that populations in U.S. waters may be in this category (see following section). In such cases, stock rehabilitation may depend on hatchery production, and the value of released conch will be determined by their survivorship to adulthood and their reproductive potential rather than their direct contribution to a fishery. Research in transgenerational enhancement may be particularly productive where populations have been severely reduced and fishing moratoria are in effect. Clearly, sound management of natural stocks is

preferable to the daunting task of rehabilitating severely threatened stocks.

Larval Ecology and Fisheries Oceanography

While the culture of queen conch larvae was relatively well perfected in the late 1980's, the larvae of queen conch and closely related species were formally described only a few years ago (Davis et al., 1993). The first data on larval abundance in the field were also published in this decade (Stoner et al., 1992; Posada and Appeldoorn, 1994). Considerable progress has been made in the field of conch larval ecology and recruitment since the first descriptive studies.

We now know that conch larvae can be found in open water to depths as great as 100 m, but that most are found in the upper mixed layer of the ocean above the thermocline (Stoner and Davis, 1997b). In calm weather most are in the upper 5 m because of positive phototaxis (Barile et al., 1994). We also know that the larvae can develop in the field at rates higher than those typically observed in hatcheries using artificial

diets. Davis et al. (1996) reported metamorphosis of queen conch in periods as short as 14 days for larvae reared in field enclosures with natural assemblages of phytoplankton for food. Growth rates are strongly temperature dependent and sensitive to the amount and types of phytoplankton food available in the water column (Davis[4]). However, we have also learned that the larvae are capable of remaining in the water column for very long periods of time (perhaps 2 months) after reaching metamorphic competence (Noyes, 1996), and queen conch larvae have been collected in the mid-Atlantic Ocean near the Azores (Scheltema[5]).

The supply of conch larvae has a very important role in determining recruitment of conch to the nursery grounds and to the fishery. Recently, it has been shown that there is a direct positive relationship between the mean densities of late-stage larvae and the sizes of the juvenile populations in nursery grounds in both the Florida Keys and in the Exuma Cays, Bahamas (Stoner et al., 1996c). While the exact relationship was different in the two geographic regions, the fact that there is a close correlation between larval supply and juvenile population size within the systems indicates that the nursery grounds are not saturated with juveniles (i.e. the nurseries are below carrying capacity). Also, a positive correlation between year-class strength and larval supply has been observed near Lee Stocking Island in the Bahamas (Stoner[6]). These correlations, over both spatial and temporal scales, suggest that the populations of juvenile conch may be recruitment limited and that larval supply may determine the strength of recruitment on at least the local scale.

We have also observed that the locations of conch nurseries may be deter-

mined in part by local patterns of abundance in conch larvae. Near Lee Stocking Island, highest densities of late-stage queen conch larvae were found directly over locations known to support large aggregations of juvenile conch during surveys spanning seven years (Stoner and Davis, 1997a). Large, stable aggregations of juvenile queen conch were consistently supplied with high densities of larvae and were directly associated with tidal channels carrying larvae from offshore spawning grounds. In contrast, more ephemeral aggregations were characterized by low or inconsistent veliger densities (particularly late-stage larvae), and were generally outside primary tidal current pathways. Distribution of juvenile queen conch appears to be directly related to the horizontal supply of larvae.

Correlations between larval supply and juvenile population size over both spatial and temporal scales, along with data from transplant experiments, suggest that populations of queen conch are often recruitment limited, not habitat limited. Larval limitation implies that pre-settlement phenomena, such as growth and mortality during planktonic stages and larval transport, may be critical to population dynamics in queen conch. The positive relationship between larval supply and population size suggests that we need to understand transport processes and the mechanisms affecting larval supply to nursery grounds in order to understand recruitment process and year-class strength.

The relationship between oceanography and delivery of queen conch larvae to nursery grounds has been investigated in two systems: in Exuma Sound, Bahamas, and in the Florida Keys. Both studies show the dependence of populations upon upstream spawners.

In Exuma Sound, prevailing summer surface currents carry larvae away from the eastern rim of the Sound near Cat Island and onto the banks near the Exuma Cays on the western side of the Sound. Also, mesoscale gyres in Exuma Sound generally advance toward the northwest (Hickey[7]), transporting and

concentrating larvae in the northern end of the system. The result is very large juvenile populations in the northern Exuma Cays and southern Eleuthera, and an historic record of high fisheries productivity in the northern Sound (Stoner, In Press). The full oceanographic interpretation of this mesoscale phenomenon is in progress.

The delivery of larvae to nursery grounds in the Florida Keys has also been analyzed (Stoner et al., 1997). In Florida, the queen conch population was reduced to such an extent that all conch fishing was banned in 1985. Between 1992 and 1994, estimates for the total number of adult queen conch in the entire Florida Keys island chain (250 km long) were between 5,800 and 9,200 individuals, and the Florida Department of Environmental Protection concluded that the population had shown no sign of recovery (Glazer and Berg, 1994; Glazer[8]). The fishing moratorium is still in effect.

Because there were so few queen conch in the local reproductive stock, Stoner et al. (1996c) postulated that the population in Florida is replenished with larvae produced outside the United States in the western Caribbean Sea (Mexico and Belize) and delivered to the nurseries on the Florida Current. To test this hypothesis, 35 collections of larvae were made in the Looe Key National Marine Sanctuary during the reproductive seasons of 1992 and 1994, concurrent with the deployment of a current meter array immediately offshore. In brief, most of the queen conch larvae collected at Looe Cay were late-stages that arrived in association with northward meanders of the Florida Current (Stoner et al., 1997). Late-stage conch larvae were never collected when the north wall of the Florida Current was offshore in the Florida Straits.

There are large spawning stocks in Belize and Mexico and recruitment of late-stage queen conch during periods of high eastward flow at Looe Key is consistent with the hypothesis that they have a source in the western Caribbean

[4] Davis, M. (In prep.). The effects of natural phytoplankton assemblages, temperature, and salinity on the length of larval life for a tropical invertebrate. Ph.D. dissert., Fla. Inst. Technol., Melbourne.

[5] Scheltema, R. S. 1995. Woods Hole Oceanographic Institution, Woods Hole, MA 02543. Personal commun.

[6] Stoner, A. W. Northeast Fisheries Science Center, National Marine Fisheries Service, NOAA, 74 Magruder Rd., Highlands, NJ 07732. Unpublished data are on file in the author's laboratory.

[7] Hickey, B. A. 1996. School of Oceanography, University of Washington, Seattle, WA 98195. Personal commun.

[8] Glazer, R. A., K. J. McCarthy, R. L. Jones, and L. Anderson. (In review). The use of underwater metal detectors to locate outplants of the mobile marine gastropod, *Strombus gigas* L.
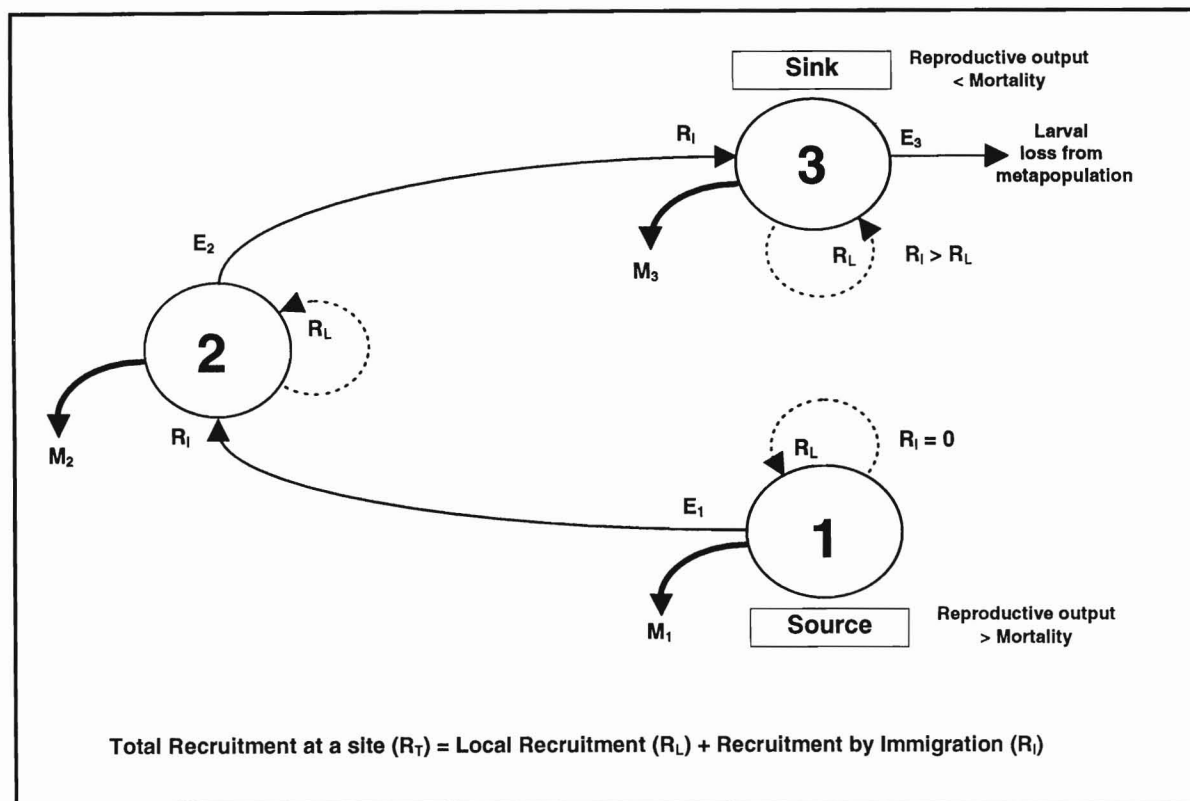
Figure 3.—Conceptual model of metapopulation dynamics. The model assumes a general circulation of water carrying larvae from Population 1 to 2 to 3. See text for definition of the model parameters.

