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IMPACTS OF FLORIDA COASTAL PROTECTED AREAS ON RECREATIONAL WORLD RECORDS FOR SPOTTED SEATROUT, RED DRUM, BLACK DRUM, AND COMMON SNOOK

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ABSTRACT

The present study examines the influence of coastal marine protected areas (MPAs) and statewide fishing regulations on recreational trophy fisheries for four important estuarine game fishes in Florida, where ~59% of the mainland coast consists of MPAs. The distribution of International Game Fish Association (IGFA) recreational world records achieved over 70 years (1939–2009) were correlated with the strength and duration of fishery restrictions in MPAs. No difference in record density was detected between coastal areas inside and outside of MPAs where fishing was managed by statewide regulations. However, 74% (n = 143) of all records for three species were concentrated near the two MPAs that had additional fishery restrictions. The highest concentration was along ~11% of the mainland coast at Cape Canaveral (CAN) near MPAs closed to all fishing since 1962. It included 42% of spotted seatrout [*Cynoscion nebulosus* (Cuvier in Cuvier and Valenciennes, 1830)], 55% of red drum [*Sciaenops ocellatus* (Linnaeus, 1766)], and 69% of black drum [*Pogonias cromis* (Linnaeus, 1766)] Florida records. Everglades National Park (ENP) had the second highest concentration with 7% of spotted seatrout, 32% of red drum, and 24% of black drum records caught along ~9% of the mainland coast. ENP partially limited fishing starting in 1980 by establishing a closed area, daily bag limits, and eliminating commercial fishing. Common snook [*Centropomus undecimalis* (Bloch, 1792)] records did not increase significantly at CAN or ENP. Recreational fishery statistics corroborated IGFA record patterns. Total recreational catch and catch per trip (CPUE) increased significantly for spotted seatrout, red drum, and black drum in northeast and southwest Florida, the two regions with the most protective MPAs, and either declined or were unchanged in the northeast and southeast, which did not have MPAs with fishing restrictions. Both datasets supported predictions of marine reserve theory that MPAs can benefit fisheries by increasing the abundance and size of exploited species. Data did not support other alternative hypotheses proposed to explain record patterns. In conclusion, evidence indicates that Florida coastal estuarine MPAs with fishery restrictions allowed recreational anglers to increase their total catch and CPUE, and achieve more game fish world records than would have occurred if all coastal areas had been regulated by existing statewide fishing regulations.

Worldwide declines in fishery production and marine biodiversity have created interest in establishing marine protected areas (MPAs) to protect ecosystems and control fishing mortality to augment more traditional fishery management measures that restrict capture size and fishing effort (Convention on Biological Diversity 2004). MPAs are defined as areas where resources are given greater and lasting protection than surrounding waters by restricting public access and allowable activities. MPAs are used to achieve a variety of goals, including the protection of specific habitats or species, fishery enhancement, resource allocation, and site security. Restrictions commonly used range from limits on coastal development or fishing gear types, to complete bans on entry, fishing, or removal of organisms. Fishery applications are focused on the optimum mix of fishing regulations and three types of MPAs: MPAs that protect habitat, but allow fishing; MPAs that allow limited fishing; and no-take MPAs, also called no-take reserves (NTRs), that prohibit all fishing and other extraction of living resources (Kellner et al. 2007). Use of NTRs for fisheries has been limited in part due to gaps in knowledge and understanding about when MPAs can best sustain or enhance fishery yield and if NTRs can increase yield sufficiently outside of reserves to compensate for lost fishing area (Sale et al. 2005, Halpern et al. 2009, Goni et al. 2010). To help address these questions, the present study examined influences that fishery regulations and coastal MPAs have on recreational trophy fisheries for four important estuarine game fishes in Florida.

Most MPAs allow some fishing, which makes it difficult to determine how much extraction can be allowed and still protect resources sufficiently to achieve MPA objectives. Measuring fishing effort and yield is difficult and there usually is a lack of replication and treatment controls (Willis et al. 2003, Hilborn 2004, Gaines et al. 2010). Most research has focused on NTRs because they represent a defined upper bound of protection with zero fishing effort and mortality. NTRs perform similarly to other types of fishery regulations by increasing average capture size and reducing fishing mortality (Hastings and Botsford 1999). They potentially can provide long-term fishery benefits by making overfishing more difficult, eliminating bycatch and habitat damage from fishing gear, protecting the genetic quality of stocks from detrimental selective effects of fishing, and accelerating stock recovery after recruitment failures from natural or anthropogenic events (Bohnsack 1998). NTRs can potentially increase total fishery yield from spillover, the migration of adults from reserves to fishing grounds, and by increasing the total reproduction and dispersal of offspring from protected populations in reserves (Watson et al. 2000, National Research Council 2001). Spillover has been documented often near MPAs by tagging studies and by observations of higher catch per trip (CPUE) and changes in community composition near MPA boundaries (Stobart et al. 2009). Most demonstrations of spillover apply to comparatively sedentary temperate and tropical reef fishes (Cole et al. 2000, McClanahan and Mangi 2000, Abesamis and Russ 2005, Alcala et al. 2005, Goni et al. 2008, Forcada et al. 2009) and lobster (Goni et al. 2010). Demonstrating increased reproduction, dispersal, and supply of offspring to fisheries is more difficult, although it is potentially a more important factor than spillover (Pelc et al. 2010).

Previous studies have shown higher species diversity, total abundance, average size, and total biomass of exploited species in NTRs than in comparable fished areas, independent of reserve size or age (Halpern 2003). NTRs have also been shown to provide better resource protection than MPAs that are only partially protected from fishing (Lester and Halpern 2008, Lester et al. 2009). While many studies have reported high densities of exploited species in MPAs, fewer studies have rigorously demonstrated sustained or enhanced fishery yield to the surrounding region (National Research Council 2001, Hilborn 2002, Abesamis and Russ 2005, Alcala et al. 2005, Sale et al. 2005, Goni et al. 2010). Many MPAs are too small to have ecological relevance or are too recently established to have measurable fishery impacts, especially for large or long-lived species (Hilborn 2006). Also, the full potential of MPAs with limited compliance or poor enforcement cannot be fully assessed.

Relatively few studies have examined estuarine MPAs with potentially more mobile species. Collins et al. (2002) concluded that estuarine reserves could potentially increase the survival of juvenile estuarine species and enhance spawning stocks based on tagging studies. Johnson et al. (1999) compared estuarine fish assemblages in unfished areas at Merritt Island National Wildlife Refuge (MINWR), Florida, with adjacent fished areas and found that both areas had a similar total cumulative numbers of species, but that unfished areas had about twice the average diversity (mean number of species per sample) and significantly higher CPUE and densities of older and larger individuals of commercially and recreationally exploited species. Tagging studies have documented both fish egress and ingress between areas closed and open to fishing at MINWR (Johnson et al. 1999, Stevens and Sulak 2001, Tremain et al. 2004). Roberts et al. (2001) credited the MINWR NTRs for high concentrations of world record estuarine game fish caught at Cape Canaveral (CAN), which generated controversy and various alternative explanations to account for those record patterns (Hilborn 2002, Tupper 2002, Roberts et al. 2002, Wickstrum 2002).

The present study uses spatial and temporal patterns of recreational world records and recreational fishery data to assess potential influences of coastal MPAs and statewide fishing regulations on recreational trophy fishing for four important estuarine game fishes in Florida. While previous studies have focused on individual NTRs, the present study examines all Florida mainland coastal MPAs. Most were established to protect habitat and allowed fishing managed by statewide regulations. A few MPAs have more restrictive fishing regulations. NTRs that prohibit all fishing cover 73 km^2, < 0.6% of the aquatic area in mainland coastal MPAs.

Methods

I used International Game Fish Association (IGFA) recreational world records achieved over 70 yrs (1939–2009) as data to assess fishery impacts of coastal management. All world records were achieved by recreational anglers and accepted by IGFA according to rigorous rules (IGFA 2000). The IGFA defines a world record as the heaviest fish landed by species in various line strength classes for conventional and fly fishing categories for men and women. IGFA record keeping began in the 1940s and new line class categories were added over time. Potential line classes for conventional tackle include 1, 2, 3, 4, 6, 8, 10, 15, 24, 37, and 60 kg, and 1, 2, 3, 4, 6, 8, and 10 kg for fly tackle. Official statistics include ties.

Four important estuarine sport fishes in the southeastern United States were selected for study: spotted seatrout [*Cynoscion nebulosus* (Cuvier in Cuvier and Valenciennes, 1830)], red drum [*Sciaenops ocellatus* (Linnaeus, 1766)], black drum [*Pogonias cromis* (Linnaeus, 1766)], and common snook [*Centropomus undecimalis* (Bloch, 1792)]. These species typically live in coastal estuaries as juveniles and migrate as adults to coastal passes or offshore to spawn (Stevens and Sulak 2001, Collins et al. 2002). They are characterized by their high longevity, large body size, and potential mobility and range from Delaware to Florida along the US Atlantic coast and throughout the Gulf of Mexico (Table 1).

Habitat

The present study was restricted to Florida to provide a similar environment and regulatory history for comparisons, and to limit potentially confounding influences of widely different environmental conditions, fishing regulations, and regulatory histories among states. Florida has extensive estuarine sport fisheries that are supported by extensive estuarine habitat scattered along the 933 km of Atlantic and 1240 km of the Gulf of Mexico coasts. Major estuaries on the Gulf of Mexico include Pensacola, Choctawhatchee, St. Andrews, St. Joseph, Apalachicola and Apalachee Bays along the panhandle, and Charlotte Harbor, Ten Thousand

Table 1. Comparison of life history characteristics and geographical distribution of spotted seatrout, red drum, black drum, and common snook. Tag return data are for fishes tagged in marine reserves at Merrit Island National Wildlife Refuge (MINWR), Florida. Geographical range abbreviations: NY is New York, FL is Florida, MA is Massachusetts, SC is South Carolina, and TX is Texas.

Species	Spotted seatrout	Red drum	Black drum	Common snook
Maximum length[1]	91 cm	120 cm	170 cm	120 cm
Maximum weight[1]	7 kg	42 kg	50 kg	23 kg
Longevity[2,3,4,5]	15 yr	35 yr	70 yr	21 yr
Geographical range[1]	NY–FL; Gulf of Mexico	MA–FL–North; Mexico	MA–FL–North; Mexico	SC–TX–Central America; Brazil–Argentina
MINWR				
Total tag returns[2]	n = 14	n = 71	n = 43	n = 56
Percent recaptured[2]	1.5%	5.2%	5.7%	18.4%
Recapture distance[2]				
Mean (km)	10.0 + 2.4	47.6 ± 6.6	44.7 ± 18.2	148 + 12.2
Maximum (km)	20.8	155	326	479

Sources: 1, Robins et al. (1986); 2, Stevens and Sulak (2001); 3, Murphy and Taylor (1994); 4, Murphy and Taylor (1990); 5, Murphy et al. (1998)

Islands, and the San Carlos, Sarasota, Tampa, and Florida Bays along the Florida peninsula. Major Atlantic estuaries include Biscayne Bay, Mosquito and Indian River Lagoons, Pelicer Creek, Tomoka Marsh, and the Banana, Guana, St. John, and Nassau Rivers.

Fishing

Recreational sport fishing is an economically and socially important activity in Florida. In 2008, for instance, about 5.8×10^6 anglers made 28.1×10^6 saltwater fishing trips where they caught 183.2×10^6 fishes, of which 92.2×10^6 were released (NMFS 2010). Florida recreational fishing regulations began in the 1980s and have tended to become more restrictive over time (Appendix 1). Most regulations consist of seasonal closures and creel limits that apply statewide, although regional differences in creel limits have been established for some species in recent years. Major commercial regulations include a ban on the commercial sale of common snook starting in 1957 and red drum in 1989. Commercial netting was banned statewide in 1995.

