Abstract—The spiny lobster (*Panulirus argus*) fishery in Florida was operationally inefficient and overcapitalized throughout the 1980s. The Trap Certificate Program initiated during the 1992–93 season was intended to increase gear efficiency by reducing the number of traps being used while maintaining the same catch level in the fishery. A depletion model was used to estimate trap fishing efficiency. The costs of fishing operations and the value of the catch were used to determine the revenues generated by the fishery under different trap levels. A negative functional relationship was found between the catchability coefficient and the number of traps, which indicated that the fewer traps operating under the trap reduction scheme were more efficient. Also, the financial analyses indicated that the higher catch efficiency resulting from fewer traps generated significantly higher revenues, despite lower stock abundances. This study indicates that the trap reduction program had improved a situation that would have been much worse.

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Management of fishing capacity in a spiny lobster (*Panulirus argus*) fishery: analysis of trap performance under the Florida spiny lobster Trap Certificate Program

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The Florida spiny lobster (*Panulirus argus*) fishery has been exploited since the early 20th century (Labisky et al., 1980); however, demand for lobster products in the U.S. markets did not materialize until the early 1960s. Rapid growth of the fishery took place in the late 1960s and early 1970s and since then total landings have varied between 1800 and 2700 metric tons (t) whole weight, with no discernible pattern. Fishing effort expanded from 250,000 traps in the early 1970s to approximately 940,000 traps by the 1991–92 fishing season (August–March). This fishery development took place mainly in the Florida Keys, where today over 90% of Florida's harvest is landed with a dockside value exceeding $40 million. Therefore, the spiny lobster fishery is one of the most important fisheries in the State. High fishing intensity, overcapitalization, negative environmental impacts, and gear conflicts characterized the fishery until the Florida Legislature enacted a trap reduction program in 1991.

The Trap Certificate Program (TCP) was implemented in the Florida spiny lobster fishery taking the 1992–93 fishing season as a base. One of the goals of the TCP was to increase the efficiency of the traps used in the fishery. Seasonal catch per trap in the Florida Keys fishery decreased from about 24.1 kg per trap using about 97,000 traps in the 1969–70 fishing season to about 3.1 kg per trap from about 851,000 traps in the 1991–92 fishing season. While the catch per trap decreased, the total seasonal landings were sustained at an average of 2.8 million kg whole weight through most of the fully developed fishery (1975 to 2004). The TCP proposed a steady reduction in the number of traps while keeping the total landings unaffected. This desirable objective was thought possible because total landings were sustained over the wide range of traps used in the fishery.

There was an operational assumption that the trap catchability (the fraction of the seasonal stock biomass taken by each trap) would increase because there would be less competition for the fixed seasonal spiny lobster biomass as the trap numbers were reduced. Under the TCP, the total number of traps was to be reduced annually by a fixed percentage of the number of traps used during the previous fishing season, starting with the 1993–94 season. However, this strategy was modified several times in the ensuing years, mainly due to economic hardships resulting from environmental impacts, e.g., Hurricane George in September 1998, and a perceived decrease in stock abundance. This TCP was the first limited access system to be implemented in the southeastern United States.

By the early 2000s the spiny lobster trap fishermen expressed reservations about whether the TCP would be able to resolve the economic hardship that they had faced. Therefore, in order to address the fishermen's concerns regarding the TCP, the Florida Fish and Wildlife Conservation Commission (FWC) implemented a project to assess the status of the TCP under the existing conditions of the spiny lobster stocks and costs of the fishery. A comprehensive cost and social survey analysis was conducted in 2004 with FWC support. An assessment of the financial impact of different levels of stock abundance on the TCP was performed. As a corollary, one of the first tasks for the project was to test the hypothesis that the seasonal trap catchability should have been positively affected by the TCP. In this article we present the results of the research on the effects of the TCP on trap catch efficiency, at both a fishery-wide and regional scale, and its financial impacts.

Methods and Materials

Evaluation of trap catch efficiency under the TCP

A quantitative model was developed to estimate the seasonal catchability coefficient, q, and to study the resulting trends as the trap reduction schedules were implemented. A seasonal depletion model similar to those used in the scientific literature concerning fishery assessments (Chien and Condrey, 1985; Sanders, 1988; Rosemberg et al., 1990) was adopted using Pope's (1972) approximation to Baranov's catch equation. This approximation assumes that the total catch (C_t) realized in a given month (t) will be taken instantaneously at the middle of the month. Such an approximation generates unbiased estimates of population abundance at the beginning (N_t) and end (N_{t+1}) of the time units given that the natural mortality rate (M) is not greater than 0.3/yr and fishing mortality rates are not greater than 1.2/yr. Hence, the basic population equation is expressed as