Sea. The 3- to 4-week development period for queen conch larvae (Davis et al., 1993) in combination with average current velocities in the Loop Current and Florida Current system would permit transport from the Yucatan Strait to the Florida Keys. Concentrations of late-stage larvae are known to be high in the Florida Current 35 km south of the middle Keys (Stoner et al., 1996c), and arrival of conch larvae in association with easterly flow at Looe Key suggests that larvae of Caribbean origin are being delivered by the Florida Current. Although the genetic similarity between queen conch in the Caribbean Sea and Florida indicates significant gene flow (Mitton et al., 1989; Campton et al., 1992), the recent study by Stoner et al. (1997) provides the first oceanographic data indicating that a population of queen conch is dependent upon a source in an upstream nation.

It is possible that queen conch populations in Florida were historically self-sustaining, when adult populations were large. Today, however, recruitment appears to depend to a large extent on irregular and unpredictable northward meanders of the Florida Current. This would explain the lack of recovery in spawning stocks of queen conch since the fishing moratorium was established in 1985. Rehabilitation of this stock may now depend upon transplanting spawners or releasing hatchery-reared juveniles. However, stock enhancement through release of juveniles is difficult and expensive because of high potential mortality (described earlier) and has a history of low success (Stoner, 1994; Stoner and Glazer, In Press). Wise management and transgenerational enhancement of marine fishery resources will depend upon extensive knowledge of larval transport and recruitment processes.

Sources of larvae may be local if retention mechanisms are strong, or they may be distant, supplied by other nations. Although little is known about large-scale patterns of abundance and larval transport for any species in the Caribbean region, it is likely that most of the national populations are interdependent because of larval drift. This "open" nature of the populations requires that population dynamics be considered from a metapopulation perspective (Gilpin and Hanski, 1991). In the theoretical model presented in Figure 3 there are three subpopulations connected by larval transport. Population 1 is maintained by local recruitment (R_L) and has no recruitment by immigration from other sources (R_I). Reproductive (larval) output from Population 1 is greater than local mortality (M), and some of that output is exported to downstream populations (E). In metapop-

ulation terminology, this population is a "source." Populations 2 and 3 are downstream from Population 1 and receive larvae both from local spawners (R_L) and from upstream sources (R_I). By definition, Population 3 is a "sink" because reproductive output is less than local mortality, and most larval production is lost from the system. Population 2 is a "source" for Population 3, but may also be a "sink" depending upon the relationship between R_L and M_2.

Practical examples of "sources" and "sinks" can be hypothesized in the Caribbean region. The Windward Islands are probably "source" locations, analogous to Population 1 in the model because of the general east-to-west circulation of surface waters through the Caribbean Sea. In the eastern Caribbean, populations of queen conch and other species with pelagic larvae must be maintained by local recirculation patterns. Island-scale self-recruitment mechanisms have been discussed in general by Farmer and Berg (1989), and more specifically for Bermuda (Schultz and Cowan, 1994) and Barbados (Cowan and Castro, 1994), which are probably dependent upon local retention of fish larvae. Florida conch populations may receive larvae from local spawning populations; however, the populations are so low today that Florida is probably a "sink" with heavy dependence upon upstream sources of larvae, as described earlier. Important conch-producing locations such as Belize and Pedro Bank are probably more analogous to Population 2 in the model, with characteristics of both "sources" and "sinks."

Position within the metapopulation structure can have important management consequences. For example, a source population will be highly vulnerable to recruitment overfishing, and emphasis must be placed on maintaining an effective and sustainable reproductive stock quality. Downstream populations are also dependent upon larvae from these source populations. A sink-type population is more susceptible to management practices occurring in the upstream source locations than to those effected by local management practice. Recovery of depleted stocks requires an adequate source of larvae

which may or may not be local. For these reasons, a strong effort should be made to identify the sources of larval recruitment for target populations, and stock management should be based upon the associated metapopulation structure.

Conserving Reproductive Stocks

It is obvious from the previous discussion that it is important to maintain a regular, high-density supply of larvae to queen conch nurseries by preserving reproductive populations of adequate size. Reproductive stocks and reproduction are protected by a variety of management techniques that have been discussed by others. In this section, results from two new investigations bearing on the role of conch reproduction are described.

In the summer 1995, the Caribbean Marine Research Center conducted surveys of adult conch in the Exuma Cays, Bahamas, to test for hypothesized relationships between adult conch density and reproductive behavior (Stoner[9]). Protection of conch in the Exuma Cays Land and Sea Park presented the unusual opportunity to examine a wide range of spawner densities, from a few conch per hectare to approximately 650 per hectare. The surveys showed that 10–30% of the conch were usually laying eggs at any one time and place during the summer reproductive season, but the data suggest a decline at densities less than about 50 adult conch/ha. Similar declines were observed in the relative abundance of mating pairs of conch at about 50 conch/ha. Given that reproduction in queen conch requires internal fertilization of eggs, it is possible that some threshold of adult density is required for males and females to detect one another and mate. The exact density at which reproduction is depressed probably varies with location, the overall size and scale of the population, and natural aggregation of adults during the summer spawning season. However, it is clear that a minimum

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[9] Stoner, A. W. Northeast Fisheries Science Center, National Marine Fisheries Service, NOAA, 74 Magruder Rd., Highlands, NJ 07732. Unpublished data are on file in the author's laboratory.

spawner density is important for successful reproduction in queen conch (Appeldoorn, 1988b). While quantitative surveys have been made in relatively few locations in the greater Caribbean region, 50 adult conch/ha is significantly higher than the densities reported in many locations, including Bermuda, Florida, Puerto Rico, the U.S. Virgin Islands, and Venezuela, in recent years (Stoner and Ray, 1996).

There are at least two ways to protect high densities of adult queen conch: depth refugia and marine reserves.

Depth Refugia

Queen conch are herbivorous, consuming micro- and macroalgae throughout their lives as benthic juveniles and adults. Therefore, conch are found in well-lighted regions of the marine environment from the shallowest subtidal zone down to depths of about 35–40 m in clear Caribbean water. There have been a few reports of queen conch observed in depths to 60 m but these individuals are very rare.

Detailed depth distributions for adult conch have been reported for Puerto Rico, the U.S. Virgin Islands, and the central Bahamas. In Puerto Rico, maximum adult density occurred at 20–25 m, but the densities at this depth were very low (0.05 conch/ha) (Torres Rosado, 1987). This deep distribution of adults was attributed to fishing pressure. In less heavily fished waters of the U.S. Virgin Islands, maximum adult density was (17.1 adults/ha) in a depth range of 18–24 m (Friedlander et al., 1994). Near Lee Stocking Island in the Bahamas, maximum density (88 adults/ha) was observed in 15–20 m depth, and densities were approximately 18 adults/ha in 20–25 m depth (Stoner and Schwarte, 1994), similar to values in the Virgin Islands. Although direct comparisons must be made with caution, it is clear that where fishing is open to scuba diving, as in Puerto Rico, maximum abundance of adult conch is driven to great depth, and numbers at all depths are generally very low. This is in sharp contrast with relatively natural populations of adults in the Exuma Park where the highest abundance of adults (270 adults/ha) occurs in depths

of just 10–15 m (Stoner and Ray, 1996; Table 1). In the Bahamas, where fishing is limited to free diving, adult conch are relatively uncommon in depths shallower than 10 m but densities increase rapidly with depth beyond the reach of the average free-diving conch fisherman.

Very few conch live deeper than 30 m, and virtually all are accessible to scuba divers. One potential form of management for a healthy reproductive population, therefore, is to limit fishing to free diving. However, because the vast majority of queen conch spend their first 2–3 years in shallow water, young adults and adults that do not migrate to deep water are all accessible to free divers, it is possible that intense fishing for conch in shallow water could ultimately reduce deep-water stocks. This apparent dilemma was discussed earlier by Stoner and Ray (1996).