Coastal Protected Areas

Florida coastal MPAs encompass 100% of the Florida Keys and ~59% of the mainland coast (Fig. 1). The first Florida MPA was established in 1903. By 2009, Florida had 60 MPAs covering ~25,502 km^2. These include 37 state Aquatic Preserves (8742 km^2), three National Estuarine Research Reserves (1683 km^2), 21 National Wildlife Refuges (~2700 km^2), three National Parks (2773 km^2), and the Florida Keys National Marine Sanctuary (9604 km^2). Most coastal mainland MPAs were established between 1967 and 1987 (Fig. 2). The largest, Everglades National Park (ENP), was established in 1947.

Most MPAs regulate fishing by uniform statewide regulations applied throughout Florida (Appendix 1). More restrictive regulations apply to parts of the MINWR at CAN and to ENP. In 1962, two no-entry estuarine NTRs covering 40 km^2 of aquatic habitat were established in MINWR to provide security for the John F Kennedy Space Center at CAN: Banana Creek (16 km^2) and North Banana River (NBR, 24 km^2). Combined they cover ~22% of MINWR aquatic area. The Banana Creek NTR flows into the Indian River and is separated from the North Banana River NTR by a land barrier. The shortest aquatic distance between Banana Creek and NBR is ~85 km south around Merritt Island near Melbourne Beach. The nearest ocean inlets are Ponce de Leon Inlet, 57 km north of Banana Creek, and Sebastian Inlet, 72 km south of NBR. A lock at Port Canaveral intermittently connects the NBR to the Atlantic Ocean. In 1990, the 60 km^2 South Banana River (SBR) was closed to all motorized vessels for manatee protection.

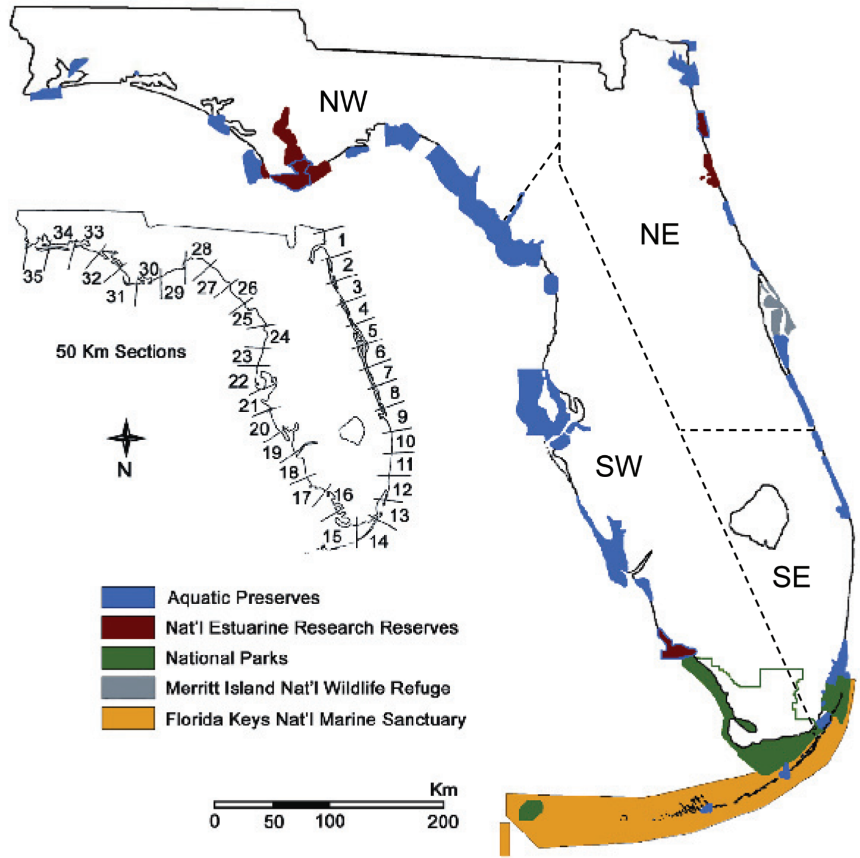

Figure 1. Locations of major state and federal coastal protected areas in Florida. Dotted lines separate post-stratified Marine Recreational Fishing Statistical Survey coastal mainland regions (NW, SW, SE, NE). Insert shows locations of 50-km coastal segments used to analyze record distributions.

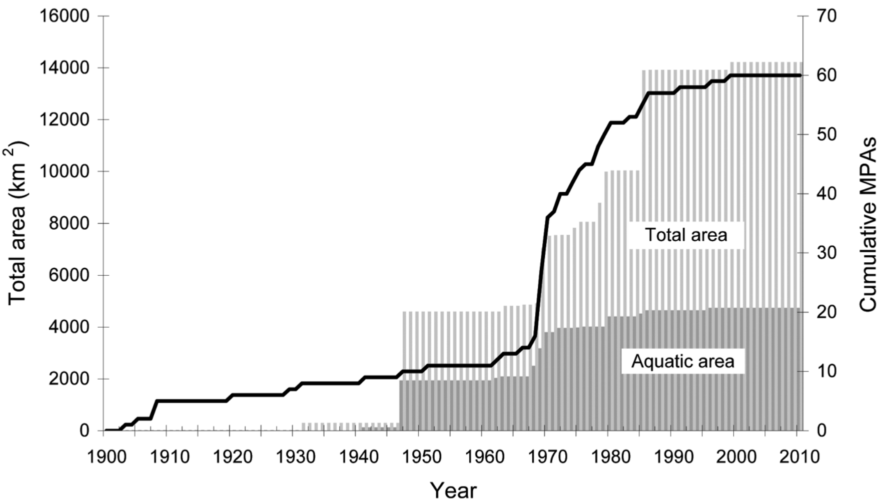

Figure 2. Change in number and total area included in Florida mainland coastal protected areas, excluding the Florida Keys. Data include: 37 Florida aquatic protected areas, three national estuarine reserves, two national parks, and 18 national wildlife refuges. Aquatic area was not available for some sites.

In 1980, ENP established a no-entry NTR as a crocodile sanctuary covering 33 km² of estuarine habitat in northern Florida Bay and initiated daily bag limits of 10 fish per species and 20 fish total for both commercial and recreational fishing, years before creel limits were applied elsewhere in Florida (Tilmant et al. 1989). Most commercial fishing was effectively eliminated by these limits and was banned entirely in 1985, leaving only recreational angling allowed in ~1600 km² of aquatic area.

Data Analyses

Two hypotheses were tested on the fishery benefits of MPAs. A spatial hypothesis predicted high concentrations of world records around MPAs compared to elsewhere and a temporal hypothesis predicted an increased proportional number of records in or near MPAs after their creation, and presumably after a sufficient time lag to allow exploited populations to increase in abundance and average size. Alternative hypotheses predicted that fewer records would occur near NTRs because less area is open to fishing and provides less opportunity to catch a world record, as displaced fishing effort concentrated in remaining fished areas could deplete those stocks (Witek 2002), or because highly mobile estuarine game fish may disperse too quickly to benefit from spatial protection.

Spatial patterns of IGFA world records were examined by mapping all record locations achieved from 1939 through 2009. Catch location for most records was imprecisely reported as a body of water or port (e.g., San Carlos Bay, Flamingo, SBR). Therefore, the mainland coast was divided into 35 segments of 50 km each (Fig. 1) and records were assigned to each segment for analysis to identify locations with significant record concentrations. The Florida Keys were excluded from this analysis of estuarine MPAs because the Keys are marine habitat and no records occurred beyond Florida Bay. For numerical analysis, records listed only as "Indian River" (two spotted seatrout, seven red drum, one black drum, two snook) were assigned to the 50-km segments along the 220-km Indian River Lagoon in proportion to known record locations for each species.

Florida coastal MPAs were classified into four categories based on their potential fishery impacts: areas managed solely by statewide fishing regulations (~41% of the coast); areas designated as state or federal MPAs managed for habitat protection or other purposes with fishing managed by statewide fishing regulations (~50% of the coast); MPAs with more restrictive fishing regulations (i.e., ENP limited to recreational fishing only); and MPAs closed to all entry and fishing (NTRs at MINWR and ENP). The null hypothesis of no difference in numbers of records observed in segments with or without MPAs was tested for the three species distributed throughout Florida by regressing numbers of records per 50-km coastal segment on the linear portion of each segment included in MPAs. A significant positive relationship would show beneficial influence of MPAs. Because common snook records were confined to southern Florida, they were excluded from this analysis.

Temporal trends were examined by species for locations with significant record densities to determine if proportional changes in composition occurred over time. Proportional changes were examined by dividing numbers of records for each species into consecutive decadal periods for analysis. Data for decades with < 10 total records were combined with consecutive decades to ensure at least 10 observations were available to analyze proportional changes in spatial occurrence. Spatial changes in proportion of records were analyzed using the Bonferroni procedure with the experimental error rate held at 0.05 (Miller 1981). Regional changes in individual record weights over time were also compared by area for each species.

Fishery influences were examined using data available through 2009 for commercial and recreational fisheries. The Marine Recreational Fishing Statistical Survey (MRFSS) has provided statistical estimates of recreational catch and effort (trips) for Florida's Atlantic and Gulf of Mexico coasts since 1981 (US Dept of Commerce 2010a). Recreational fishing trends were examined by comparing the standardized number of trips and anglers per km of coastline for the east and west Florida coast. To provide smaller spatial resolution, MRFSS data were post-stratified into five standard Florida regions: northeast (NE, Nassau to Brevard County; segments 1–7 in Figs. 1, 3), southeast peninsula (SE, Indian River to Miami-Dade County; segments 8–13), southwest peninsula (SW, ENP and Collier to Levy County; segments 14–25), northwest panhandle (NW, Dixie to Escambia County; segments 26–35), and the Florida Keys (Monroe County; Figs. 1, 3). Catches of target species in the Keys were inconsequential and excluded from catch analysis. Numbers of county pleasure boat registrations also were examined as a potential index of fishing effort on a smaller spatial scale. A correlation between pleasure boat registrations and regional estimates of total fishing trips was used to estimate the number of fishing trips for CAN (Brevard and Volusia Counties) in the NE region. This approach could not be applied to ENP in the SW region because fishing access to ENP was more complicated with possible access points in Miami-Dade County (SE region), the Florida Keys, and Collier County (SW). Florida fishing licenses could not be used to estimate fishing effort because they were not necessarily registered by county.

As a final step, multiple alternative hypotheses proposed to explain observed record patterns were evaluated using the same local and statewide spatial and temporal criteria used to assess MPAs.