$$N_{t+1} = \frac{\dfrac{N_t}{e^{M/2}} - C_t}{e^{M/2}}, \tag{1}$$

and the average population abundance is expressed as

$$\overline{N_t} = \frac{N_t}{e^{M/2}} - \frac{C_t}{2}. \tag{2}$$

Also, the relative stock abundance expressed as the catch in numbers per unit of effort (CPUE) in the time period t is assumed directly proportional to the average abundance. Hence,

$$CPUE_t = q_i * \overline{N_t}, \tag{3}$$

and therefore,

$$q_i = \frac{CPUE_t}{\overline{N_t}}. \tag{4}$$

Application of Equation 1 to express seasonal depletion in the spiny lobster fishery requires that N_t varies with monthly fishing and natural mortality. However, at the beginning of the fishing season (August) the stock abundance is composed of the remainder of the previous season's stock abundance that escaped natural and fishing mortality (N_t), plus the new recruits (R_{t+1}) that accumulated during the closed season (April–July). In this manner, the abundance at the start of the season (August t+1) is expressed as

$$N_{t+1} = \frac{N_t}{e^{4M}} + R_{t+1}. \tag{5}$$

The seasonal depletion model expressed by Equations 1 and 5 was fitted to the monthly catch in numbers per unit of effort data for the period including the 1991–92 through the 2002–03 fishing seasons, i.e., from the season previous to the base year for implementation of the TCP to the last fishing season when no further trap reductions were implemented. For this purpose the FWC provided landings and effort data for the commercial fishery extracted from the Marine Fisheries Information System. This system consists of all wholesale seafood dealers receipts of salt-water product purchases (trip tickets). Trip tickets show landings, fishing effort, gear, location, and date of landings per trip. The information used in this research is limited to the Florida Keys where most of the spiny lobster landings occur. Counts of the total number of traps deployed during the 1991–92 and 1992–93 fishing seasons were obtained from the National Marine Fisheries Service. Trap numbers for subsequent seasons were obtained from the trap certificates issued by the State of Florida according to the TCP. Numbers of commercial trips per season were obtained from the trip ticket system for those records containing lobster landings. Numbers of recreational spiny lobster landings were obtained from the FWC. The FWC transforms the weight of commercial landings into numbers using sex and size frequency samples collected by the FWC and the National Marine Fisheries Service. The number of undersized lobsters used as attractants in the trap fishery was provided by the FWC from their observer program established in 1993. This program measures the total catch on selected commercial lobster fishing trips.

The catchability coefficient was assumed to vary among the seasons following a random walk model of the type:

$$q_i = q_{i-1} e^{\varepsilon_i}, \tag{6}$$

where the ε_i are annualized, and normally distributed with mean zero and variance σ_e^2. The model was fitted by minimizing the negative log-likelihood objective function using the Solver minimization tool in Excel (Microsoft Corp., Redmond, WA):

$$\frac{n}{2}\sum_t \left(\ln(U_t) - \ln(\hat{U}_t)\right)^2 + \frac{\sum_i \varepsilon_i^2}{\sigma_\varepsilon^2}, \tag{7}$$

where n represents the number of months, U_t represents CPUE in month t, and σ_e^2 was fixed to achieve a coefficient of variation of 20% in log space—a percentage that was adopted to represent the likely response of the change in q to trap reductions.

The monthly CPUE was measured in numbers of spiny lobsters caught per trap day per trip, where a trip is defined as the day when a set of traps was serviced. The difference between trips represents the effective soak time measured in days. Therefore, any seasonal change in catchability would refer directly to a per-trap-day condition defined between fishing trips. One important consideration in the preparation of the data to fit the model using the objective function (Eq. 7) was the realization that soaking times may vary throughout the fishing season, with an increasing trend expected as the fishing season progresses and local population abundance is depleted. The soaking time may also vary among fishing seasons as a consequence of differences in seasonal abundance. Therefore, if these variations in soaking times occur, the catch per trap day per trip would have to be standardized to the changing seasonal soaking time.

Financial performance under the trap reduction program

The financial analysis to assess the results of the TCP was based on monthly and seasonal revenue estimations that required information on the average unit price paid for product landed per trap day per trip, and the cost per trap day per trip incurred in the realization of the landings. The average monthly price paid per kilogram of spiny lobster landed was obtained from the trip ticket database provided by the FWC for each of the fishing seasons covered in this analysis (1991–2002). The average cost data (indirect and direct) was obtained from a census carried out from February 2003 through January 2004 sponsored by the FWC, which included interviews of 221 fishermen operating in the spiny lobster fishery.