Marine Reserves

Closed areas represent another mechanism for maintaining high densities of adult conch. The Exuma Cays Land and Sea Park is a marine fishery reserve established in 1958 and administered by the Bahamas National Trust in the central Bahamas. The Park is large, spanning a section of the northern Exuma Cays 40 km long and 8 km wide. No fishing of any kind has been permitted since approximately 1984. Stoner and Ray (1996) conducted extensive, depth-stratified surveys in the Park and near Lee Stocking Island to compare the abundance of adults, juve-

niles, and larvae of queen conch in a marine fishery reserve and in a nearby fished area of the Exuma Cays. Large differences in densities of adult conch between the reserve and the fished area are obvious (Table 1). Differences in densities of adult conch were significant in all depth zones down to 30 m, except in the very shallow shelf region (0–2.5 m depth), and, as would be expected, this marine reserve conserves spawners. One of the most notable differences between the two sites was that densities were 30 times higher in the shallow bank environment of the reserve than in comparable habitat in the fished area. The bank represents a very large habitat in the Exuma Cays and the contribution of the bank to the adult population was enormous. Additionally, conch density on the bank in the reserve was sufficiently high to promote reproduction in that habitat.

Because of the high abundance of spawners, there were about 10 times more newly-hatched larvae in the unfished area than the fished area (Stoner and Ray, 1996). An alongshore drift of about 1.5–3 km per day and a mesoscale gyre in the northern Exuma Sound then carry larvae produced in the fishery reserve to nurseries in the northern Exuma Cays and southern Eleuthera. Reports from fishermen and from the Department of Fisheries indicate that the numbers of juvenile conch have increased in these areas over the last 10 years, the time period during which fishing has been closed in the Exuma Park. Although the observations must be considered anecdotal, the high production of larvae in the fishery reserve undoubtedly contributes to fished populations in downstream areas.

The apparent success of the Exuma Cays Land and Sea Park in protecting spawning stocks of queen conch and in producing high numbers of larvae for export to surrounding areas is due, in part, to its large size (about 320 km²). Reserves must be large enough such that most of the reproductive stock cannot migrate out of protected areas to be captured. We also need to consider larval transport and physical oceanography in the design of fishery reserves. They must receive a regular supply of larvae

from some spawning population, and they must be established in locations that will contribute to the downstream fishery. Reserve design should be developed in the context of metapopulation dynamics discussed earlier.

Conclusions

Research on queen conch continues to accelerate because of stock depletion throughout the Caribbean region and interest in stock rehabilitation. Recent advances are related to habitat requirements and survivorship of juveniles, larval ecology, fisheries oceanography, and certain management practices.

The majority of juvenile conch occur in a few unique habitats. These nursery grounds are defined by a suite of abiotic and biotic characteristics, including water circulation, patterns of larval accumulation and settlement, production of foods, and differential mortality. These nursery habitats must be identified and protected from destruction.

Stock enhancement through release of hatchery-reared conch has not been successful because of low growth rates and high natural mortality in juvenile conch. Release techniques are improving in parallel with good information on the variables that affect the highly variable mortality rates, but seed costs remain high, and hatchery-reared conch bear certain physiological, morphological, and behavioral deficiencies.

Recruitment to the juvenile class appears to be dependent upon the numbers of larvae supplied to the nursery grounds, on both spatial and temporal (interannual) scales. Locations with large populations of juveniles and adults receive regular deliveries of conch larvae in high density.

Populations of queen conch within the Caribbean region are probably interdependent because of larval drift on ocean currents for periods of time between two weeks and two months. The extent of interdependence among populations and among nations is poorly known; however, management of the conch resource must be considered within a metapopulation context. The significance of larval drift to fisheries management is an area of research that warrants much new research.

Table 1.—Density of adult queen conch in the Exuma Cays Land and Sea Park near the island of Waderick Wells and in the fished area near Lee Stocking Island, Exuma Cays. Values for adult density are mean ± SE for each depth interval. The bank habitat was represented by a 5 km wide band of the shallow (0–5 m deep) Great Bahama Bank immediately to the west of the island chain. The shelf habitats were to the east of the islands where depths increased gradually out to the shelf-break which began at about 30 m depth. Stoner and Ray (1996) provide full details.

Habitat/ depth (m)	Marine reserve	Fished area
Bank	53.6	1.7
Shelf		
0.0–2.5	0 ± 0	0 ± 0
2.5–5	34 ± 22	2.2 ± 1.7
5–10	49 ± 18	7.2 ± 4.1
10–15	270 ± 85	60 ± 47
15–20	104 ± 58	88 ± 32
20–25	148 ± 72	18 ± 9
25–30	122 ± 70	0 ± 0

Figure 1a.—Percent of inshore landings by vessels and boats compared to percent of inshore interviewed landings by vessels and boats (data for 1976–80 is unavailable).
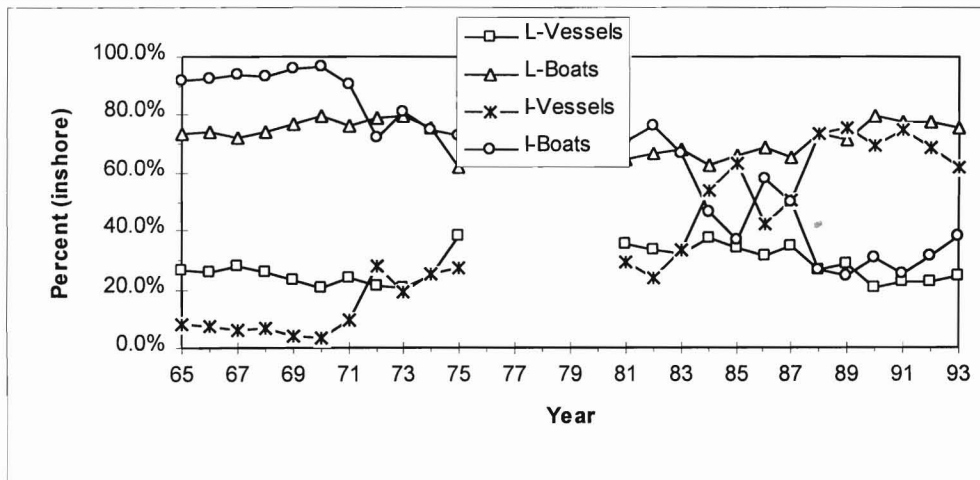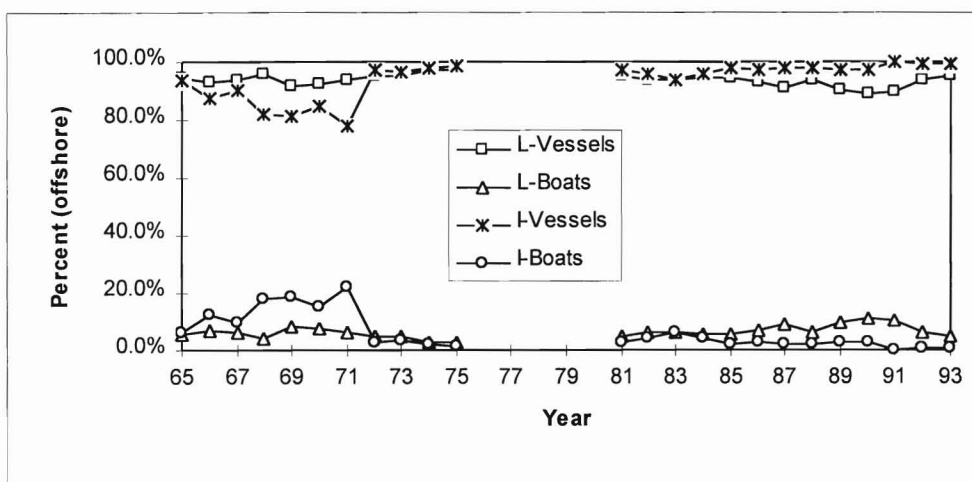

Figure 1b.—Percent of offshore landings by vessels and boats compared to percent of offshore interviewed landings by vessels and boats (data for 1976–80 is unavailable).

landings by vessels and by boats in the inshore shrimp fishery. The lines labeled L-Vessels and L-Boats show the percent of total landings in the inshore by vessels and boats, respectively. The lines labeled I-Vessels and I-Boats show the percent of interviewed landings in the inshore by vessels and boats, respectively. In 1965, boat total landings were about 72% and vessel landings were about 28%. Boat interviewed landings, however, were about 92% and vessel landings were about 8%. Sampling of vessels and boats was nonproportional (nonrepresentative) since there were too many boats being interviewed in the inshore shrimp fishery relative to vessels in 1965. This pattern continues until 1972. Sampling of vessels and boats was much more representative from 1972 to 1983 (ignoring 1976–80). In

1984, obviously, vessels are more frequently targeted for interview than boats even though this is a predominately a boat-type fishery. The interviewed data have become highly nonrepresentative in these latter years causing higher bias in the estimated total days fished through simple average CPUE in the inshore shrimp fishery. Figure 1b shows the trend on the offshore shrimp fishery. Under proportional sampling, the lines for L-Vessels and I-Vessels should coincide and the lines for L-Boats and I-Boats should coincide. The degree of noncoincidence of these lines reflects the nonproportionality in the Figures 1a and 1b. Figure 2a, which shows the percent of inshore landings by boats and vessels being interviewed, illustrates this problem more clearly. While the 30–60% of boat landings were inter-

viewed in early years, virtually no interviews have occurred since 1989. Interviewed vessels landings have remained around 10% until 1989 when these interviews also began to decline.