Results

Spatial Patterns

Florida achieved 278 world records from 1939 through 2009, including 72 of the 100 total IGFA records for spotted seatrout, 74 of 169 for red drum, 46 of 104 for black drum, and 86 of 108 for common snook (Fig. 3). A plot of total records per 50-km coastal segment (Fig. 4) shows that 74.4% of all 192 records for spotted seatrout, red drum, and black drum were caught along ~20% of Florida mainland coast at either CAN or ENP. The highest density of records for black drum (69%), red drum (55%), and spotted seatrout (42%) were caught along 11% of the mainland coast (200 km) at CAN, within 100 km of the boundary between MINWR NTRs (Table 2, Fig. 4). ENP extends ~150 km from eastern Florida Bay to Everglades City, ~9% of the mainland

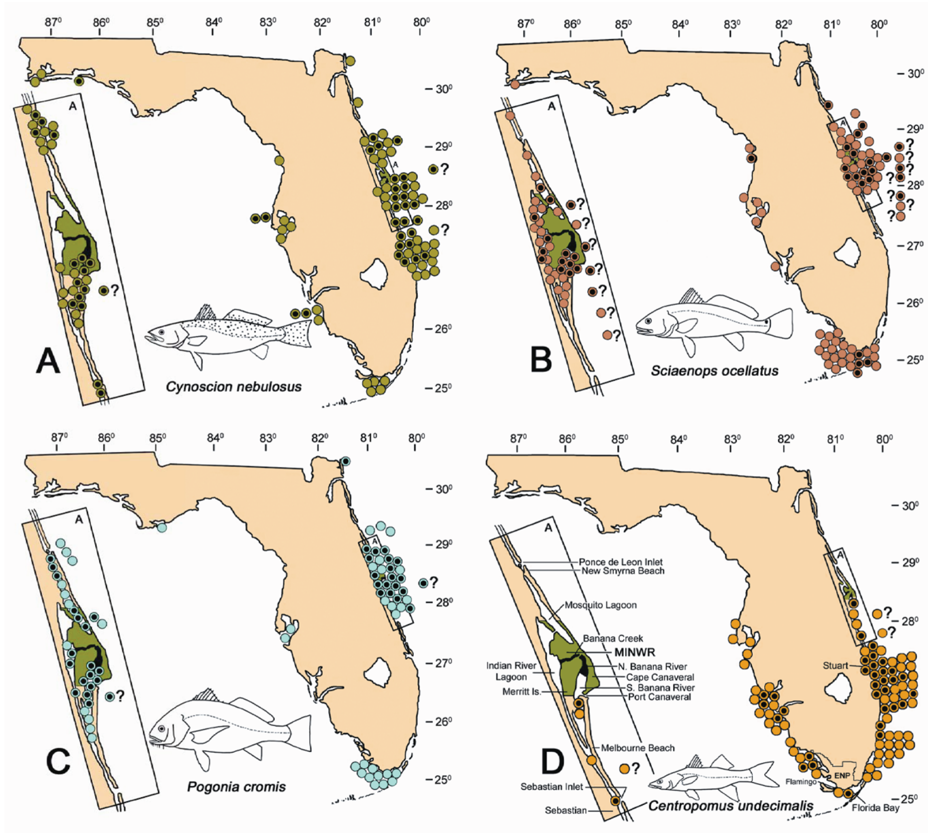

Figure 3. Distribution of International Game Fish Association (IGFA) world records in Florida for (A) spotted seatrout, (B) red drum, (C) black drum, (D) and common snook (1939–2009). Circles with black centers represent the largest fish in an IGFA record category. Question marks indicate records reported only as "Indian River" with an unspecified location. Inserts on the left show an expanded map of the Merritt Island National Wildlife Refuge and the Cape Canaveral area, ~100 km from the separation of Banana Creek and the North Banana River. Names of key locations are shown in Figure D.

Table 2. Total numbers and percentage of International Game Fish Association world records in Florida by region (1939–2009).

	Spotted seatrout	Red drum	Black drum	Common snook
Cape Canaveral	31 (44%)	41 (55%)	31 (67%)	4 (5%)
Everglades National Park	5 (7%)	24 (32%)	11 (24%)	7 (8%)
Other Florida locations	36 (49%)	9 (12%)	4 (9%)	75 (87%)
Total records	72	74	46	86

coast. It had the second highest total record density for red drum (32%), black drum (24%), and spotted seatrout (7%; Table 2, Fig. 4). The remaining Florida records (n = 49, 25.5%) were widely scattered from other Florida locations along ~1400 km (80%) of coastline (Table 2). All 86 common snook records came from southern Florida and were mostly caught near inlets south of Tampa on the west coast (24%) or south of CAN on the east coast (63%). ENP accounted for (8%) and CAN (5%; Fig. 4).

Influence of MPAs

A plot of total records per 50-km coastal segment against the proportion of coast included in MPAs showed that most (119 of 192) records for spotted seatrout, red drum, and black drum came from four segments in the two regions with the most restrictive fishing regulations (CAN and ENP, Fig. 5). No relationship was found between total numbers of records and the proportion of the coast included in MPAs managed by statewide fishing regulations (slope = 0.01, $r^2 = 0.008$, $P > 0.05$). Therefore, I could not reject the null hypothesis that no difference existed in record density for coastal segments managed by statewide fishing regulations, irrespective of MPAs presence.

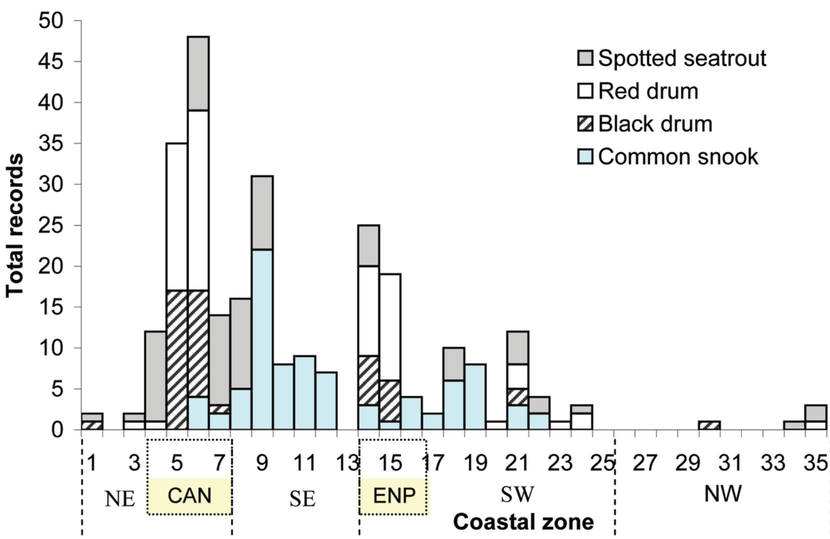

Figure 4. Distribution of Florida International Game Fish Association (IGFA) world records by 50-km coastal segment for spotted seatrout, red drum, black drum, and common snook. Segment locations are shown in Figure 1. Segments 4–7 represent Cape Canaveral (CAN) and 14–16 represent Everglades National Park (ENP). Marine Recreational Fishing Statistical Survey post-stratified regions shown include the NE (segments 1–7), SE (8–13), SW (14–25), and NW (26–35).

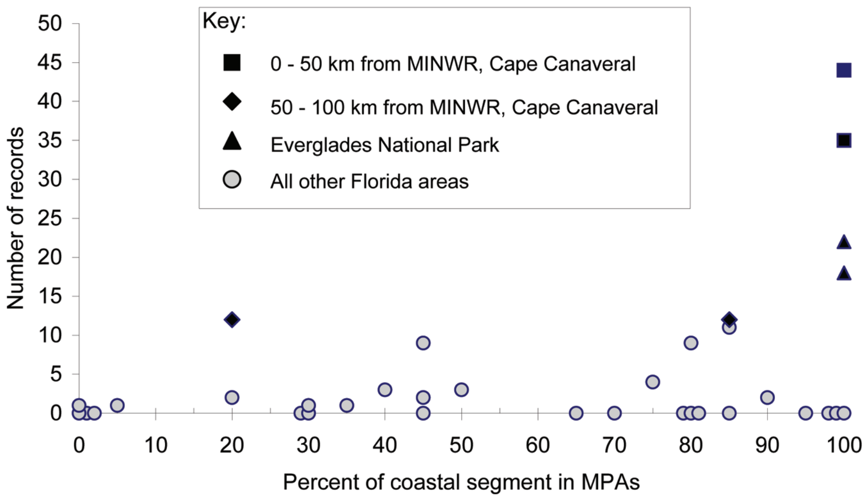

Figure 5. The relationships between International Game Fish Association (IGFA) records in 50-km coastal segments and the proportion of the segment included in designated coastal protected areas. Coastal segments delineated as Cape Canaveral records < 50 km from Merritt Island National Wildlife Refuge (MINWR), Cape Canaveral records between 50 and 100 km from MINWR, Everglades National Park, and all other Florida areas. Segment locations shown in Figure 1.

Temporal Trends

World record numbers for all four species increased slowly for several decades before increasing sharply following the introduction of new IGFA line classes and ENP management measures in 1980 (Fig. 6). After 1985, record numbers continued to increase for red drum and black drum at CAN and for spotted seatrout and common snook from other Florida areas. Record growth slowed considerably from 2000–2009, reflecting the difficulty of achieving new records in established line classes. The last record was in 2007. Among the last 24 records achieved, 12 came from CAN (five red drum, seven black drum), three from ENP (two red drum, one common snook), and the remainder were spotted seatrout caught elsewhere. One angler had four spotted seatrout records in the SW near Ft. Myers, another had two records at Palm Harbor (peninsula Gulf coast), one came from the panhandle, and one from Ft. Pierce on the Atlantic coast. Nine of the records displaced previous records in six line classes and 15 were in 11 vacant line classes; 19 were caught by women; 20 were caught by fly fishing; and four people caught 19 of the 24 total records. Both common snook records were landed by women on fly tackle vacant in categories. These results indicate a tendency for successful anglers to target specific record categories in recent years.

The temporal hypothesis required demonstrating a proportional increase of world records near MPAs after their establishment. After MINWR NTRs were established in 1962, CAN accounted for 45% of the 72 Florida spotted seatrout records, 55% of the 76 red drum records, and 68% of the 46 black drum records. CAN had one of the 10 spotted seatrout records in Florida before 1972 and 31 of 62 records after that (Fig. 6A). Red drum and black drum records also increased sharply from 1990 to 2000 for red drum (Fig. 6B) and from 1990 to 2004 for black drum (Fig. 6C). All 27 black drum records achieved after 1985 came from CAN. Overall, ENP had an

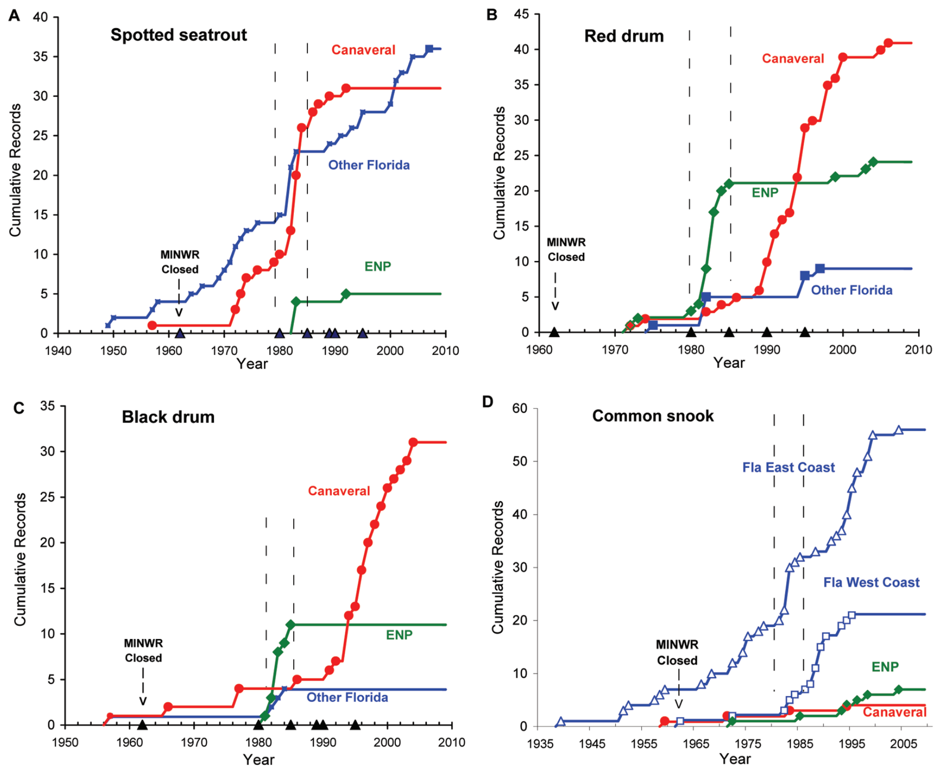

Figure 6. Cumulative trends in Florida world records for (A) spotted seatrout (n = 72), (B) red drum (n = 74), (C) black drum (n = 46), and (D) common snook (n = 86). Cape Canaveral extends ~200 km, Everglades National Park (ENP) ~150 km, and all other Florida coastal locations ~1,250 km. Vertical dashed lines show the period of rapid world record increases (1980–1985) following the addition of new International Game Fish Association line classes. Triangles mark key events by year: areas closed to fishing in Merritt Island National Wildlife Refuge (1962); commercial fishing banned in ENP (1985); daily bag limits established in ENP (1980); first state-wide fishing regulations for red drum (1985), spotted seatrout (1989), black drum (1989); South Banana River closed to motorized vessels (1990); state-wide commercial net ban (1995).