The information collected in the 2003–04 cost survey included the general characteristics of the fishermen and their historical involvement in the multispecies fisheries associated with spiny lobster in South Florida. Other data important to this analysis provided by the FWC were the fraction of the total effort dedicated to spiny lobster operations, as well as the variable and direct costs associated with the fishermen's participation in the spiny lobster fishery. The variable cost information per trip included fuel and oil, bait, ice, food and supplies, and other costs. The direct cost data used in the analysis consisted of the value of the vessel and the age of the vessel so that vessel depreciation could be analyzed, annual dockage cost, trap costs (including repairs and labor), principal and interest on loans (IP), and protection and indemnity (PI) payments. The average costs for docking, IP, and PI included the zero costs reported by many fishermen who used dock facilities without cost or did not have debts on loans or insurance, and as such these were considered in the average direct cost estimation.

The cost analyses conducted in this study considered that the direct costs related to vessel depreciation, dockage, and vessel repairs should be proportionally distributed between the spiny lobster fishing operations and other fishing operations carried out by the same vessels. In the survey, the combined data for the entire fishery provided an average of 66% of fishing time allocated to spiny lobster. This proportion, therefore, was applied to the direct cost components pertaining to docking, IP and PI payments, and vessel repairs as directed to spiny lobster fishing on a fishery-wide scale. Similarly, the regional spiny lobster direct costs for the segregated areas were estimated by the average percent participation in spiny lobster fishing in each region declared in the survey.

The average total number of trips carried out seasonally per vessel and the average number of traps serviced per trip necessary to estimate costs on a per-trap-day-per-trip basis were also obtained from the survey data.

The vessel depreciation life was estimated at 18 years with data from the 2003–04 FWC survey. The age structure of the fleet, generated from the 2003–04 survey data, indicated that a large fraction of the vessels are in or above the 16–20 year class range that includes the depreciation life span of the vessels. Therefore, the cost analysis considered only the cost associated with the fishery-wide average payments on principal and interest that fishermen were paying for their vessels since most of the vessels are already paid off. The seasonal direct costs were converted to a per-trip basis by dividing by the average number of spiny lobster fishing trips.

The financial analyses were assessed on a fishery-wide and regional basis. Thus, it was necessary to consider the seasonal changes in stock abundance, and the dynamic changes in the catchability coefficient that occurred as a consequence of the trap reduction schedule. Because the cost data pertain only to the 2003–04 fishing season, the financial analyses were designed as case scenarios, where the CPUE was a function of the average population abundance, and the value of the CPUE was assumed for a fishing season of reference. In order to generate the catch per trap day per trip scenarios, results from the application of the assessment methods (Eqs. 1–7) were used as follows:

1 The average monthly abundance for the season with the highest abundance (1997–98), the lowest abundance (2001–02), and an intermediate abundance were used to estimate seasonal catch per trap day per trip according to Equation 3.
2 The catchability coefficient, q, required for the estimation of the catch per trap day per trip in Equation 3 was selected for the following conditions: a) low q—when the number of traps was high (1991 fishing season); b) high q—when the number of traps was low (2001 fishing season); and c) intermediate q—corresponding to the trap levels achieved by the TCP during the 1997–98 season.

3 The monthly net revenue generated on a per trap day per trip basis under each of the above scenarios was estimated as the difference between the monthly value of the catch per trap day per trip and the average cost of operating per trap day per trip based on the 2003–04 census. Total revenue for the season was simply the product of the average revenue per trap day per trip and the average number of traps serviced per trip and the average number of trips per season.

In the analyses pertaining to a fishery-wide scale the case scenarios were as follows:

1 The catch per trap per trip referred to the following three conditions: if fishing took place during the season with the highest (1997–98), or the lowest (2001–02), stock abundance during the TCP, or with the stock abundance of the season just prior to the implementation of the TCP (1991–92), and
2 The catchability coefficient condition resulted from the number of traps operated in the fishery that corresponded to the three CPUE scenarios expressed above.

Thus, it was possible to use the value per kilogram landed per trap day per trip and the cost per trap day per trip data to simulate the financial consequences for a maximum range of catchability and abundance combinations.