In the offshore shrimp fishery, which is predominantly a vessel fishery, the same general pattern occurs for both vessels and boats. Higher proportions of boats were sampled in the earlier years and higher proportions of vessels were sampled in the latter years (Figure 2b). As with the inshore shrimp fishery the percent of boat landings interviewed from the offshore is very small whereas the same for the vessels has varied around 20% for the entire time period. Ideally, under the proportional sampling, the two lines in Figures 2a and 2b should coincide. The degree of noncoincidence reflects the degree of nonproportionality.

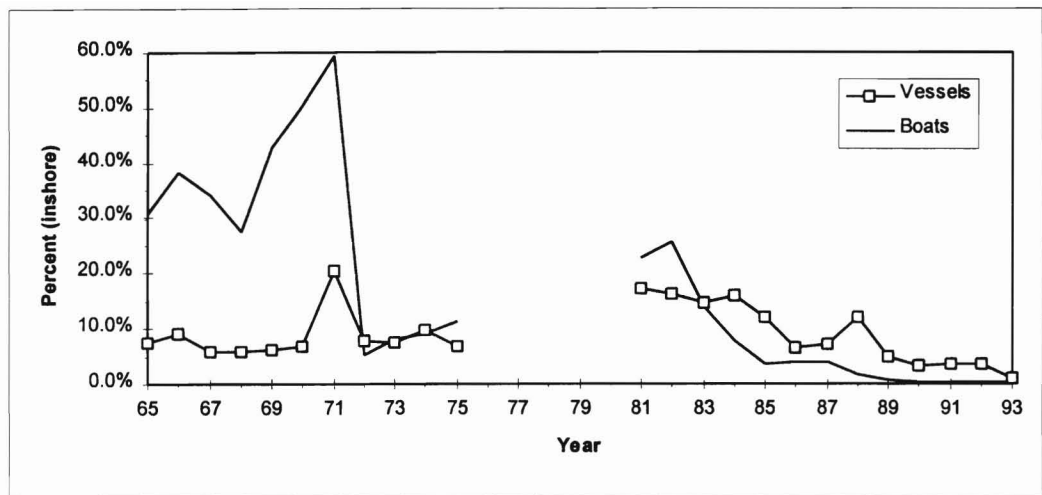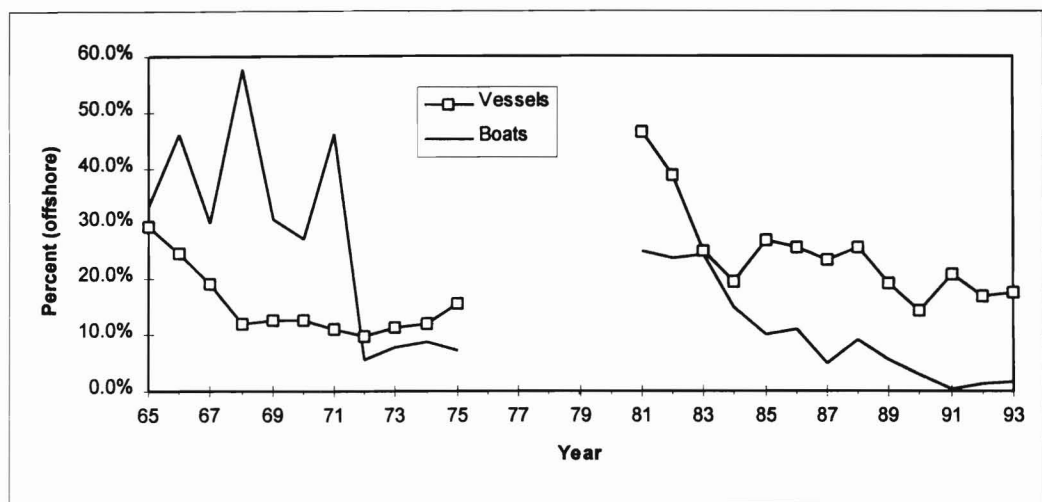Figure 2a.—Percent of inshore landings interviewed by vessels and boats (data for 1976–80 is unavailable).

Figure 2b.—Percent of offshore landings interviewed by vessels and boats (data for 1976–80 is unavailable).

This paper presents the development of a method to standardize effort. It also presents an alternative to the NMFS method to estimate nominal effort. These methods are expected to produce better estimates of nominal and standardize effort suitable for use in research both by biologists (Nichols et al.[1]) and economists (Grant and Griffin, 1979; Griffin et al., 1993a, b; Hendrickson and Griffin, 1993) on issues such as bycatch. We also characterize the historical trends of vessel configuration in the shrimp fishery, relative fishing power, and nominal and standardized effort.

Methods

The Modeling Approach

Shrimp catch for a given vessel at a given location × time (cell) is a func-tion of vessel effort and abundance of shrimp, i.e.

$$C_{ijt} = E_i \left(\alpha A_{ji}^{\beta} \varepsilon_{ijt} \right), \quad (1)$$

where, C_{ijt} is catch by vessel i in loca-tion j and time t, E_i is effort level (power or ability) of vessel type i, A_{jt} is abun-dance level in location j and time t, ε_{ijt} is the random error term, and α and β are the model parameters.

Equation (1) is log-linear which is expected to provide a better fit than a straight linear model (Gulland, 1956; Beverton and Holt, 1957; Robson, 1966). The standard assumptions asso-ciated with such models (Draper and Smith, 1981; Kleinbaum et al., 1988; Sen and Srivastava, 1990; Hamilton, 1992), were checked statistically for validity. Only C_{ijt} is directly observable and available, while variables E_i and A_{jt} can be modeled as a function of other variables as discussed below.

Effort (Power or Ability) Model

Vessel effort produced during a unit of fishing time is a function of its physi-cal characteristics. The skills of the cap-tain and the crew, as well as the onboard technology (electronic equipment, etc.), are important variables, but often are difficult to measure and incorporate in the model. The lack of data prevented inclusion of these variables in the model. The log-linear effort model for vessel i can be written as

$$E_i = \alpha_E V_{i1}^{\beta_{E1}} V_{i2}^{\beta_{E2}} \dots V_{in}^{\beta_{En}} \varepsilon_{Ei} \quad (2)$$

where, V_{ik} is the kth characteristics ($k = 1, 2, \dots, n$) of vessel i, (e.g. horsepower,

length, gear type, etc.), α_E, β_{E1}, β_{E2}, ..., β_{En}, are the model parameters, and ε_{Ei}, is the random error term. This type of function allows for diminishing returns. That is, as inputs (vessel length, quantity of fishing gear, etc.) increase for a given level of stock abundance, output (catch of shrimp) will increase but at a decreasing rate.

Abundance Model

Abundance, defined as the amount of shrimp available for harvest, is dependent upon time and location[4]. When necessary, some of these factors were incorporated into the model using dummy variables. The log-linear abundance model can be written as

$$A_{jt} = \alpha_A X_{jt1}^{\beta_{A1}} X_{jt2}^{\beta_{A2}} \ldots X_{jtm}^{\beta_{Am}} \varepsilon_{Ajt} \qquad (3)$$

where, X_{jtl} is the lth abundance factor, $l = 1, 2, ..., m$, in time period t in location j, α_A, β_{A1}, β_{A2}, ..., β_{Am}, are the model parameters, and ε_{Ajt}, is the random error term.

Catch Model

Using equations (2) and (3), the catch model can now be expressed as

$$C_{ijt} = \left(\alpha_E \prod_{k=1}^{n} V_{ik}^{\beta_{Ek}} \varepsilon_{Ei} \right) \alpha$$

$$\left(\alpha_A \prod_{l=1}^{m} X_{jtl}^{\beta_{Al}} \varepsilon_{Ajt} \right)^{\beta} \varepsilon_{ijt}$$

$$= \begin{bmatrix} \alpha_E \alpha \alpha_A^{\beta} \prod_{k=1}^{n} V_{ik}^{\beta_{Ek}} \\ \prod_{l=1}^{m} \left(X_{jtl}^{\beta_{Al}} \right)^{\beta} \left(\varepsilon_{Ei} \varepsilon_{Ajt}^{\beta} \varepsilon_{ijt} \right) \end{bmatrix}$$

$$= \lambda \prod_{k=1}^{n} V_{ik}^{\lambda_k} \prod_{l=1}^{m} X_{jtl}^{\delta_l} \xi_{ijt} \qquad (4)$$

[4] Shrimp is an annual crop and very dependent on environmental parameters such as water temperature, salinity, etc., in any given time period and location. However, these environmental parameters were not used in the model since they were not available throughout the Gulf.

where, $\lambda = \alpha_E \alpha \alpha_A^{\beta}$; $\lambda_k = \beta_{Ek}$ ($k = 1, 2, ... n$); $\delta_l = \beta_{Al}\beta$ ($l = 1, 2, ..., m$); and $\xi_{ijt} = \varepsilon_{Ei} \varepsilon^{\beta} \varepsilon_{Ajt} \varepsilon_{ijt}$.