intermediate number of records for red drum and black drum compared to CAN and other Florida locations (Fig. 6). All 11 black drum records and 21 of 24 red drum records at ENP were achieved between 1980 and 1985. Proportion changes in record numbers were significant at CAN and ENP (t-test: $P < 0.05$, Fig. 7). Proportions increased significantly at CAN for spotted seatrout in the 1980s and for red drum and black drum in the 1990s (t-test: $P < 0.05$; Fig. 7A,C,E), and declined significantly for spotted seatrout at CAN in the 1990s (t-test: $P < 0.05$). In contrast, proportional increases from ENP were only detected for spotted seatrout at ENP in the 1980s (t-test: $P < 0.05$, Fig. 7B) and significant declines occurred for red drum and black drum in the 1990s (t-test: $P < 0.05$; Fig. 7D,F).

Weight Comparisons

Plots of individual record weights by location over time show the rapid accumulation of records following the introduction of new IGFA line classes and ENP creel limits in 1980 for spotted seatrout, red drum, and black drum (Fig. 8). In the 1980s ENP records were small fish caught in newly established line classes, all of which were later replaced by larger fish from CAN. By 2009, CAN had the largest records in 17 of 31 total line classes for spotted seatrout, 18 of 41 for red drum, and 17 of 31 for black drum. In comparison, ENP had none of the largest records in 13 of 36 line classes for spotted seatrout, three of 24 for red drum, and 11 for black drum. Other Florida locations followed with zero of five for spotted seatrout, two of nine for red drum, and one of four for black drum. Seven of eight new spotted seatrout records caught after 1999 were small fish (mean = 1.04 kg, range 0.45–1.6 kg; n = 7) caught in previously vacant line classes (Fig. 8A). One large, 5.2 kg spotted seatrout from Ft. Pierce displaced an existing 6 kg line class fly fishing record.

Mean record weights for spotted seatrout, red drum, and black drum were significantly larger (t-test: $P < 0.05$) at CAN than ENP, while mean red drum and black drum weights were not significantly different between ENP and other Florida locations (Fig. 9). Spotted seatrout weights were similar for CAN and the Florida east coast and similar for ENP and the west coast, but sizes were significantly larger (t-test: $P < 0.05$) for the Atlantic vs the Gulf coast.

Fishing

Recreational fisheries accounted for most (82%–100%) of the 1981–2009 mean total annual landings of 3.625×10^6 kg for spotted seatrout, red drum, black drum, and common snook (Table 3A). Recreational landings were about equally divided between coasts for black drum (47% E, 53% W) and common snook (45% E, 50% W), but were much higher on the west coast for red drum (74% W, 26% E) and spotted seatrout (85% W, 16% E). Landings, however, accounted for a small portion of the total recreational catch for these regulated species. Anglers, for example, retained 15% and released 85% of their total catch of red drum and kept 13% and released 87% of black drum (Table 3B). Partly for this reason, total catch and number of fishes were used to evaluate recreational fishing instead of total landings and weight, which are used to evaluate commercial fisheries. Also, total catch numbers are commonly used by anglers to measure success, and unlike landings or weight, better reflect catch-and-release fishing and potential release survival and mortality.

Recreational fishing effort in terms of density of recreational anglers and total fishing trips was similar between the Florida Gulf and Atlantic coasts within years, despite geographical and habitat differences (Fig. 10). From 1981 to 2009, total fishing

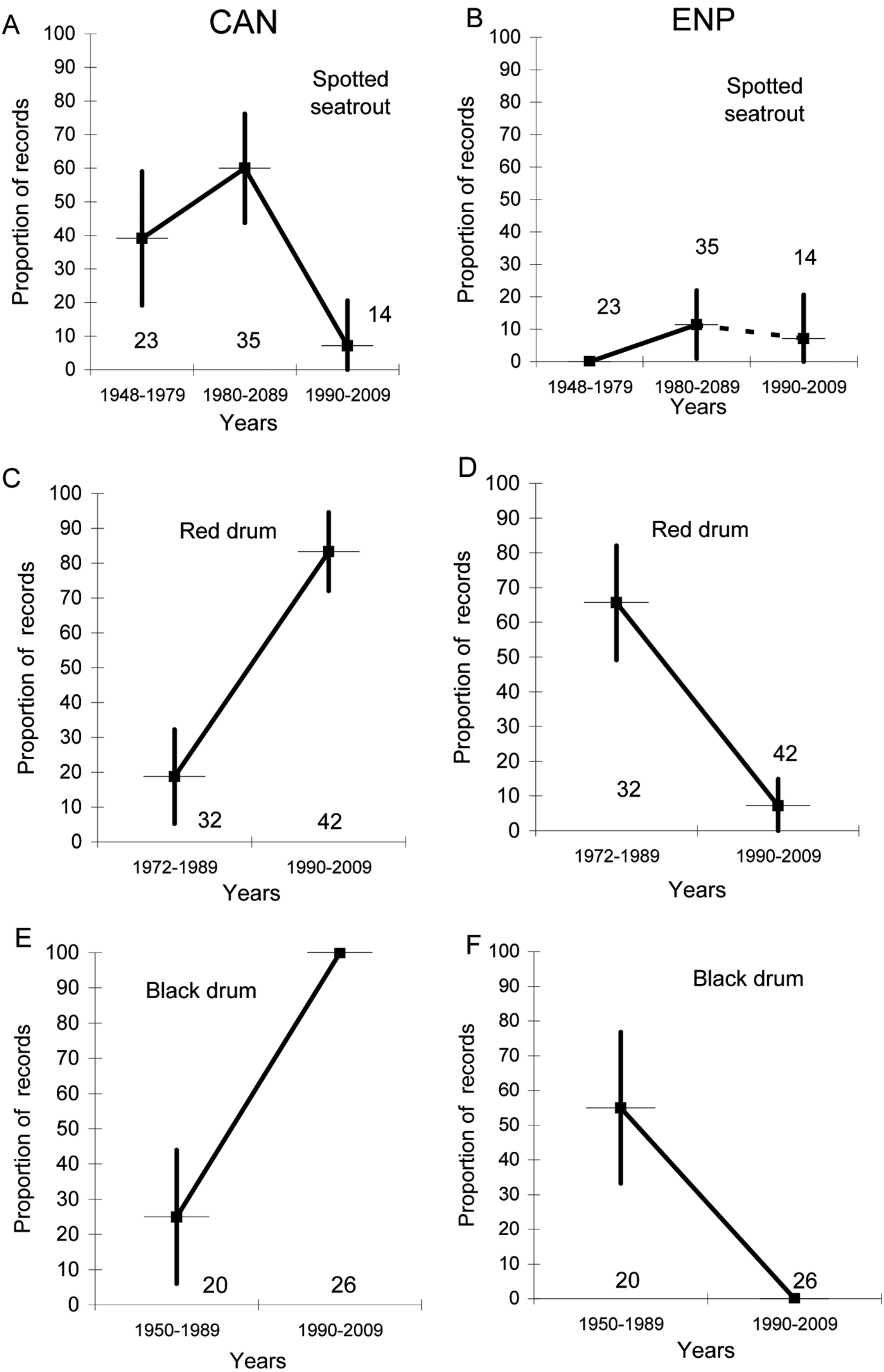

Figure 7. Mean proportion of world records (± 95% CI) for (A,B) spotted seatrout, (C,D) red drum, and (E,F) black drum over decadal periods from the Cape Canaveral (CAN, left) and Everglades National Park (ENP, right). Solid lines between periods indicate significant (t-test: $P < 0.05$) proportional changes; dashed lines indicate no significant differences. Numbers show total records achieved during time intervals. Data from decades with fewer than 10 total records were combined with sequential decades for analysis.

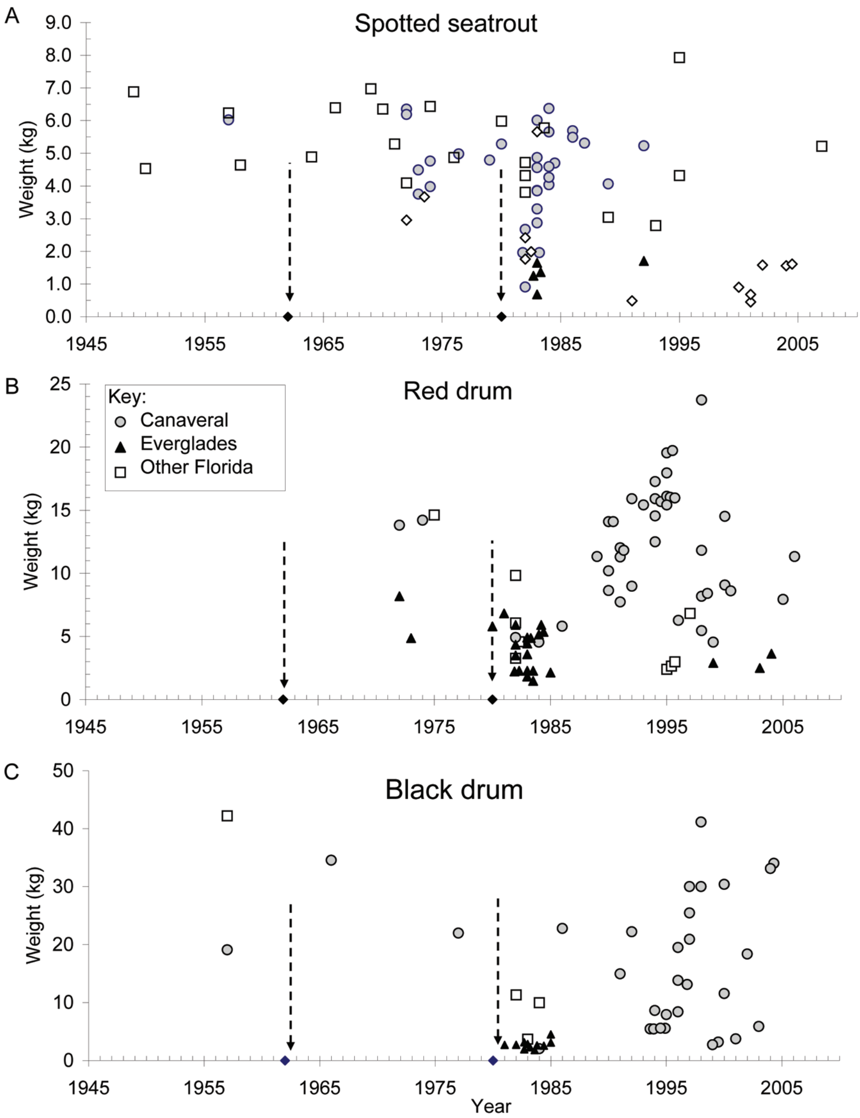

Figure 8. Individual world record weights by region for (A) spotted seatrout, (B) red drum, and (C) black drum. Vertical dashed lines mark the establishment of no-take MPAs at Cape Canaveral in 1962 and enhanced fishing restrictions in Everglades National Park in 1980.