Results

Trap catch efficiency

The assumption that the trap catchability would increase with the reduction of traps used in the Florida lobster fishery was verified during the TCP (Fig. 1) The trap soaking time was found to vary throughout the fishing season, with an increasing trend as the fishing season progressed and local population abundance was depleted. The soaking time also varied among fishing seasons (Fig. 2) as a consequence of differences in seasonal abundance. Therefore, the catch per trap day per trip was standardized to the changing seasonal soaking time. For this purpose an average monthly soaking time was estimated for every month in each season from the records in the trip ticket database. The resulting CPUE was consequently the average catch in numbers per trap day per trip. The seasonal CPUEs are plotted in Figure 3 where a persistent pattern of stock depletion is observed. A consistent fit of the depletion model was obtained for most years (Fig. 3) when the monthly natural mortality rate (M) commonly used in Caribbean spiny lobster assessments (FAO, 2001) was 0.0317 (or 0.38 annually). The overall fit resulted in a residual sum of squares (RSS) of 1.277.

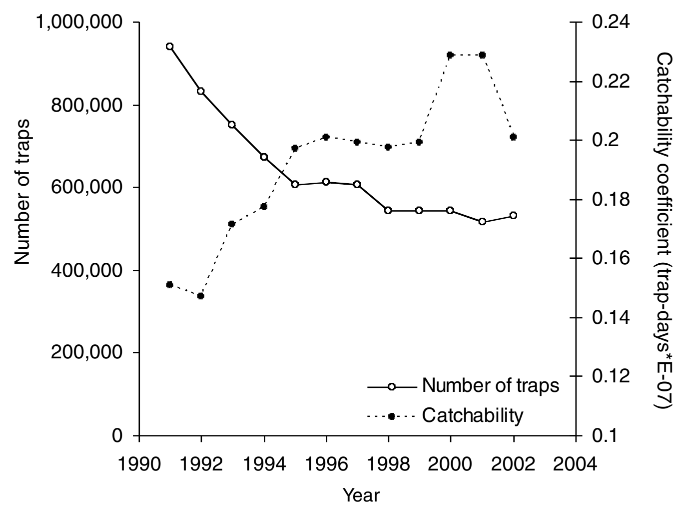

Figure 1

Number of traps under the Trap Certificate Program (○) and catchability coefficient trend (●) for spiny lobster (*Panulirus argus*) in the Florida fishery from 1991 to 2002.

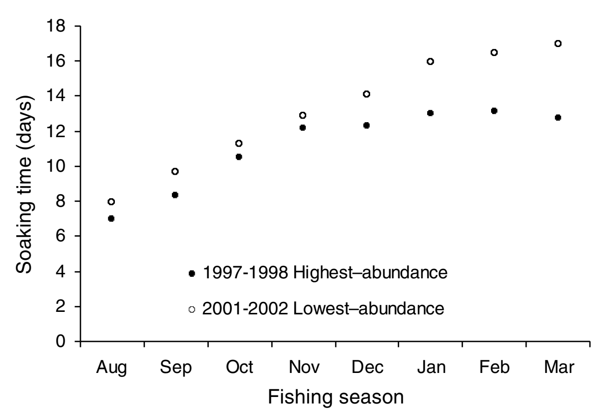

Figure 2

Average trap soaking time in number of days for fishing seasons with highest spiny lobster stock abundance (1997–98) (●) and lowest stock abundance (2001–02) (○) in the Florida fishery.

The 1991–92 fishing season had a higher stock abundance than the 2001–02 fishing season (which actually had the lowest abundance observed during the study period). The catchability coefficients were lowest during the 1991–92 seasons when the number of traps operating in the fishery was at the highest level. Meanwhile the highest catchability coefficient was found in the 2001–02 season when the fewest traps were used in the fishery. Figure 4 clearly shows a negative functional correlation between the historic trends in seasonal catchability estimates and trap reductions under the TCP. This relationship, when the fishing effort is by passive fishing units (e.g., traps, longlines, gillnets, etc.), has also been reported for the spiny lobster fisheries of Australia (Groeneveld et al., 2003), Brazil (Ehrhardt, 2005), and Nicaragua (Ehrhardt (2005); crawfish (Romaire and Pfister, 1983; Fouilland and Fossati, 1996); and cod (Angelsen and Olsen, 1987). Figure 4 indicates a significant increase in the fraction of the stock that was taken per trap-day as the number of interacting traps was reduced from about 851,000 to about 550,000. It is observed that during the period of the TCP, the 1991–92 to the 2002–03 fishing seasons, the fishing effort expressed in traps-days became at least 50% more efficient due to changes in trap catching efficiency. This increase was independent of the decreasing stock abundance levels.