Using the Beverton and Holt (1957) definition of relative fishing power (RFP), the RFP index of vessel i can be calculated simply by taking the ratios of the estimated C_{ijt} to C_{sjt}, where the subscript s refers to the standard vessel chosen subjectively. For any given time-location stratum and for a constant level of nominal days fished, the estimated RFP index of vessel i is defined as,

$$RFP_i = \frac{\prod_{k=1}^{n} V_{ik}^{bk}}{\prod_{k=1}^{n} V_{sk}^{bk}} = \prod_{k=1}^{n} \left(\frac{V_{ik}}{V_{sk}} \right)^{bk} \qquad (5)$$

The model in (5) proposed here is a more general model than the ones used by Beverton and Holt (1957) and Robson (1966) by allowing the inclusion of dummy variables.

Now, the estimated standardized total effort (TE) of all vessels (V) can be computed as

$$TE = \sum_{i=1}^{V} (RFP_i)(DF_i), \qquad (6)$$

where DF_i is the nominal days fished by vessel i, and V is the total number of vessels. It should be noted that DF_i is both estimated and observed data. Only noninterview landing data has estimated days fished, whereas, interview landings data has observed days fished.

Results

The Standardization Model

The General Linear Model (GLM) procedure, utilizing SAS software, was used to derive the standardization of effort. This is the most common procedure used in the situations where the cells have missing values and are unbalanced. Moreover, it has been shown to be robust to the departures from some of the standard GLM assumptions. The log transformation was used in an attempt to normalize the data, to homogenize the variances, and to achieve ad-

ditivity in the model. We modeled the natural log (ln) of catch per trip (CPT)[5] as function of several abundance and vessel characteristics variables:

$$\begin{aligned} \ln(CPT) = \ &g[\text{month, area, depth, year,} \\ &\text{construction, ln(gross} \\ &\text{tons), ln(length), ln(year} \\ &\text{built), ln(horsepower),} \\ &\text{ln(no. crew), ln(footrope),} \\ &\text{ln(no. nets), ln(days fished/} \\ &\text{trip)]} + \varepsilon. \qquad (7) \end{aligned}$$

The only variables contributing significantly to the models were month, area, depth, year, ln(length), ln(footrope), and ln(days fished/trip). The coefficient of determination (R-square) for this reduced model was 0.7935. The fitted model (Table 1a) as well as all the terms in the fitted model (Table 1b) are highly significant (with each $P < 0.0001$). Table 2 gives the regression coefficients and corresponding P values for the model. The RFP index estimate can now be computed as follow:

$$\begin{aligned} RFP \ index \ &= \ \frac{(FRL_{CV})^{0.34}(VL_{CV})^{0.31}}{(FRL_{SV})^{0.34}(VL_{SV})^{0.31}} \\ &= \ \left(\frac{FRL_{CV}}{FRL_{SV}} \right)^{0.34} \left(\frac{VL_{CV}}{VL_{SV}} \right)^{0.31} \qquad (8) \end{aligned}$$

[5] Some may prefer to use ln($CPUE$) as the independent variable. This would be algebraically identical to our model since ln($CPUE$) = ln(CPT/ $DFPT$) = ln(CPT) − ln($DFPT$) where $DFPT$ is days fished/trip.

Table 1a.—ANOVA table for the standardization model for ln(CPT)[1].

Source	DF	Sum of squares	Mean square	F value	Prob > F
Model	55	455,828	8,288	20,594	0.0001
Error	294,841	118,657	0.4024		
Corrected	294,896	574,484			

[1] CPT is catch per trip.

Table 1b.–Breakdown of model degrees of freedom from Table 1a.

Source	DF	F Value	Prob > F
Month	11	3,763	0.0001
Year	27	1,034	0.0001
Area	9	579	0.0001
Depth	5	343	0.0001
Ln(DFPT)	1	100,000	0.0001
Ln(Footrope)	1	2,993	0.0001
Ln(Length)	1	1,091	0.0001

Table 2.—Estimates of standardization model parameters and p-values.

Variable	Estimate	Prob > |T|	Variable	Estimate	Prob >|T|
Intercept	2.7214	0.0001	1981	0.3856	0.0001
January	−0.1116	0.0001	1982	0.0746	0.0001
February	−0.3244	0.0001	1983	−0.0184	0.0667
March	−0.3793	0.0001	1984	0.1848	0.0001
April	−0.4081	0.0001	1985	0.3328	0.0001
May	−0.1872	0.0001	1986	0.2428	0.0001
June	0.2324	0.0001	1987	0.0050	0.6139
July	0.4172	0.0001	1988	−0.1059	0.0001
August	0.2917	0.0001	1989	0.0132	0.2287
September	0.1447	0.0001	1990	0.0183	0.109
October	0.1246	0.0001	1991	0.1433	0.0001
November	0.1098	0.0001	Area 1–3	0.6861	0.0001
1965	0.6380	0.0001	Area 4–6	0.5443	0.0001
1966	0.6384	0.0001	Area 7–9	0.6066	0.0001
1967	0.6807	0.0001	Area 10–12	0.4355	0.0001
1968	0.5792	0.0001	Area 13–15	0.6432	0.0001
1969	0.3223	0.0001	Area 16–17	0.6098	0.0001
1970	0.5948	0.0001	Area 18–19	0.5995	0.0001
1971	0.4782	0.0001	Area 20–21	0.4557	0.0001
1972	0.4472	0.0001	Area 22–28	0.6285	0.0001
1973	0.2613	0.0001	Depth 1 (inshore)	0.0978	0.0001
1974	0.3107	0.0001	Depth 2 (1–5 fm)	0.1819	0.0001
1975	0.3645	0.0001	Depth 3 (6–10 fm)	0.0502	0.0001
1976	0.3320	0.0001	Depth 4 (11–15 fm)	0.0824	0.0001
1977	0.3358	0.0001	Depth 5 (16–25 fm)	0.0071	0.1227
1978	0.2862	0.0001	Ln(Days fished)	0.9942	0.0001
1979	0.1717	0.0001	Ln(Footrope length)	0.3377	0.0001
1980	0.1337	0.0001	Ln(Vessel length)	0.3146	0.0001

where *FRL* is footrope length, *VL* is vessel length, *CV* denotes the candidate vessel for standardization, and *SV* denotes the standard vessel. If the standard vessel[6] has a *FRL* = 30 yd and *VL* = 55 ft and the candidate vessel has a *FRL* = 48 yd and a *VL* = 65 ft, then the *RFP* can be computed as

$$RFP\ index = \left(\frac{48}{30}\right)^{0.34}\left(\frac{65}{55}\right)^{0.31} = 1.24.$$

Thus, the candidate vessel would be expected to land 24% more shrimp if both vessels were fishing at the same time and in the same location. Since consolidated vessels do not have vessel characteristics recorded, we first estimated the average *RFP* for the documented vessel in a given cell and applied that *RFP* to the consolidated vessels.

Expansion Model Selection

Ideally the form of the expansion model should be similar to the standardization model. In the expansion model, however, much of the data is consolidated and vessel identities are unknown; therefore, vessel characteristic information is unavailable for a portion of the interview landings data set. Consolidated records do, however, distinguish between boats and vessels.[7] In the equation, we considered any U.S. Coast Guard registered vessel ≤60 feet in length as a boat, since that size craft can fish in most state waters.

Several different models (various functions of boat/vessel, area, depth, month, catch per trip, catch per unit effort, price, and dollars per trip) were considered. Interestingly, equations that were not price related had a much higher error sum of squares (on the

origional scale) than models that were price related. Shrimpers are commercial fishermen and earn their living by harvesting shrimp that have value; thus, while catch is important in explaining effort, the value or price of shrimp is also very important. Of the price-related models, the following model was judged to be the most appropriate for expansion due to its simplicity and its relatively lower error sum of squares over all years

$$ln(dfpt) = f\{vess,\ area,\ depth,\ month,\\ ln(cpt),\ ln(price),\\ [ln(price)]^2\} \qquad (9)$$

where *dfpt* is days fished per trip. The variables *vess* (boat or vessel), *area* (10 area groups: 1–3, 4–6, 7–9, 10–12, 13–15, 16–17, 18–19, 20–21, 22–28, and ≥29), *depth* (6 depth groups: inshore, 1–5 fm, 1–10 fm, 11–15 fm, 16–25 fm, and ≥26 fm), and *month* (12 months) are included in the model through use of dummy variables. A separate regression equation was estimated for each year (1965–93) for which data were available. Using the fitted model, interviewed effort estimates were calculated as $exp(ln(dfpt))$ and compared with effort data based on actual interviews. The model underestimated the actual days fished as the mean of the log normal distribution $exp(\mu+0.5\sigma^2)$ (Dudewicz and Mishra, 1988; Seber and Wild, 1989). Thus, multiplying the model estimate with a bias correction factor of $exp(s^2/2)$ provided an effort estimate with greater accuracy (Fig. 3). This correction factor accounts for the log transformation.