trips increased 50% on the Gulf coast and 60% on the Atlantic coast, while angler density increased 37% and 35%, respectively. An annual mean of 4.15×10^6 mainland fishing trips were taken from 1981 through 2009; 41% were in the SW, 23% were in both the SE and NE, and 13% were in the NW (Table 4). Estimated total annual fishing trips increased in the SE and SW, declined in the Florida Keys, and varied without trend in the NE and NW (Fig. 11). Mean number of regional fishing trips was significantly correlated with total pleasure boat registrations (t-test: $r^2 = 0.88$, $P < 0.05$, $n = 5$; Fig. 12). Therefore, because CAN (Brevard and Volusia Counties) consistently accounted for 52.0% (range 48.1%–55.2%) of the total pleasure boat registrations in the

Table 3. Mean annual recreational and commercial fishery statistics for Florida.

A. Mean annual total Florida landings (kg, 1981–2009). Source: Marine Recreational Fisheries Statistics Survey (US Department of Commerce 2010a).

	Spotted seatrout	%	Red drum	%	Black drum	%	Common snook	%
Total landings	2,046,401		899,994		450,648		227,904	
Recreational[3]	1,677,811	82%	899,994	100%	376,093	83%	227,904	100%
Commercial[4]	368,589	18%	na[1]	–	74,554	17%	na[2]	–
Distribution (%)								
Recreational								
East coast		16%		26%		47%		45%
West coast		84%		74%		53%		55%
Commercial								
East coast		25%		na[1]		20%		na[2]
West coast		75%		na[1]		80%		na[2]

B. Mean annual recreational catch and disposition in numbers (1981–2008). Source: US Department of Commerce (2010b).

	Total catch	Retained (%)	Released (%)
Red drum	3,359,900	514,700 (15%)	2,845,200 (85%)
Spotted seatrout	13,773,000	1,821,600 (13%)	11,951,400 (87%)

1 Commercial fisheries were closed for red drum in 1986.
2 Commercial fisheries were closed for common snook in 1957.
3 Available from: http://www.st.nmfs.noaa.gov/pls/webpls/MR_CATCH_TIME_SERIES. Accessed November 2010.
4 Commercial landings available at: http://www.st.nmfs.noaa.gov/st1/commercial/landings/annual_landings.html

NE, CAN also probably accounted for at least half of the total NE fishing trips. Since 1964, the average annual growth in pleasure boat registrations was 5.0% for Florida, 4.9% for CAN, and 2.8% for urbanized Miami-Dade County (Fig. 13). Miami-Dade had more registered boats than CAN in 1964, and by 1998, CAN boat registrations surpassed those in Miami-Dade County (Fig. 13).

Total recreational catch, fishing effort (boat registrations and number of fishing trips), and catch composition were compared for coastal counties in the five MRFSS Florida regions (Table 4). Mean total catch increased substantially for all four species in the NE and for three species in the SW. Spotted seatrout dominated the total catch numbers among species. Regionally, the SW dominated total catch for spotted seatrout, red drum, and common snook, and the NE had the highest proportion of the total black drum catch. Total catch and CPUE of black drum increased substantially only in the NE and declined or was stable in other regions (Fig. 14E,F). Red drum catch increased in the SW and NE, and CPUE increased in the NE, SW, and NW (Fig. 14C,D). Common snook catch and CPUE increased substantially in all regions except the NW (Fig. 14G,H). Spotted seatrout total catch increased in the SW and NE, and declined in the NW, while CPUE declined in all three regions (Fig. 14A,B).

No significant correlations were found between the percent of IGFA world records achieved in a region and either the total percentage of recreational catch or total fishing trips (Fig. 15). The SW, for example, accounted for most of the recreational catch but had relatively few world records for spotted seatrout (62% vs 22%), red drum (59%

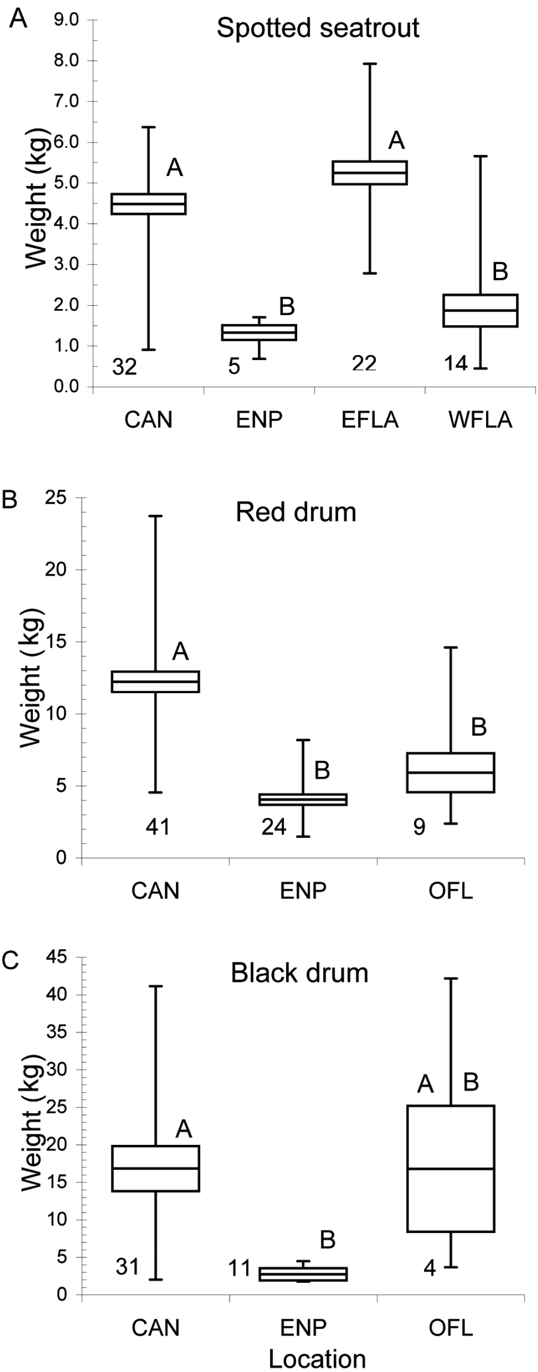

Figure 9. Mean weights of International Game Fish Association world records for (A) spotted seatrout, (B) red drum, and (C) black drum by region: Cape Canaveral (CAN), Everglades National Park (ENP), eastern Florida (EFLA), western Florida (WFLA), and other Florida areas (OFL). Boxes show ± 1 SE; vertical bars show ranges; and numbers show sample sizes. Different letters indicate significant differences in mean weights.

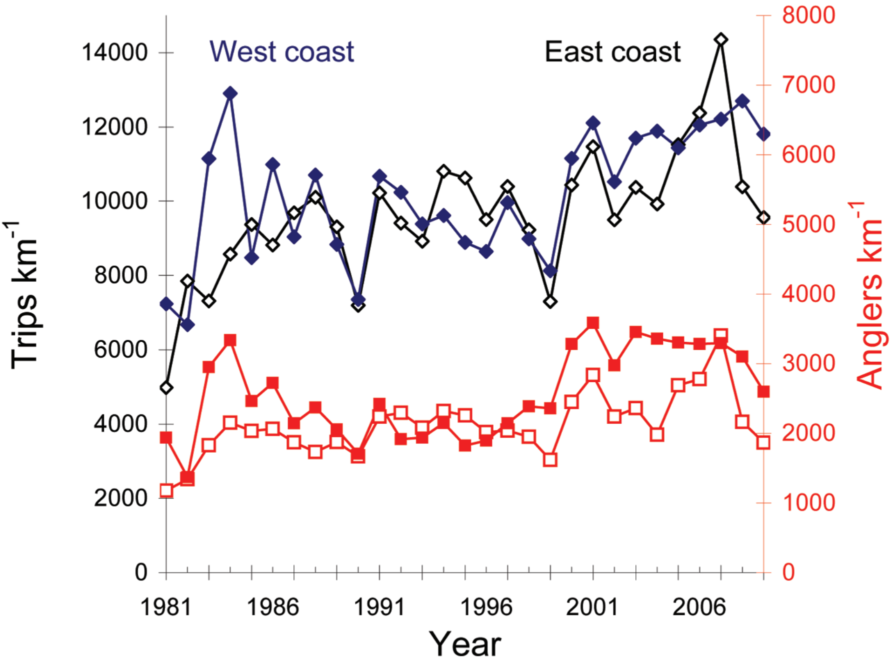

Figure 10. Florida annual standardized recreational fishing effort (1981–2009). Total trips per km of coast (diamonds, left axis) and total anglers per km (squares, right axis) for the Florida east (solid markers) and west coasts (open markers). Data source: US Dept of Commerce 2010a.

vs 42%), and common snook (71% vs 33%). In contrast, the two east coast regions represented small percentages of the total catch, but accounted for high percentages of total records for all four species. The NE, for example, had 25% of the total catch and 57% of the total records for red drum, 12% vs 47% for spotted seatrout, and 46% vs 67% for black drum. The SE had the largest disparity with 3% of the catch and 26% of records for spotted seatrout. Likewise, regional percentages of world records were not significantly correlated with number of fishing trips ($r^2 = 0.6577$ spotted seatrout, 0.6534 red drum, 0.4523 black drum, 0.5752 common snook; $n = 5$; t-test: $P > 0.05$).

A comparison of cumulative records in original and newer IGFA line classes show the difficulty of achieving new records over time (Fig. 16). Out of 220 total new records achieved after 1980, 11 records were obtained in original line classes with previously existing records, while 209 records were established in the newer line classes. In both cases, the number of new records slowed greatly after 2000.

Alternative Hypotheses

Alternative factors proposed to account for record patterns near NTRs were evaluated in terms of their local or statewide application and on their potential to influence record patterns (Table 5).

Local Factors at CAN.—Landlocked Reproductive Populations.—MINWR is unique in having the only known nearly landlocked reproductive populations of red and black drum in Florida (Johnson and Funicelli 1991, Reyier and Shenker 2007).

Table 4. Regional distribution of mean annual recreational fishing trips[1], pleasure boat registrations[2], and percentage of the total catch[1] for spotted seatrout, red drum, black drum, and common snook in Florida (1981–2009).