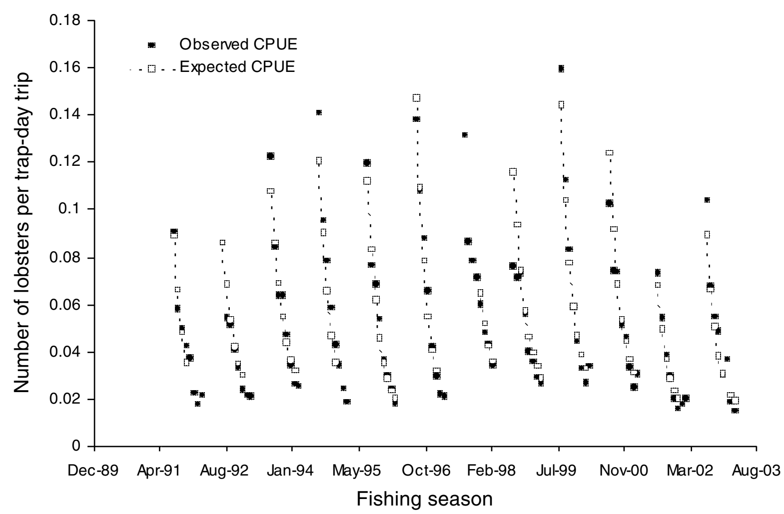

Figure 3

Observed (●) Florida seasonal spiny lobster (*Panulirus argus*) catch in number of lobsters per trap per day per trip (CPUE) corrected by soaking time in days and expected (○) CPUE obtained by fitting the depletion model to the observed data during the 1991 to 2002 fishing seasons. Fishing seasons are from August to April.

Financial performance

Fishery-wide analysis The fishery-wide financial performance was assessed based on monthly revenues using the costs per trap day per trip and the average monthly value paid per kilogram of lobster landed in the 2002–03 season estimated from the trip ticket database. The average seasonal direct costs and indirect costs per trip were transformed to a per-trap-day-per-trip condition based on the average number of 347.8 (standard deviation=213) traps pulled per trip and 78 trips per season reported in the 2003–04 survey. Therefore, it was possible to judge the consequences of the increases in the catching efficiency of the traps due to the TCP and the decreasing trend in stock abundance observed in the period of analysis.

Analysis of the different scenarios considered in this study indicates highly significant differences regarding the seasonal dissipation of revenues as a function of the number of traps used in the fishery. However, such dissipation is dramatically influenced by the lower catchabilities observed when a large number of traps are deployed in the fishery. For example, Figure 5A shows the monthly revenues of the 1991–92 scenario of high abundance and lowest q fishing season, prior to the TCP implementation, and the 2001–02 fishing season with the lowest abundance and highest q. The figure indicates that revenues dissipated quickly and became negligible by March in both cases. The total seasonal revenue per vessel was $17,701 and $13,405 for the 1991–92 and 2001–02 fishing seasons, respectively. Thus, although a much larger stock abundance was present during the 1991–92 fishing season relative to the 2001–02 season, the less efficient traps at that time generated a catch per trap day per trip that did not contribute significantly to the total revenues. If the catchability coefficient of 2001–02 could have been applied to the stock abundance available in the 1991–92 season, the total annual revenue per vessel would have been $38,654, or about 2.18 times larger than that which was actually obtained.

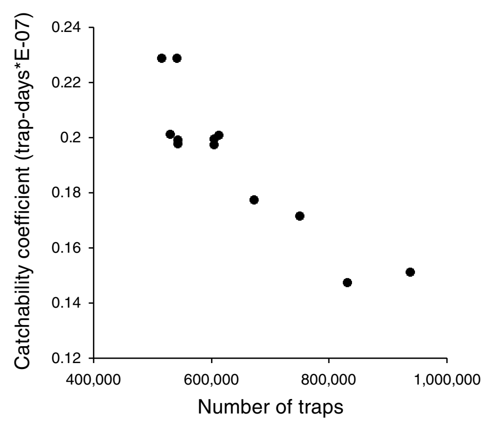

Figure 4

Trend of decreasing catchability (measured in trap days) with increasing number of traps in the spiny lobster (*Panulirus argus*) fishery in Florida from 1991 to 2002 fishing seasons.

In the scenario under which the TCP would not have been established, very small revenues would have been generated by the fishery. This case compares the revenue conditions for the 2001–02 fishing season abun-

