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# The increasing importance of marine recreational fishing in the US: Challenges for management

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ABSTRACT

Harvests from recreational fishing are increasingly as important as commercial harvest to populations of popularly fished marine recreational species. However, it has yet to be determined whether the increasing importance of recreational fishing is a general trend of marine fisheries in the US or whether such a trend is limited to only those species recognized as popular recreational fishes. 71% of marine species in the US have experienced an increase in the proportion of total harvest from the recreational sector during the time harvest data are available for both sectors. Species demonstrating an increase in the proportion of harvests by the recreational sector included those generally regarded as commercial, bait, and bycatch species, as well as those considered recreational species. Marine species categorized as overfished could not be predicted from either fishery characteristics or life history characteristics in a PCA analysis of available data for fished species in the US. Consequently, there appears to be little to predict vulnerability of populations to fishing efforts save that all fished species can be made vulnerable to overexploitation. Well-developed yield-based strategies, designed for commercial fisheries, are not likely to be effective in managing populations as the diverse recreational fishing sector continues to increase in its importance. Thus, new management strategies for US marine fisheries are needed. Some possible alternative strategies are discussed.



## 1. Introduction

Recreational fishing is an increasingly important consideration in the management of marine fisheries in terms of the economic impact (Steinback et al., 2004), the number of participants (Kearney, 2002; Marine Recreational Fisheries Statistical Survey [MRFSS], National Marine Fisheries Service [NMFS], Fisheries Statistics Division, Silver Spring, MD; http://www.st.nmfs.noaa.gov/st1/recreational/queries data retrieved 20 March, 2009), and the magnitude of the catches (Coleman et al., 2004; Cooke and Cowx, 2004; NRC, 2006; Post et al., 2002; Schroeder and Love, 2002). The high value of recreational fisheries is commonly recognized in developed countries and, though largely unassessed in developing countries, recreational fisheries appear to be of similar importance there as well (Pitcher and Hollingworth, 2002). The recreational sector has become increasingly important over the past 50 years for many marine species (Coleman et al., 2004; Cooke and Cowx, 2006; NRC, 2006), compared to the commercial sector, and this sector has dominated the harvest for some marine fisheries in the United States (US) since at least the early to mid-1960s (DeSylva, 1969). A similar rise in the recreational sector has occurred in the European Union where some recreational fisheries are now on a par with that of their commercial counterparts (Pawson et al., 2008). However, whether the increasing importance of the recreational sector has been limited to only popular, high-profile recreational fisheries, or whether such change is a general trend for marine fisheries remains unclear.

Research on the economic, ecological and social impacts of recreational fisheries has lagged behind similar research on commercial sector fisheries (Pitcher and Hollingworth, 2002). Furthermore, Kearney (2002) asserted that the mainstream scientific literature contains few assessments of recreational fisheries. He interpreted this deficiency as a lack of recognition by fisheries scientists of the potential importance of recreational harvests.

If recreational fisheries are increasing in their importance, trends indicating such change should be evident in trends of harvests estimated from landings statistics. Researchers have previously used recreational harvest data to document the importance of recreational harvests for popular species (Coleman et al., 2004; Cooke and Cowx, 2004). Although these studies show that marine recreational harvests can be of similar magnitude as commercial harvests, such approaches do not identify whether the recreational harvest relative to the commercial harvest has changed over time.

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Nor do such analyses focus on whether individual fisheries exhibit trends in recreational or commercial harvests over time. A direct comparison of the change of the harvest of each sector is required to answer these questions. For example, consider a stock subject to commercial and recreational exploitation, both of which harvest in proportion to stock abundance. In this case, if the stock abundance changes both the commercial and recreational harvests would exhibit the same proportional change over time. In a second scenario, the recreational fishery expands over time while the commercial sector does not. In this instance, only the recreational sector would exhibit a positive proportional change in harvest over time. Here, we examine harvest trends over time for all US marine stocks for which data were available for both the recreational and commercial sectors and test whether there is a general trend for increasing proportional change in the recreational sector.

If harvests from marine recreational fishing are indeed increasing in importance, then identifying the characteristics of exploited species and their fisheries that make species vulnerable to recreational fishing pressure would be particularly useful for management. For example, recreationally targeted species might share a suite of life history characteristics, and some of these characteristics may make certain species more vulnerable to recreational fishing than others. Similarly, the characteristics of a fishery may contribute to the inherent vulnerability of a species to recreational fishing pressure. Multivariate ordination techniques have often been used to identify species that possess suites of characteristics that confer resilience or susceptibility to exploitation (King and McFarlane, 2003; Winemiller and Rose, 1992). We apply these techniques to better understand how combinations of life history and fisheries characteristics relate to the vulnerability of fished species.

Our goals for this study were to use available data to test the hypothesis that marine recreational harvests are increasing compared to commercial harvests in the US and to evaluate whether certain sets of species are more likely to be vulnerable to recreational fishing pressure. To evaluate our hypothesis, we examined trends in harvest data from commercial and recreational marine fisheries in the US. We applied principal components analysis to identify the life history and fisheries characteristics that make species particularly vulnerable to recreational fishing.