		Florida region					
	Mean number	NW	SW	Keys	SE	NE	Total
Pleasure boat registrations	415,170	13%	37%	3%	29%	17%	100%
Recreational fishing trips	702,847,647	13%	39%	5%	22%	22%	100%
Total catch (MRFSS ab1, b2)	14,946,162	19%	62%	0%	4%	15%	100%
Spotted seatrout	10,831,770	14%	59%	0%	1%	25%	100%
Red drum	2,480,290	0%	71%	0%	21%	7%	100%
Black drum	434,501	10%	34%	0%	9%	46%	100%
Common snook	1,199,601	23%	62%	0%	3%	12%	100%

Source: 1, Marine Recreational Fishing Statistical Survey (MRFSS) post-stratified data (SEFSC, NMFS); 2, Florida Department of Highway Safety and Motor Vehicles 2011.

Any reproductive isolation, however, was a preexisting factor that existed throughout the study and cannot explain the observed record patterns at CAN alone. Because fishing is size selective and total individual fecundity is an exponential function of fish size, local retention of offspring would have much less influence in areas with intense fishing or depleted populations compared to NTRs with a high abundance of large individuals that can interact synergistically to increase total fecundity and total abundance (Cudney-Bueno et al. 2009).

Unique Habitat at CAN.—The Canaveral lagoon complex is highly productive and had been intensively fished as early as the 1950s (Anderson and Gehringer 1965). Other Florida estuaries are also highly productive and heavily fished, but did not show similar record trends. CAN has no unique habitats that could explain world record patterns. Johnson et al. (1999) showed that similar habitats existed within and outside of MINWR NTRs and concluded that fishing was the primary factor explaining the density differences of exploited species. The one unique factor at CAN compared to other Florida estuaries is the long-term presence of highly enforced NTRs.

Increased Habitat Productivity at CAN.—No evidence was found to show that productivity increased at CAN during the study. Conversely, habitat productivity may have declined due to seagrass loss and reduced water quality (Gilmore 1995).

Expansion of Sport Fishing to Lightly Exploited CAN Stocks.—The possibility that stocks were lightly exploited at CAN prior to 1962 is contradicted by fishery data showing heavy recreational and commercial exploitation at CAN before NTRs were created. Anderson and Gehringer (1965) documented CAN fisheries from 1959 to 1962. On average, 628 commercial fishers landed 2.7×10^6 kg annually compared to an average of 764,000 sport fishers who fished about 2.7×10^6 hrs annually and landed 1.47×10^6 kg (~3.09×10^6 fish). Two-thirds of the total annual landings of 680,000 kg of spotted seatrout were caught by recreational anglers. Also, recreational fishing data showed that the trend in total numbers of recreational fishing trips was unchanged since 1981 in the NE region (Fig. 11).

SBR Closed to Motorized Vessels (1990).—The 60 km^2 SBR no motor zone established in 1990 was confluent with the North Banana River NTR and potentially influenced world record increases after 1990. Although fishing was still allowed in the

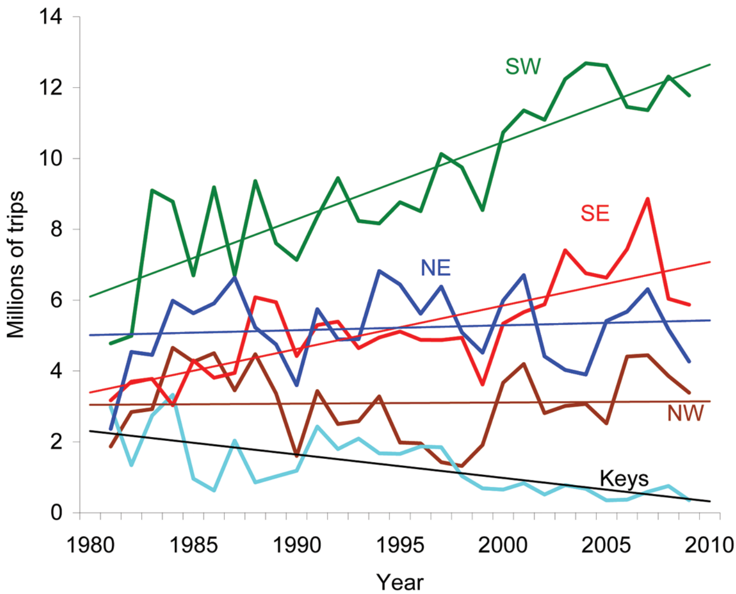

Figure 11. Changes in total number of Florida coastal fishing trips by region (1981–2009). Lines show linear fits. Regions are shown in Figre 1. Data sources: Marine Recreational Fishing Statistical Survey post-stratified data.

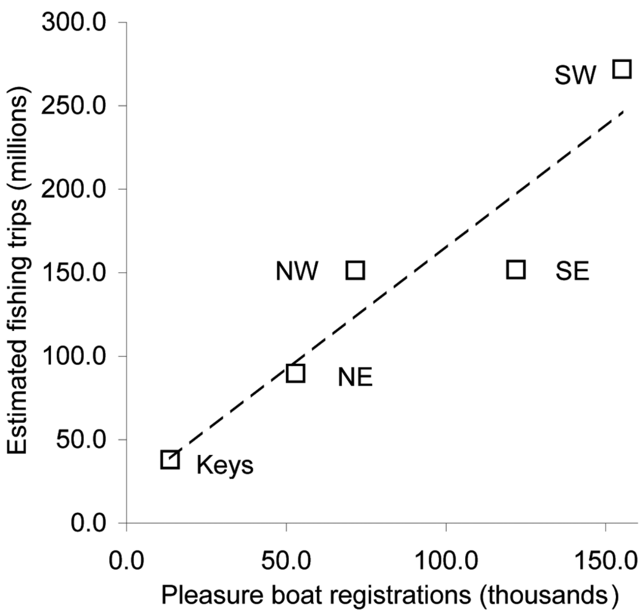

Figure 12. Correlation ($r^2 = 0.88$, $P < 0.05$) between total fishing trips and pleasure boat registrations for Florida regions.

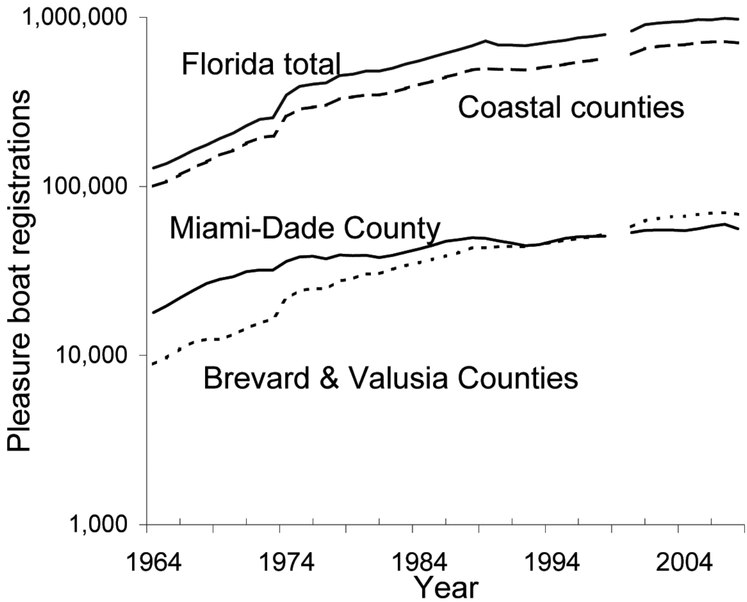

Figure 13. Florida pleasure boat registrations (1964–2007) showing trends for all of Florida, all coastal counties, Miami-Dade County, and Brevard and Volusia Counties combined. Sources: Florida Statistical Abstract series 2010; Florida Department of Highway Safety and Motor Vehicles 2010.

SBR, fishing access was much more difficult and undoubtedly reduced total fishing mortality in the SBR. Fish migrating from the NBR to the SBR had a better chance of surviving, growing, and reproducing before being caught. The sharp increase in red and black drum records at CAN after 1990 is consistent with this possibility.

Local Factors at ENP.—ENP Daily Creel Limits (1980).—Daily bag limits had a potential direct influence on total records by lowering recreational fishing mortality and effectively eliminating most commercial fishing as an economically viable activity in ENP. The large number of new records from ENP in the early 1980s occurred during this time.

ENP Crocodile Sanctuary (1980).—This NTR reduced fishing mortality in ENP, but its impacts on records cannot be determined, because no studies are available to show population responses inside the crocodile reserve for the four game fishes examined in the present study. Mangrove surveys have shown, however, that grey snapper [*Lutjanus griseus* (Linnaeus, 1758)] were significantly larger in the NTR than outside (Faunce et al. 2002). Because this NTR was created in 1980, it was unlikely to have influenced ENP records in the short term between 1980 and 1985.

ENP Commercial Fishing Ban (1985).—This ban formalized the recreational fishing-only status of ENP, but probably was not an important factor in this study because most commercial fishing had already been effectively eliminated for economic reasons by the daily creel limits applied to all fishing in 1980.

Statewide Factors.—New IGFA Line Classes (~1980).—New IGFA line classes created new opportunities and led to many new records in Florida (Fig. 16), but they

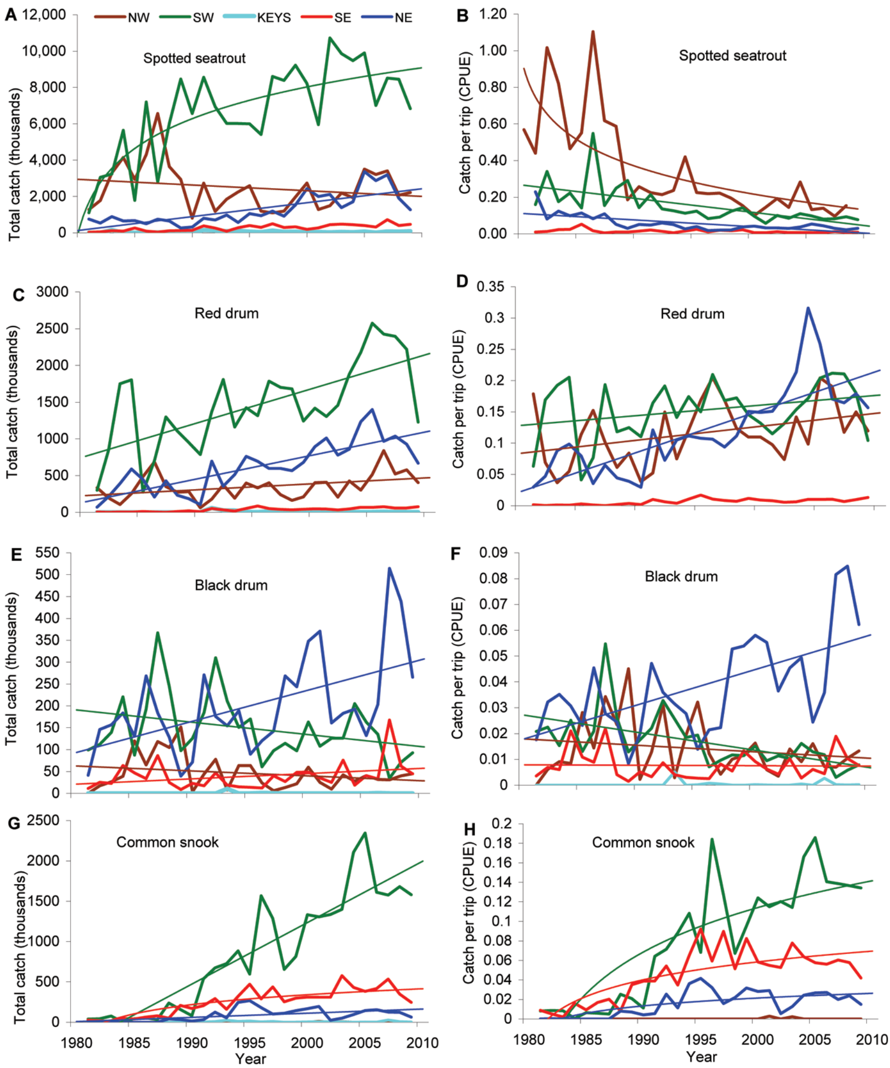

Figure 14. Regional changes and trends (fitted lines) in total catch (left column) and catch per trip (CPUE, right column) for (A and B, respectively) spotted seatrout, (C,D) red drum, (E,F) black drum, and (G,H) common snook (1981–2009). Regions are shown in Figure 1. Data source: Marine Recreational Fishing Statistical Survey type a, b_1, and b_2.