Expansion Model Validation

Table 3 provides the R-square values for the selected expansion model (discussed above) by year. It also provides the actual total interviewed effort and predicted total interviewed effort, which helps to assess the predictability of the expansion model. The difference between actual and predicted total interviewed effort is expressed as percent of actual total interviewed effort. Examination of Table 3 shows the difference between actual and estimated interviewed days fished to be within 1% for

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[6] The average fishing craft (vessel and boat) in 1965 is assumed to be the standard vessel for 1965 and across all years. Since boats are smaller than the standard vessel, their *RFP* in 1965 will be less than 1.0. Conversely, vessels will be larger than the standard vessel, and their *RFP* will be greater than 1.0 in 1965.

[7] Boats are generally smaller craft (from 25 to 60 feet in length) fishing predominately in bays and shallow offshore waters and are not registered with the U.S. Coast Guard. Vessels are generally larger craft (from 60 to 90 feet in length) fishing predominately in offshore waters and registered with the U.S. Coast Guard.
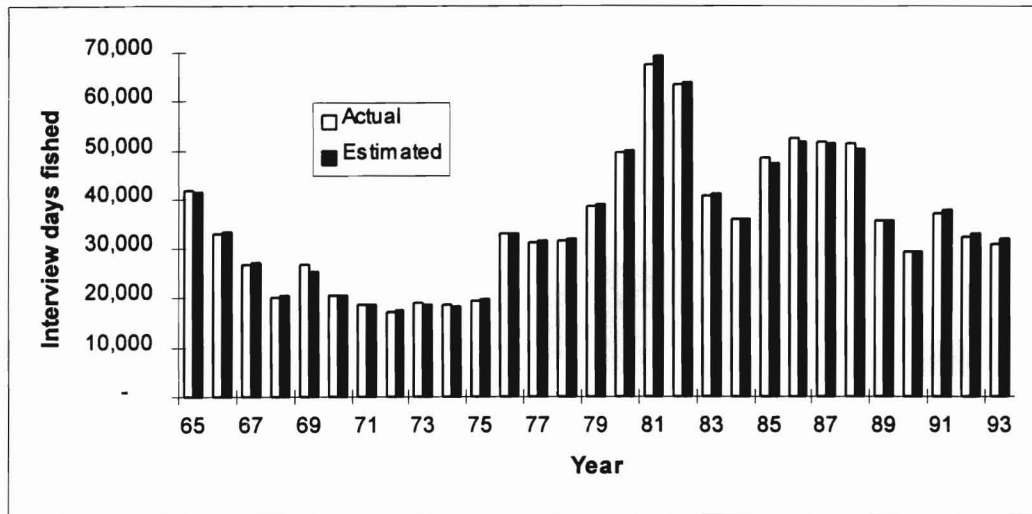
Figure 3.—Actual interviewed days fished vs. adjusted estimated interviewed days fished by year.

Table 3.—The R-square and cross validation of the expansion model.

Year	R-square	Interview days fished		% Difference
		Actual	Estimated	
1965	0.7770	41,858	41,675	−0.44%
1966	0.8169	32,917	33,196	0.85%
1967	0.8174	26,724	27,120	1.48%
1968	0.8140	20,280	20,393	0.56%
1969	0.8001	26,762	25,226	−5.74%
1970	0.8661	20,356	20,419	0.31%
1971	0.8535	18,527	18,640	0.61%
1972	0.8672	17,189	17,461	1.58%
1973	0.8273	18,980	18,707	−1.44%
1974	0.8418	18,599	18,477	−0.66%
1975	0.8696	19,501	19,821	1.64%
1976	0.8803	32,880	33,133	0.77%
1977	0.8576	31,135	31,724	1.89%
1978	0.8457	31,481	31,739	0.82%
1979	0.7762	39,107	39,012	−0.24%
1980	0.7975	49,581	50,106	1.06%
1981	0.8186	67,445	69,308	2.76%
1982	0.8136	63,369	64,060	1.09%
1983	0.8506	40,839	41,198	0.88%
1984	0.8410	35,913	35,790	−0.34%
1985	0.8685	48,380	47,158	−2.53%
1986	0.8521	52,385	51,832	−1.06%
1987	0.8556	51,846	51,231	−1.19%
1988	0.8510	51,182	50,072	−2.17%
1989	0.8098	35,686	35,493	−0.54%
1990	0.8128	29,245	29,144	−0.35%
1991	0.8232	36,948	37,645	1.89%
1992	0.8627	32,151	33,052	2.80%
1993	0.8752	30,926	31,842	2.96%

13 out of 29 years, and within 2% for 23 out of 29 years. Other annual validation comparisons by area, depth, and month are reported in Griffin and Shah.[8]

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[8] Griffin, W. L., and A. K. Shah. 1995. Estimation of standardized effort in the heterogeneous Gulf of Mexico shrimp fleet. NOAA, NMFS, MARFIN Contr. Rep. NA37FF0053-01, 50 p.

The actual interviewed effort is predicted with very high precision through the selected expansion model.

Relative Fishing Power

The *RFP* of the average fishing craft (vessels and boats for the total fleet) moved upward from 1.00 in 1965 to 1.23 in 1980, then dropped in 1981 to 1.15 and remained relatively constant through 1988 and then increased again (Fig. 4). This implies that the *RFP* of craft fishing in the Gulf of Mexico shrimp fishery (boats and vessels) in 1980 was 23% more powerful than the standard craft fishing in 1965. In 1993 the relative fishing power was slightly less than that in 1980. The *RFP* of the inshore and offshore fisheries follows the same trend as the total, but the curve is much smoother for the offshore fishing. Comparing the *RFP* between craft that fish inshore and those that fish offshore, we find that craft fishing inshore in 1965 were only 80% as powerful as those fishing offshore. This was still true in 1993.

The drop in 1981 in *RFP* (which remained constant through 1987) can be explained using fuel price and price received for shrimp (Fig. 5). The fuel price began to increase at the end of 1973 and doubled in 1974. At the same time, shrimp prices declined from 1973 to 1974. Shrimpers had a hard time covering cost in 1974 and 1975 (Warren and

Griffin, 1980). The fuel price continued to increase, but more slowly, into the beginning of 1979. However, the real shrimp price also increased in 1979 offsetting the increase in the fuel price. As a result, shrimpers invested in new vessels during the profitable years, 1976–78, increasing the *RFP*. During 1979 fuel prices began to rise rapidly, and in 1980 the real shrimp price began to decline from US$5/pound in 1979 to US$2 by 1993. Shrimpers who ordered vessels in 1978 received them in 1979 and 1980; therefore, the *RFP* continued to increase through 1980. Beginning in 1979, shrimpers began to take steps to be more fuel-efficient. Investment in new vessels nearly came to a halt, causing the *RFP* to remain stable through 1987. After 1987, *RFP* increased through 1993, except for 1989; however, this increase was due not to the entry of newer and more powerful vessels into the fishery, but rather, to older and less powerful vessels leaving the fishery. Although the price of fuel declined through 1986, it was not sufficient to generate interest in investing in new shrimp vessels.