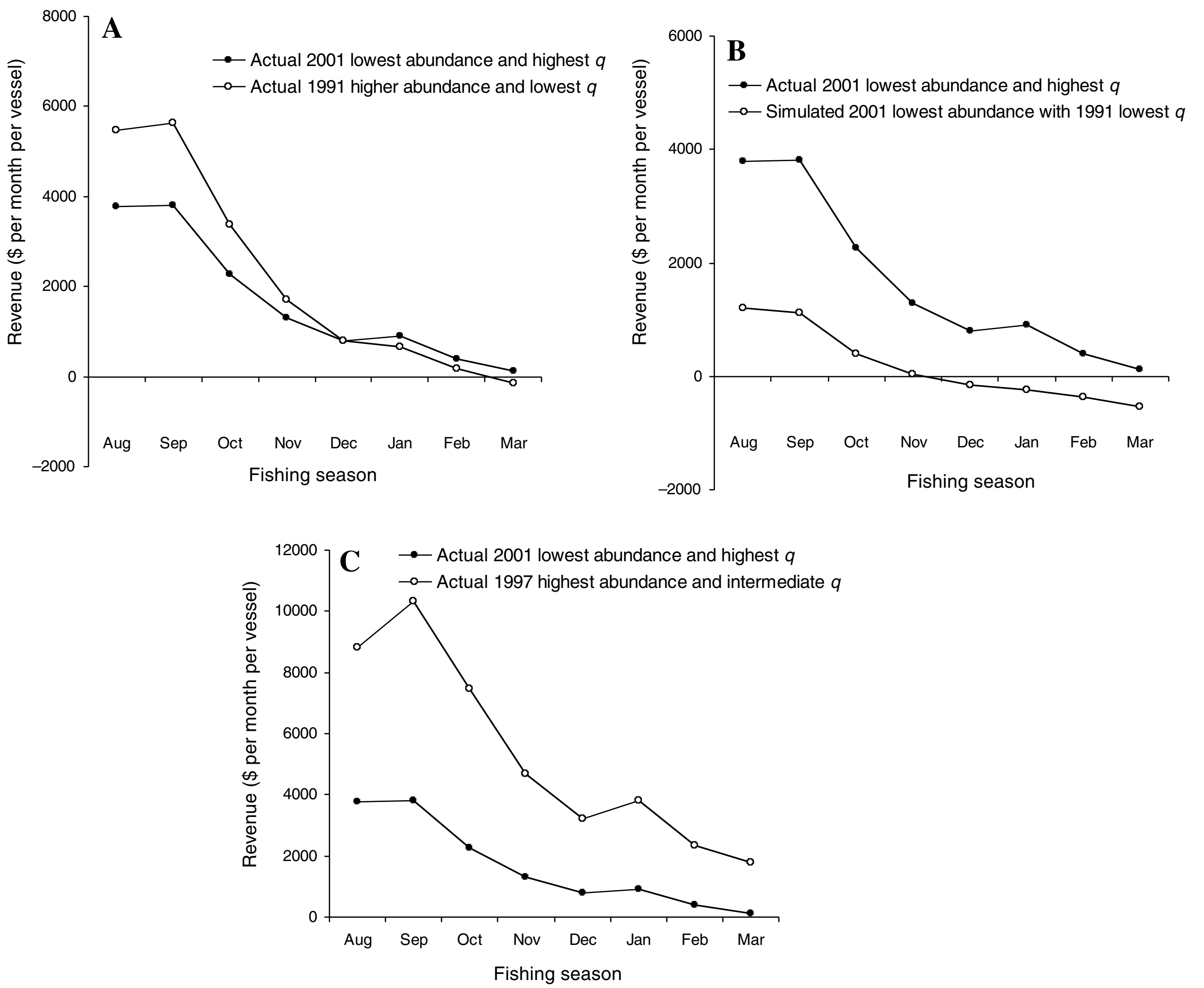

Figure 5

Average Florida regional monthly revenues per trap-fishing vessel under (**A**) the 1991 spiny lobster (*Panulirus argus*) high abundance and lowest q (○) and the 2001 lowest abundance and highest q (●); (**B**) the 2001 lowest abundance and highest q (●) and a simulated condition of the 2001 abundance subjected to the 1991 lowest q (○), and (**C**) the 2001 lowest abundance and highest q and the 1997 abundance and the intermediate q estimated for that season.

dance under the exploitation of the catchability coefficients before the TCP (the 1991–92 fishing season) and the actual 2001–02 catchability (Fig. 5B). In the absence of the TCP, the revenues per vessel would have been close to zero by November, and negative starting in December, resulting in total seasonal revenues of only $1,470 instead of the $13,405 that was actually obtained due to the increased CPUE that resulted as a consequence of the TCP implementation.

In the case scenario corresponding to the highest fishing season stock abundance observed during the study period (1997–98), the reduced number of traps generated an intermediate value of q; hence, the total seasonal revenue for the 1997–98 scenario was $42,468 compared with $13,405 for the 2001–02 scenario (Fig. 5C). If the reduced number of traps of the 2001–02 season had existed in the 1997–98 fishing season, the annual expected revenue under the 1997–98 stock abundance would have been $51,608.