do not explain the concentrations of records from particular areas. Although new records could have come from anywhere in Florida, the vast majority was caught near highly protected MPAs at ENP and CAN. As described earlier, 89% (34 of 38) of the new Florida records established between 1980 and 1985 were landed in ENP. Anglers may have targeted ENP as a desirable area to obtain new records because of its accessibility to Miami, its reputation, or because new fishing regulations favored recreational angling. All records caught in ENP before 1985, however, were replaced by larger records caught at CAN. This drop in records from ENP has been attributed

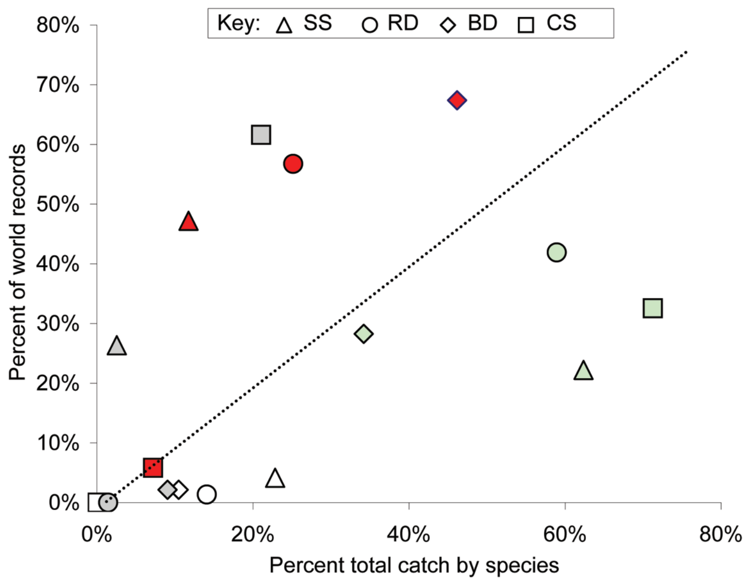

Figure 15. Percentages of Florida world records vs total catch by region for spotted seatrout (SS, triangle), red drum (RD, circle), black drum (BD, diamond), and common snook (CS, square). Correlation not significant (t-test: $r^2 = 0.2122$, $P > 0.05$). Dotted line indicates equivalent percentages of catch and records. Points at the lower right show a higher percentage of catch than records and points at the upper left show the opposite. Key to regional symbols: NW (open), SW (light fill), SE (medium fill), and NE (dark fill).

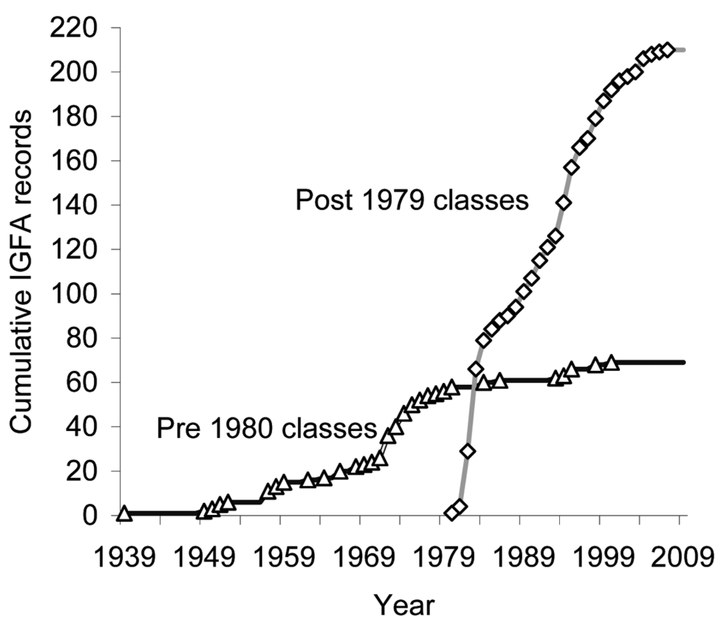

Figure 16. Cumulative number of world records achieved in Florida for International Game Fish Association (IGFA) line classes established before and after 1980.

Table 5. Comparison of factors proposed to explain concentrations of gamefish world records at Cape Canaveral (CAN) and Everglades National Park (ENP). Primary factors occured in the right place and time to be directly influential. Indirect factors are not sufficient to explain patterns alone but could indirectly contribute to records by interacting with other factors. MINWR is Merritt Island National Wildlife Refuge, IGFA is International Game Fish Association, NTR is no-take reserve.

		Spatial test		Temporal test		
Proposed factor	Date	Location	Unique to location?	Occurred at appropriate time?	Influence	Source
Partially landlocked reproductive populations	Preexisting	CAN	Yes	Yes	Primay (CAN)	2, 5
Unique habitat at CAN	Preexisting	CAN	No	No	No	4, 8
Established 40 km^2 MINWR no-take reserves	1962	CAN	Yes	Yes	Primay (CAN)	3, 6
Expansion of IGFA world record line classes	1980	Statewide	No	Yes	Indirect	8
ENP daily commercial and recreational bag limits	1980	ENP	Yes	Yes	Primary (ENP)	1
ENP 33 km^2 crocodile sanctury NTR	1980	ENP	Yes	Yes	Primary (ENP)	1
ENP prohibited all commercial fishing	1985	ENP	Yes	No	No	8
First Florida fishing regulations (Creel and size limits)	Continuous					
spotted seatrout	Nov 1989					
red drum	Sept 1985	Statewide	No	Yes	Indirect	4, 7, 8
black drum	July 1989					
common snook	July 1985					
Established 60 km^2 So. Banana River no motor zone in 1990	1990	CAN	Yes	Yes	Primary (CAN)	3
Promotional prize money offered for largest fish	1994	Statewide	No	Yes	No	8
Statewide commercial net fishing ban	1995	Statewide	No	No	No	4, 8
Increased habitat productivity at CAN	After 1962	CAN	No	No	No	
Sport fishing expanded to a lightly exploited CAN stocks	After 1962	CAN	No	No	No	10
Growth of recreational angling	Continuous	Statewide	No	Yes	No	
Expanded voluntary catch-and-release ethic	Continuous	Statewide	No	No data	No	10

Source: 1, Faunce et al. (2002); 2, Johnson and Funicelli (1991); 3, Johnson et al. (1999); 4, Olander (2002); 5, Reyier and Shenker (2007); 6, Roberts et al. (2001); 7, Tupper (2002); 8, Wickstrom (2002); 9, Witek (2000); 10, D Kelly, Florida Sportsman Magazine, pers comm).

to continued recreational fishing mortality (Tilmant et al. 1989) and perhaps to detrimental habitat changes in Florida Bay (Robblee et al. 1991, Butler et al. 1995).

Statewide Recreational Fishing Regulations.—Florida statewide recreational size and bag limits are important conservation measures frequently credited as explanations for CAN record patterns (e.g., Olander 2002, Wickstrom 2002). Records for red drum increased sharply starting in 1989, 4 yrs after the first statewide regulations were enacted, and for black drum starting in 1992, 3 yrs after statewide regulations were employed. Spotted seatrout records, however, began increasing in 1972, 17 yrs before statewide regulations were enacted. Observations that the average size of recreational fishes landed in Florida doubled in the decade after establishing minimum size regulations (Tupper 2002) can largely be explained as a mathematical consequence of regulations that eliminated small fishes from being retained, even if the stock size structure did not change. Long-term benefits of fishing regulations ultimately depend on release survival rates (Bartholomew and Bohnsack 2005). Because fishing regulations apply statewide, they alone cannot explain the large numbers of records at CAN or the fact that similar record increases did not materialize elsewhere. The simplest explanation is that when statewide regulations were enacted, fish already present in NTRs had a head start advantage in density and size compared to other areas. The new regulations gave fish migrating out of NTRs a better chance to survive and grow before being caught.

Statewide Commercial Net Ban (1995).—Probably the most popular belief among anglers is that a statewide net ban explained CAN world record patterns by allowing CAN to rebound after years of depletion by commercial net fishing (Olander 2002, Tupper 2002, Wickstrom 2002, Witek 2002). This interpretation conflicts with the facts that the net ban took effect in July 1995, many years after CAN records began increasing for spotted seatrout, red drum, and black drum, and while commercial net fishing was active. Also, fishery data showed that commercial fisheries accounted for only a small portion of total landings. Reported spotted seatrout landings, for example, were an order of magnitude higher for recreational vs commercial fisheries from 1981 to 1995 (Bortone and Wilzbach 1997). While the net ban certainly benefited anglers by reallocating fish to the recreational sector, it does not explain the high density of records near MPAs.

Promotional Prize Money Offered for the Largest Fish.—This factor can be discounted as important for the present study, because it applied statewide and there was no evidence or inherent reason why locations near MPAs should respond any differently than elsewhere.

More Anglers.—As described earlier, numbers of world records were not directly correlated with either total fishing trips or total catch.

Expansion of a Voluntary Catch and Release Ethic.—The proportion of catch released by recreational anglers is large and has grown for decades (Table 3). Although voluntary catch and release fishing may have increased in popularity, most releases for regulated species are mandatory based on creel limits applied throughout Florida.

Discussion

Trophy fishing is an elite category of recreational angling that depends on having access to an abundance of large older fishes. Mean size and abundance are especially sensitive to fishing mortality. Therefore, trophy fisheries require that exploited populations have sufficient reproduction, survival, and individual growth to overcome natural and fishing mortality. The number of world records achieved in Florida for target species in the present study is significant and reflects stock conditions over time. Achieving a world record is influenced by the abundance and availability of appropriately sized fishes for the tackle being used, as well as angler skill, preparation, and luck. Each new record is much more difficult to achieve because larger fishes are less frequent and more difficult to land within a line class. Doubling fishing effort can double total catch, for example, but will not double the number of records obtained. Achieving a new record becomes a much rarer event. This fact was demonstrated by the few new records achieved after 1980 in original IGFA record classes. In newer line classes, record numbers grew rapidly in the 1980s and then slowed considerably after 1999, reflecting the difficulty of achieving new records over time. This increased difficulty to achieve also may discourage many anglers from pursuing new records.

The creation of new IGFA line classes in 1980 led to many new world records in Florida. Initially, 34 of 38 new records for spotted seatrout, red drum, and black drum came from ENP between 1980 and 1985, and all were eventually replaced by larger fishes from CAN. This pattern reflects larger sized fishes at CAN and may reflect anglers targeting specific areas based on reputation. In recent years, successful anglers also appear to be targeting specific record categories. Between 2000 and 2004, for example, seven new records of small spotted seatrout (< 2 kg) were caught on the Florida west coast by three anglers in vacant line classes. The numbers and sizes are consistent with a increased abundance following the 1985 Florida net ban, but also indicate that anglers targeted species and record classes that offered a good chance of success. Common snook records in 2004 and 2005 were also small and in vacant line classes.