Comparison of Estimated Nominal Effort

Figures 6a–c compare our estimates with those of NMFS for total, inshore, and offshore nominal days fished, respectively, by year. Through 1975, our
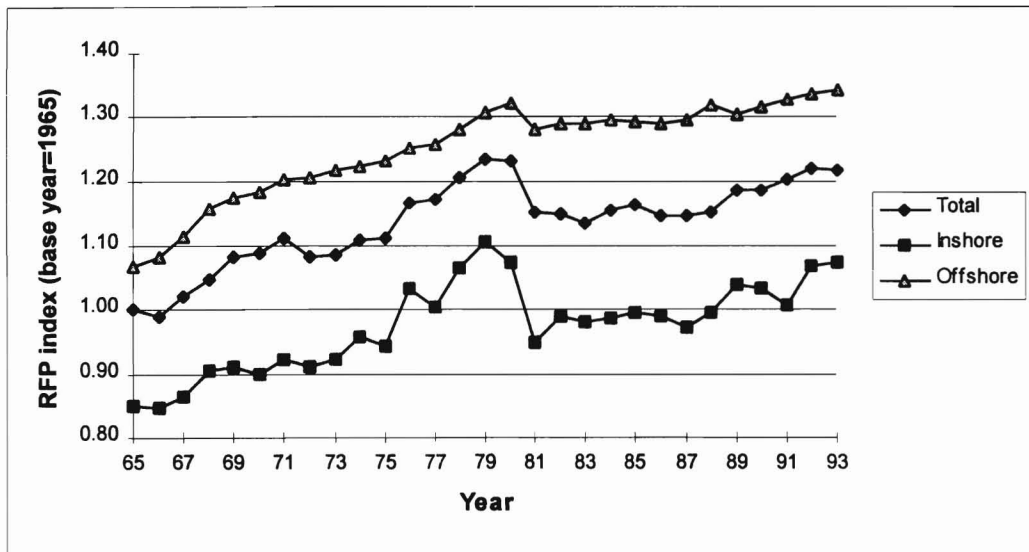
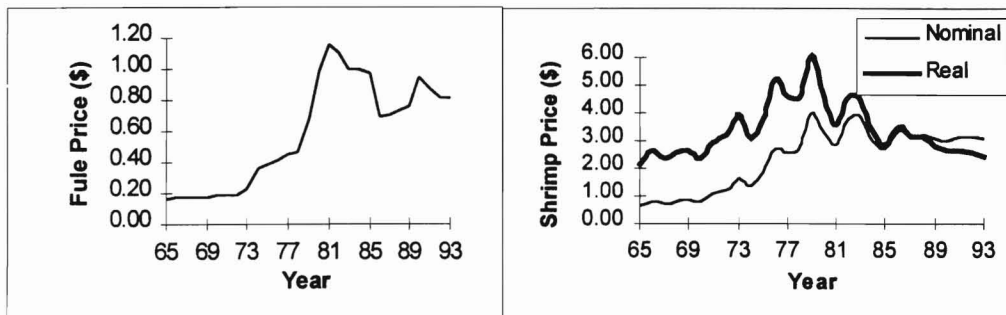Figure 4.—Change in *RFP* in the total, inshore and offshore shrimp fishery by year.

Figure 5.—Price of diesel fuel and average price of shrimp (nominal and real dollars) in offshore shrimp fishery. Real dollars based on the consumer price index (1982–84=100).

estimates of total nominal days fished (Fig. 6a) almost coincide with those of NMFS. After 1975, both estimates have the same trend, but ours are higher for all years except 1979, 1980, and 1992. Inshore (Fig. 6b), estimates coincide through 1971. Beginning in 1981, our estimates of inshore days fished exceed those of NMFS. Offshore estimates (Fig. 6c) by both methods track reasonably well. However, total days fished decreased beginning in 1988, largely due to a decline in the inshore fishery.

The discrepancies between these estimates and those of NMFS may be explained in part by a bias in data obtained by NMFS. Their nominal effort data is generated entirely from interviews obtained by port agents. Therefore, interview bias, including that from selection of craft type by the interviewer, becomes important. In 1965, 72% of in-shore shrimp landings came from boats (≤60 ft), and 28% from vessels (> 60 ft and registered by the U.S. Coast Guard). Inshore, agents interview landings were 92% from boats and 8% from vessels. Beginning in 1989, vessels were targeted for interview more frequently than boats, and virtually no boats have been interviewed either inshore or offshore since 1989. Thus, the interview process in itself has introduced a bias in nominal effort data inshore resulting from non-proportionate sampling of the craft types. During the 29 years from 1965 through 1993, interviews with offshore shrimpers have remained at about 20% of the recorded vessels, however.

Standardization of Effort

Figures 7a–c show nominal days fished compared to standard days fished for total, inshore, and offshore shrimp fisheries, respectively. Using 1965 as the base year[9], real effort has increased 165% in the total shrimp fishery from 1965 to 1993, whereas nominal days fished increased only 118%. Thus, taking account of the increased fishing power of the fishing craft, there are 47% more standard days in 1993 than would be suggested by the nominal days fished. Examining the inshore shrimp fishery we find nominal days fished has increased 266% during this time period, whereas standard days increased 361%. Offshore nominal days fished increased 75% and standard days fished increased 120%. This increase in days fished is the actual increase in U.S. waters only.

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[9] Choosing the base year is an arbitrary choice. We could just as easily have chosen 1993 instead of 1965. The trend will be the same as will the percentage change in real days fished over time. The absolute magnitudes will differ, however.

Figure 6a.—Comparison of our estimates with the NMFS estimates of total nominal days fished by year.
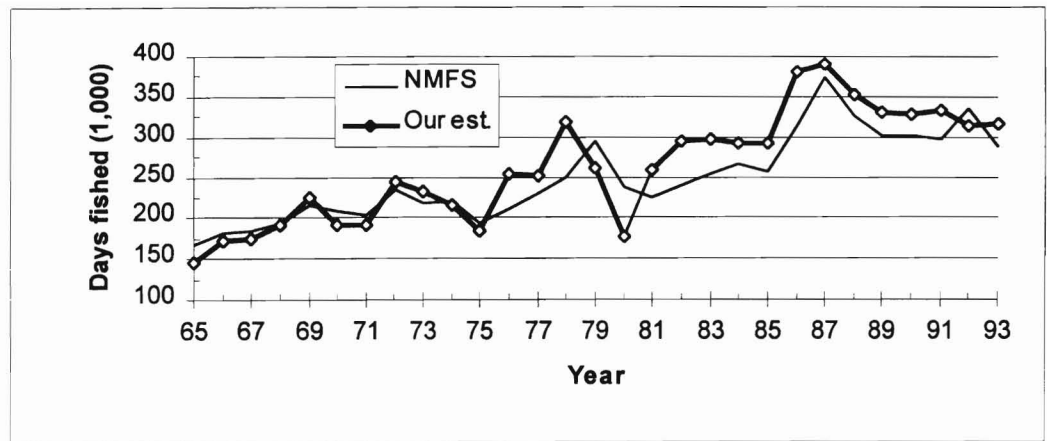

Figure 6b.—Comparison of our estimates with the NMFS estimates of nominal days fished in inshore shrimp fishery by year.
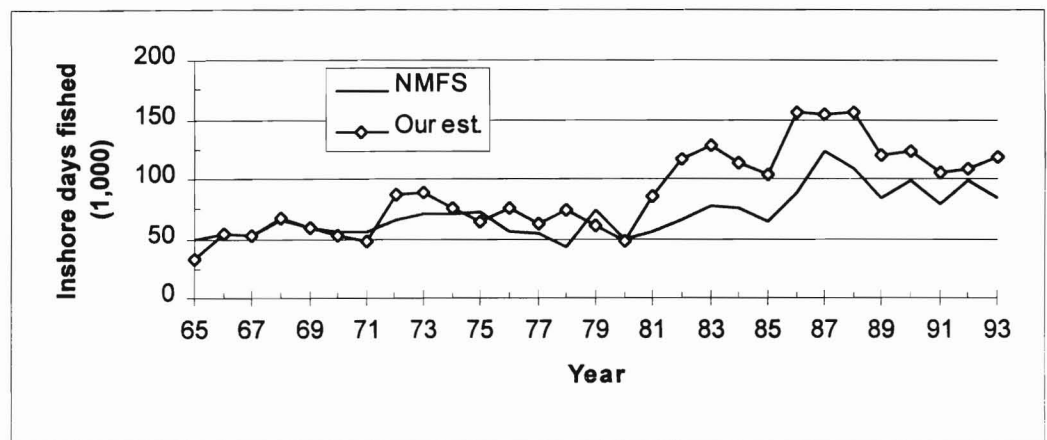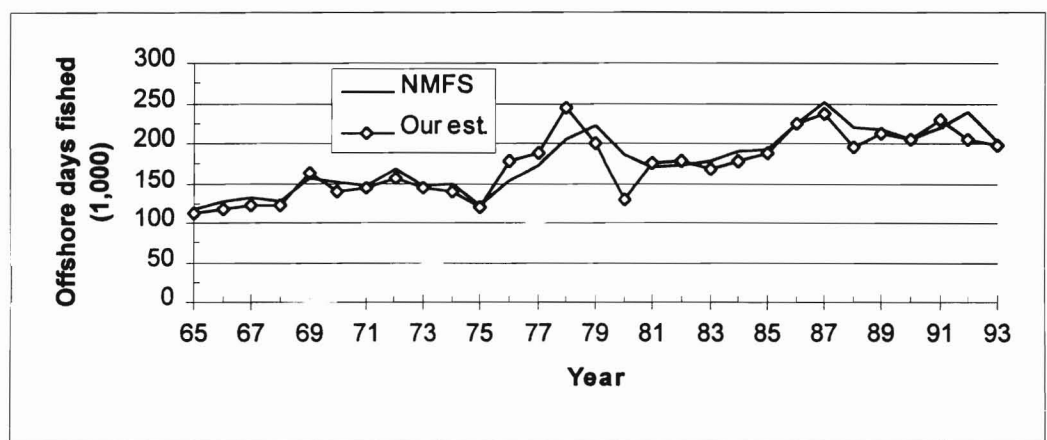

Figure 6c.—Comparison of our estimates with the NMFS estimates of nominal days fished in offshore shrimp fishery by year.