Regional analysis Direct costs were calculated on a per trap day per trip condition for each region. The total costs (direct and indirect) per trip show a significant decreasing trend from Key West (including the Dry Tortugas) through the Upper Keys, and Miami shows an intermediate total cost per trip. The total cost per trap day per trip varied among the regions because of the different number of traps serviced per trip in each of the regions and hence the total cost per trap day per trip did not follow a marked regional trend.

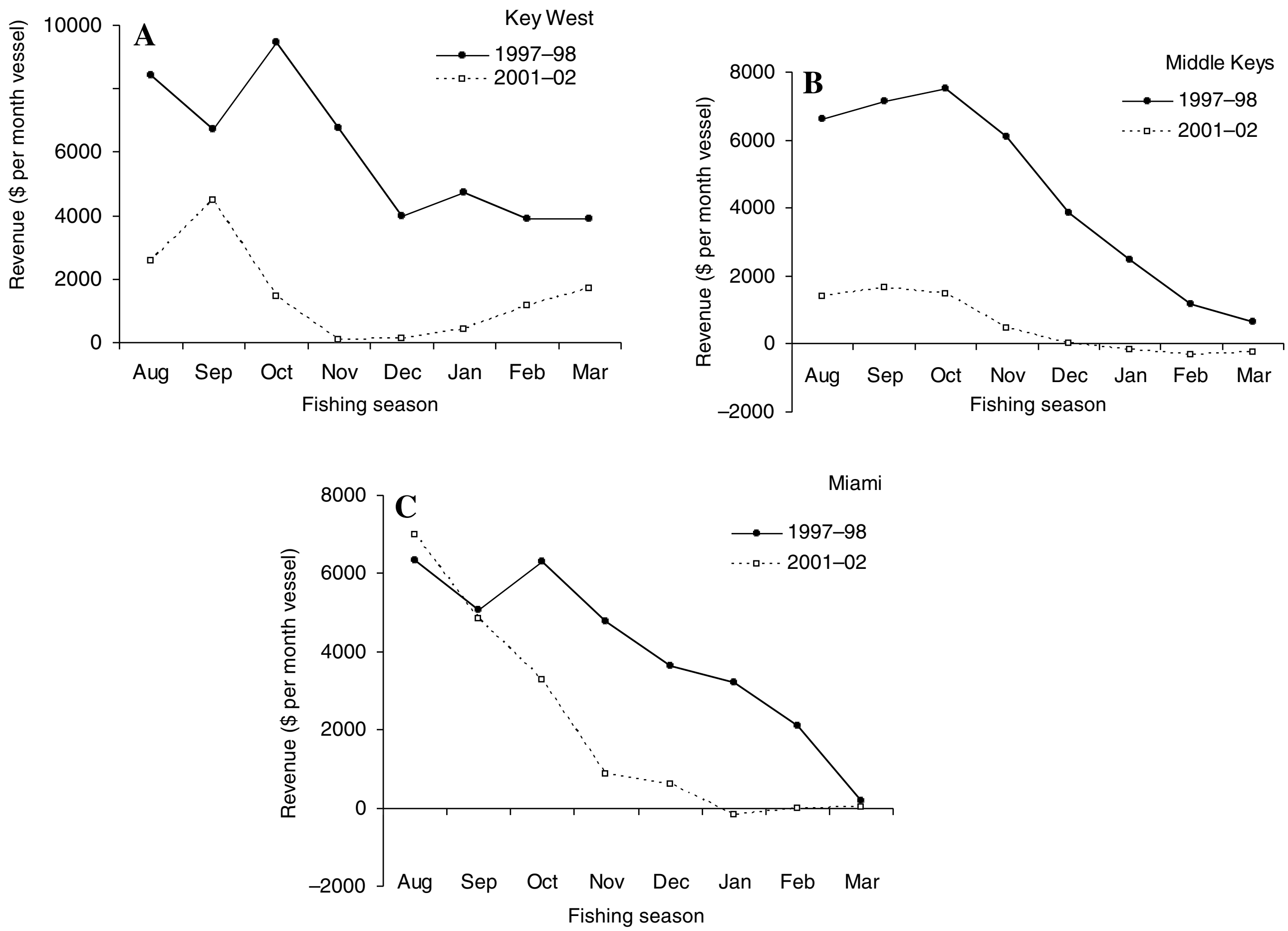

Figure 6

Average monthly revenues resulting for the season with highest (1997–98) (●) and lowest (2001–02) (○) spiny lobster (*Panulirus argus*) stock abundance and their respective q estimates for the trap fishery in three regions in South Florida: (**A**) Key West, (**B**) Middle Keys, and (**C**) Miami.