To demonstrate fishery benefits of MPAs, the present study required showing significant spatial concentrations of world records associated with MPAs and proportional numerical record increases after MPAs were established. Both spatial and temporal criteria were achieved for three estuarine game fish (spotted seatrout, red drum, and black drum) for MPAs at MINWR and ENP, which had more restrictive fishing regulations. CAN and ENP contributed 74% of all state records for spotted seatrout, red drum, and black drum along ~20% of the Florida coast. As predicted, the proportion of records increased near MPAs after fishing restrictions were applied. These data do not support alternative predictions that fewer records would occur near NTRs. Total records increased significantly near the NTRs despite areas being closed to fishing, fishery displacement, and potential species mobility and migratory behavior.

Florida fishery statistics were examined to determine if IGFA world record patterns were correlated with, and possibly could be explained by, regional trends in total catch or fishing effort, and to determine if recreational catch statistics corroborate world record patterns. Presumably, if MPAs result in more world records for trophy fishing, then total catch should also increase for the broader fishery. Recreational catch data showed similar patterns to those observed in IGFA records. The two regions with restrictive MPAs, NE and SW, also had significant and substantial increases in total catch and CPUE for red drum and black drum, and in total catch for spotted seatrout. In contrast, total catch and CPUE (except for red drum CPUE in the NW) remained flat or declined in the NW and SE regions that did not have MPAs with fishery restrictions. The possibilities that total records achieved were simply a result of either the total number of fishing trips or total catch were discounted by the lack of correlations between these variables and the number of records in a region.

No impacts on numbers of world records were detected for MPAs managed by statewide fishing regulations. This result should not be construed to imply that coastal MPAs created to protect habitat failed to benefit fisheries since production may have increased from additional habitat protection. This result does indicate, however, that any potential increased production was rapidly exploited and neutralized by fishing in the absence of additional fishery restrictions.

The spatial and temporal hypotheses for MPAs were rejected for common snook since few records occurred at CAN (n = 4) and ENP (n = 7). CAN is located at the northern boundary of snook records and may be marginal habitat for snook, which are sensitive to cold winter temperatures in this part of their range. Johnson et al. (1999) reported a 31:1 ratio of snook caught in unfished vs fished areas at MINWR with the same effort and concluded that MINWR was primarily used by immature snook which migrated offshore as they matured. Snook tagged at MINWR had a 22% recapture rate and were mostly recaptured at coastal inlets to the south, including Sebastian, St. Lucie, Ft. Pierce, Jupiter, and Hillsborough inlets, Port Everglades, and the Florida Keys (Johnson et al. 1999, Stevens and Sulak 2001). These recaptures suggest that common snook may be too migratory to benefit greatly from CAN NTRs. If MINWR had been located a little farther south, results may have been different. Despite few world records at CAN, NTRs may have facilitated the establishment of snook at MINWR since Anderson and Gehringer (1965) did not report any common snook among 227 taxa observed in CAN fisheries from 1956 to 1962, before NTRs were established. In the next 25 yrs, common snook had expanded northward to MINWR either as a result of NTR protection or perhaps climate change (Parker and Dixon 1998). Fishing regulations cannot explain this invasion, which occurred before 1985 when the first recreational fishing regulations for snook were enacted. Increased total catch and CPUE in the SW, SE, and NE starting in the late 1980s was probably a direct result of fishery management practices.

The simplest and best explanation for the concentration of world records at CAN is the presence of NTRs in MINWR. Anglers benefited from larger populations, increased survival, and higher individual growth in MPAs, which supplied more and larger fishes for nearby fisheries compared to other Florida areas. Direct spillover from NTRs is well documented by tagging studies at MINWR and elsewhere showing movement capabilities of 10s to 100s of km for these estuarine species (Murphy and Taylor 1990, Murphy and Taylor 1994, Schirripa and Goodyear 1994, Murphy et al. 1998, Johnson et al. 1999, Stevens and Sulak 2001, Tremain et al. 2004, Bacheler et al. 2009). The disproportionate increase in records after decadal time lags following NTR establishment is evidence that increased reproduction was also important and supports predictions that at least a generation is required for recruitment enhancement for long-lived species and that more than a decade is required to rebuild spawning stocks sufficiently to show large-scale effects on catches (Michelli et al. 2004, Hilborn 2006). The time lags for species in the present study were proportional to longevity: 12 yrs for spotted seatrout with a 15-yr longevity (Murphy and Taylor 1994), 27 yrs for red drum with a 35-yr longevity (Murphy and Taylor 1990), and 30 yrs for black drum with a 60 to 70-yr longevity (Murphy et al. 1998). Standardized CPUE from 1986 to 1990 at MINWR (Johnson et al. 1999) was 12.8 times higher for black drum, 6.3 times higher for red drum, and 2.3 times higher for spotted seatrout in unfished than in fished areas. These ratios were directly correlated the increases in numbers of world records at CAN after 1980 and the increased recreational catch and CPUE in the NE.

Other factors that potentially contributed to spatial record concentrations at CAN besides NTRs included enhanced retention of offspring from nearly landlocked reproductive populations and reduced fishing in the SBR by no-motor zone starting in 1990. Changes in state fishing regulations and fishing practices may have contributed to new records by interacting with populations in MPAs. Evidence did not support other alternative hypotheses proposed to explain world records patterns, including the possible presence of unique habitats, increased habitat productivity, or the statewide commercial net ban in 1985.

Summary and Conclusions

Marine reserve theory predicts that MPAs with restricted fishing will lower total fishing mortality and increase fish abundance and average size for exploited species. Eventually fisheries may benefit with higher total catch from spillover and/or from higher total reproduction. Two sets of data examined in the present study support these predictions for three coastal estuarine game fishes in Florida.

First, as predicted, the spatial and temporal distribution of IGFA world records achieved over 70 yrs demonstrates increased abundance and size of estuarine game fishes near protective MPAs and was correlated with the strength and duration of MPA fishery restrictions. The highest record concentration came from CAN, which had NTRs closed to all fishing in MINWR since 1962. The next highest concentration came from ENP, which had partially limited fishing since 1980 with one NTR, daily bag limits, and the elimination of commercial fishing. For the rest of Florida, no difference in world record density was found between coastal areas within or outside of designated MPAs managed by statewide fishing regulations. Although Florida NTRs were not established for fishery purposes, it is remarkable that 74% of Florida world records for three game fish species came from the two areas with NTRs. However, world records for common snook, the most vagile species examined, were not correlated with proximity to MPAs, although some evidence suggests that NTRs may have contributed to their establishment at MINWR after the 1950s.

Second, recreational fishery statistics also confirmed patterns observed for IGFA records. Trends in total number of fishing trips increased in the two southern regions, but did not changed significantly in the two northern regions. Total recreational catch for spotted seatrout, red drum, and black drum increased significantly in NE and SW Florida, the two regions with the most protective MPAs. CPUE also increased in both regions for red drum and black drum. In contrast, total catch remained unchanged or declined for these species the NW and SE regions that did not have MPAs that restricted fishing. CPUE also declined for spotted seatrout and black drum.

The present study was based on the well established premise that maximum fish size is inversely related to fishing mortality. While no impacts on total catch or world records were detected for MPAs where fishing was managed by statewide fishing regulations, results provide evidence that MPAs with more restrictive fishing regulations can reduce total fishing mortality and increase total recreational catch and CPUE, and help sustain recreational trophy fishing. In conclusion, Florida estuarine MPAs that restricted fishing allowed recreational anglers to attain higher total catch and achieve more world records for spotted seatrout, red drum, and black drum than would have occurred if all coastal areas had been regulated by existing statewide fishing regulations. Total yield is only one of many considerations and should not be a sole requirement or prerequisite for designing MPAs or establishing reserves. Other ecosystem services should also be considered including ecosystem protection, fishery stability, and non-extractive economic and social needs.

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Appendix 1. Summary of the history of major Florida fishing regulations. Extracted from: http://www.dep.state.fl.us/mfc/MFC-rule-hist.htm and http://myfwc.com/RulesandRegs/SaltwaterRules_summarizedRegs_Archive.htm (accessed Nov 2010).

Spotted seatrout	
Nov 1, 1989	Designated "restricted species," minimum size 14" (35.6 cm), limit 1 > 24" (61 cm) per day, daily bag limit 10, prohibits snatch hooking or multiple hooks with natural bait, 3" (7.6 cm) minimum net mesh size, establishes regional commercial limits set at 70% of average 1984–1987 harvest, sets daily commercial vessel landings limits, prohibits sale when regional quotas are filled.
Jan 1, 1993	Minimum net mesh size 3.5" (8.9 cm).
Jan 1, 1996	Seasons closed in Feb in NW Florida and Nov–Dec elsewhere; bag limit seven in NW Florida and five elsewhere; minimum size 15" (38.1) TL, 24" (61 cm) maximum length for NW Florida and 20" (50.8 cm) elsewhere except for 1 fish > 20" daily; allows only hook and line and cast nets; changes closed season to Nov–Dec in Nassau through Flagler counties only.
2000	Bag limit four per day South region, five per day NE and NW regions. Closed seasons: Nov–Dec South region, Feb NW and NE regions.
Red drum	
Sept 12, 1985	Minimum size 16" (40.6 cm) NW Florida and 18"(45.7 cm) elsewhere, maximum size 24"(61 cm), limit 1 > 32"(81.3 cm) per day, daily bag limit one.
Nov 7, 1986	Zero bag limit.
Feb 12, 1987	18" (45.7 cm) minimum size, March–April closed season, sets gear limits.
May 1–Sept 30, 1987	No possession.
Oct 1–Dec 31, 1987	Temporary season, one bag limit (5 commercial), 18"–27" (45.7–68.9 cm) slot limit, designated "restricted species," sets gear restrictions.
Jan 1, 1989–Oct 1, 1991	Prohibits sale, one bag limit, 18"–27" (45.7–68.9 cm) slot limit.
Jun 3, 1991	Designated "protected species," sets gear limits.
Jan 1, 1996	Eliminates March, April, and May closed season, sets gear limits.
Black drum	
Jul 1, 1989	Designated "restricted species," minimum size 14" (35.6 cm), maximum size 24" (61 cm), limit 1 > 24" (35.6 cm) per day, daily bag limit five, commercial limits 500 lbs/day (227 kg), prohibits snatch hooking or multiple hooks with natural bait.
Common snook	
1957	Prohibited commercial sale, limited allowable fishing gear to hook and line only, and set a bag limit of four per day.
1981	Bag limit two per day.
1982	Started seasonal closures.
Jul 23, 1985	Minimum size of 24" (61 cm) total length, daily bag limit of two fish, only one > 34" (86.4 cm), established closed seasons (January and February, June–August), prohibited sale, and allowed only hook and line gear.
Jul 9, 1987	Treble hooks with natural bait prohibited.
Mar 1, 1994	Changed Jan and Feb closed season to Dec 15–Jan 31.
Dec 31, 1998	Minimum size 26" (66 cm), no possession > 34" (86.4 cm) and zero bag limit for crew of for-hire vessels.
2002	Bag limit two per day Atlantic; one per day ENP and Gulf Coast.
2006	Minimum size 27" (69 cm).
2009	Bag limit one per day and closed seasons. Atlantic slot limit 28"–32" (61.6–70.4 cm); ENP and Gulf Coast slot 28"–33" (61.6–72.6 cm).
Everglades National Park (additional regulations)	
1980	Bag limit of 10 for any fish species per day and a maximum of 20 fish for all species per day applied to commercial and recreational fishing.
1985	All commercial hook-and-line and net fishing eliminated.
Florida	
Jul 1995	Statewide commercial net ban.