Prior to 1977 when Mexico extended its territorial limits, offshore shrimpers also fished a significant amount of time in Mexican waters (Fig. 8). Therefore, comparing 1993 to 1965, U.S. shrimpers in offshore waters of the Gulf of Mexico increased nominal days fished only 16%. Nominal days fished inshore increased 266% during this same 29-year period, most in Louisiana and Texas (about 315%). In response to the increase in the days fished inshore, the Texas Legislature passed Senate Bill 750, a shrimp license management program with a buy-back option, designed to stop the increase in licenses sold for the bay and bait shrimp fisheries.[10]

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[10] Texas sells a commercial shrimp bay license, a commercial shrimp Gulf license, and a bait license.

Figure 7a.—Comparison of percent change in nominal days fished (our estimates) with standard days fished for total U.S. shrimp fishery in the Gulf of Mexico by year.
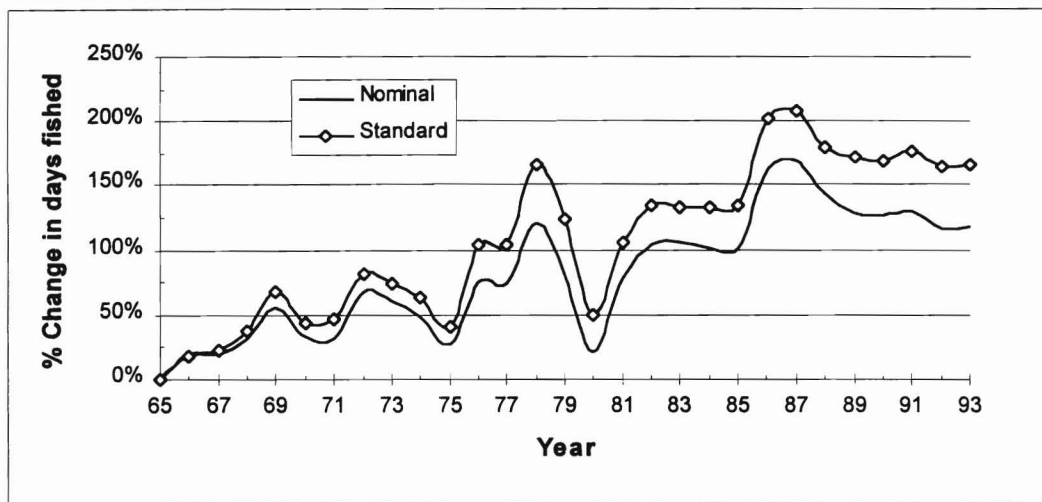

Figure 7b.—Comparison of percent change in nominal days fished (our estimates) with standard days fished for the inshore shrimp fishery in the Gulf of Mexico by year.
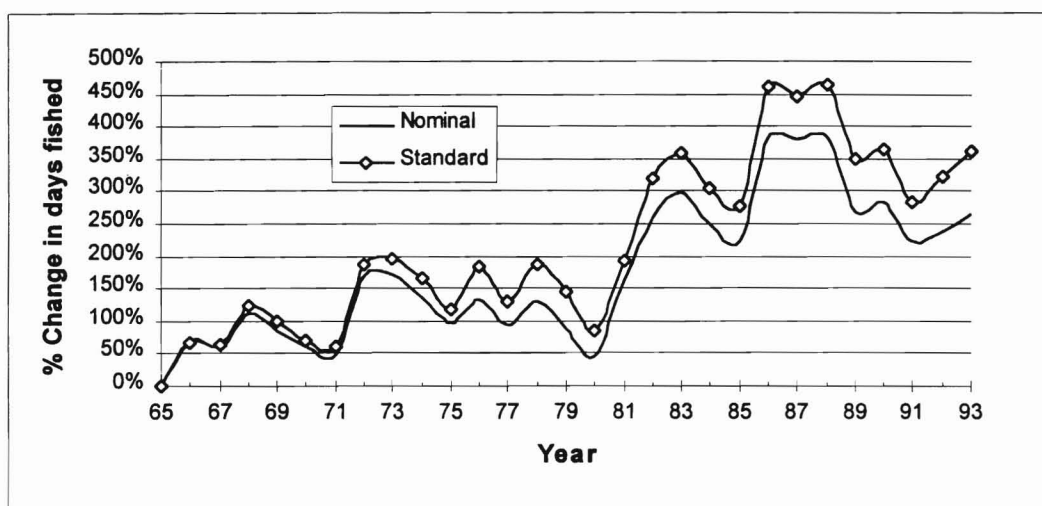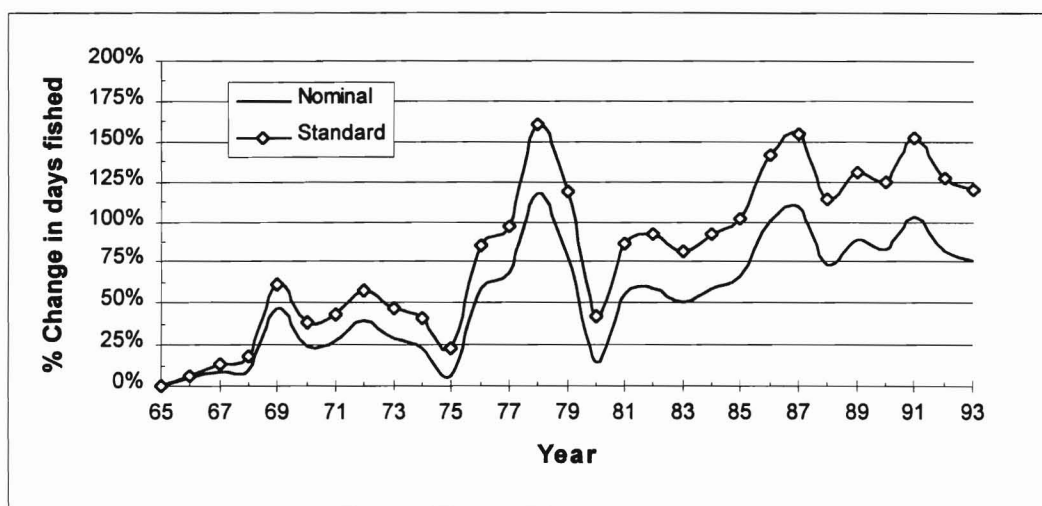

Figure 7c.—Comparison of percent change in nominal days fished (our estimates) with standard days fished for the offshore shrimp fishery in the Gulf of Mexico by year.
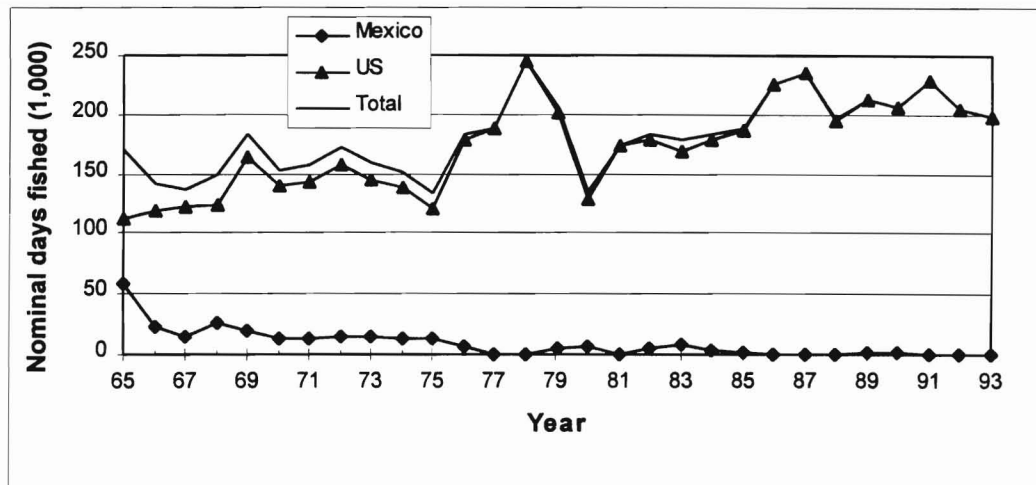
Figure 8.–Nominal days fished (our estimates) in U.S. waters, Mexican waters, and total offshore waters, in the Gulf of Mexico by year.

Conclusions and Recommendation

The modeling approach presented here is a reasonable and logical alternative to the NMFS approach. Our approach eliminates the need for subjectivity in pooling over neighboring cells, in the case of missing cells, to estimate nominal days fished. Since we fit an expansion model for each year, our approach is more sensitive to yearly changes and is more likely to capture these changes. Our approach yields higher inshore days fished in the latter years than does the NMFS due to the reduction in interview landings data in the inshore area. This causes a bias in the NMFS estimates of days fished and most probably in our estimate as well. It is strongly recommended that future data collection by the NMFS be more proportional than what it has been since 1984.

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