The total costs results were used in the seasonal financial analysis for the outcome of fishing for lobsters in the regions. The case scenarios in the regional analyses considered 1) the estimated CPUEs for the seasons with the highest (1997–98), and lowest (2001–02) stock abundance, and 2) the estimated CPUEs for the seasons with the highest and the lowest abundance standardized to the catchability coefficients corresponding to the 1991–92 fishing season (prior to the TCP) and to the 2001–02 fishing season (ten years later).

Case scenario 1: For Key West, two very different monthly revenue trends resulted for the fishing seasons with the highest and the lowest stock abundance relative to the 2003–04 costs and values per kilogram (Fig. 6A). The difference in stock abundance had a very significant and striking financial impact, the total seasonal revenue was $47,922 for 1997–98 (highest abundance) and $11,985 for 2001–02 (lowest abundance). In the case of the Lower Keys the monthly revenues for 2001–02 were almost negligible. In the Lower Keys the total seasonal revenues were $15,851 for the 1997–98 fishing season, and $3227 for the 2001–02 season. The seasonal revenue trends for the Middle Keys indicate that the revenue differences were very significant between the two seasons. The total seasonal revenues for the Middle Keys were $35,505 and $4,266 for the 1997–98 and 2001–02 fishing seasons, respectively (Fig. 6B). The seasonal revenue trends for the Upper Keys show that the total seasonal revenues were very different: $31,204 for the 1997–98, and $6324 for the 2001–02 fishing seasons. In the case scenario results for Miami the total seasonal revenues were $31,619 for the 1997–98 fishing season, and $16,422 for the 2001–02 fishing season (Fig. 6C).

Generally, the 2001–02 monthly revenues in each of the regions were indicative of a fishery undergoing significant economic troubles given that revenues after November were insufficient to maintain a viable fishery. This generic condition is clearly due to the low abundance of the resource adopted in this particular

Table 1

Simulated total seasonal revenues in dollars per vessel for the highest (1997–98) and lowest (2001–02) spiny lobster (*Panulirus argus*) stock abundance seasons with catch per unit of effort standardized to the lowest (1991–92) and highest (2001–02) trap fishing seasons observed during the study period in the Florida trap fishery.

		Region				
Abundance	Catchability	Key West	Lower Keys	Middle Keys	Upper Keys	Miami
High	Low	36,298	12,006	26,893	23,635	23,949
High	High	54,920	18,165	40,690	35,761	36,236
Low	Low	7,919	2,132	2,819	4,178	10,851
Low	High	11,985	3,227	4,266	6,324	16,422

scenario, which had distinct effects on the different regions.

Case scenario 2: In this case scenario the catch per trap day per trip for the 1997–98 and 2001–02 fishing seasons were each standardized to the 1991–92 and 2001–02 catching efficiencies. The trap catching efficiencies were estimated as the simple ratio of the corresponding catchability coefficients estimated for each season to those obtained for the 1991–92 and the 2001–02 seasons. The results of the case scenarios are presented in Table 1.

The total revenues in Table 1 are indicative of the significant impact of the TCP on the potential revenues for each region under conditions of the minimum and maximum stock abundance observed during the study period. The greater catching efficiency of the traps, as reflected by the higher 2001–02 catchability coefficient relative to the 1991–92 catchability, generated much larger revenues. In the absence of the TCP those generated revenues are much less than those that created the recent economic hardships in the fishery.

Conclusions

The analyses in this study indicate several very fundamental impacts of the TCP. First, it generated a significant increase in the catching efficiency of the traps used in the fishery. Second, if the TCP had not been implemented, given the significant decrease in the stock abundance observed since the mid-1990s, the fishermen most likely would have encountered much greater economic hardships.

There are many positive consequences of the TCP, the traps are now more efficient because they retain a higher fraction of the fishable stock, and the fishery-wide investment on traps is at least 40% less than during the 1991–92 fishing season. It is important to note, however, that fewer fishermen now participate in the fishery and the number of traps per fisherman appears to have increased. Thus, the trap certificates are allotted among fewer fishermen; hence, the revenue of the resource is now distributed among fewer participants.

The revenues by regions are very different, portraying the economic conditions that differ among the regions. The TCP appears to have benefited the overall economics of the participating fishermen but the decreased stock abundance observed in the last few seasons of the study period has had a profound and different impact on the economics of fishing operations within the regions.

Finally, this assessment demonstrates that the TCP had succeeded with regard to its original objectives. The truly significant problem is the reduction in the stock abundance, which may not only be due to the local exploitation.

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