## 2. Methods

### 2.1. Analysis of harvest data

We analyzed harvest data from US marine fisheries to determine if trends were detectable in the harvest of the recreational sector relative to that of the commercial sector during a recent 25-year period. Analysis included only those fisheries for which both commercial and recreational harvest data were available concurrently; consequently, the period examined varied by species. In general, for Atlantic coast species, recreational data were available from 1981 to 2006 from the Marine Recreational Fisheries Statistical Survey (MRFSS, NMFS-FSD, Silver Spring, MD, data retrieved 22 June, 2008). Data for Pacific species were available for 1993–2006 from the Recreational Fisheries Information Network (RecFIN, Pacific States Marine Fisheries Commission, www.recfin.org data retrieved 22 June, 2008). RecFIN data were available prior to 1993, but to minimize the effect of survey design changes, analyses included only RecFIN data from 1993 forward. The RecFIN data set also underwent a survey design change that could affect harvest estimates beginning in 2004; however, plots of the time series of recreational harvests for RecFIN species revealed very little to no change in trends of harvest estimates prior to 2004 when compared to those from 2004 forward. Consequently, we included RecFIN data from the years after the design changes (i.e., 2004, 2005, and 2006) in the analysis. Commercial data for all species came from the NMFS commercial statistics (NMFS-FSD, Silver Spring, MD).

Both recreational and commercial harvest data were normalized (Zar, 1996) and given a standard score based on the available data for each sector prior to analysis. Data were standardized to account for the vast differences in the scale of catch for different US fisheries, and to ensure measures were comparable in our analyses. Thus, the term "harvest" henceforth refers to standardized harvest.

We analyzed the proportional change in harvest for each species over the period for which data were available. We used average harvests of the first and last five years of each time series to define the relative proportional change in recreational and commercial harvests in each species. To allow direct comparisons among species, we expressed these data as trend vectors in Cartesian coordinates. The origin of each trend vector was defined as the (0, 0) point, and the end point of each vector was

$$\left(\frac{(Com_2 - Com_1)}{Com_1}, \frac{(Rec_2 - Rec_1)}{Rec_1}\right), \qquad (1)$$

where *Com* and *Rec* are the commercial and recreational harvests and subscripts indicate average harvests for the first (1) or final (2) five years of the time series. When fewer than 11 years of data were available in the time series, the endpoints of the trend vector were calculated from three years of data. To ensure the same year was not included in the calculation of both endpoints, a minimum of one year separated the endpoints. Thus, all species required at least seven years of harvest data from both sectors for corresponding years. Years in which data were unavailable for either sector were excluded from analysis.

The trend vectors of relative harvest change for each species provide two pieces of information: their angle $\theta$, and their length. The angle of the trend vector indicates the relative change in harvest between the sectors. Based on possible values of $\theta$, we defined four quadrants of response (Table 1; Fig. 1). If there is no consistent trend among all species included in the analysis, one would expect equal numbers of trend vectors terminating in each of the four quadrants. This expectation was tested with a $\chi^2$ test. We also compared counts of trend vectors terminating in quadrants II and IV with a $\chi^2$ test. This comparison was intended to include only species demonstrating trends that strongly favor one sector or the other; thus, species showing similar harvest trends for both sectors, i.e., those with trend vectors terminating in quadrants I and III, were excluded from consideration.

To refine the analysis of harvest change between the fishing sectors further, we created a binary classification by defining vectors whose directions were $45^\circ < \theta < 225^\circ$ as evidence for increasing importance of recreational fishing and vectors with direction $0^\circ < \theta < 45^\circ$ and $225^\circ < \theta < 360^\circ$ as indicative of an increasing commercial importance. This categorization was also examined using a $\chi^2$ test of the null expectation of an even division between the two categories. In addition, we conducted a series of *post hoc* comparisons to examine patterns in trend vectors based on geographic, ecological or fishery factors. In all tests of significance, we used $\alpha = 0.05$.

The length of the trend vector indicates the magnitude of the relative change in harvest. Trend vectors of different species would be comparable to one another if the number of years of data included in each were equal. However, the total number of years of data available for and included in our analysis varied by species (Table 1). Consequently, vector lengths were expressed on a per year basis before trend vectors for all species were plotted together for direct comparison.

**Table 1**
Common, scientific, and family names for species numbers (left column) shown in Figs. 1 and 2. Species are categorized by the quadrant (I–IV) that the trend vector terminates in for each species. Subsection headings (I–IV) describe the general harvest trends interpreted for each quadrant. Number (right column) indicates the total number of years data were available from both sectors in corresponding years, and consequently, the number of years of data included in the analysis.

| Species number | Common, scientific (*genus species*), and family names | Years of data available |
|---|---|---|
| (I) Harvest increasing for both sectors ($\theta$ values range: $0^\circ < \theta < 90^\circ$) | | |
| 1 | Pinfish, *Lagodon rhomboids*, Sparidae | 21 |
| 2 | Grunt (white), *Haemulon plumieri*, Haemulidae | 9 |
| 3 | Northern anchovy, *Engraulis mordax*, Engraulidae | 10 |
| 4 | Red grouper, *Epinephelus morio*, Serranidae | 25 |
| 5 | Mahi-mahi, *Coryphaena hippurus*, Coryphaenidae | 25 |
| 6 | Cobia, *Rachycentron canadum*, Rachycentridae | 26 |
| 7 | Atlantic herring, *Clupea harengus*, Clupeidae | 26 |
| 8 | Atlantic croaker, *Micropogon undulates*, Sciaenidae | 26 |
| 9 | Striped bass, *Morone saxatilis*, Moronidae | 26 |
| 10 | White perch, *Morone Americana*, Moronidae | 26 |
| 11 | Southern flounder, *Paralichthys lethostigma*, Paralichthyidae | 26 |
| (II) Recreational harvest becoming more important ($\theta$ values range: $90^\circ < \theta < 180^\circ$) | | |
| 12 | Pacific cod, *Gadus macrocephalus*, Gadidae | 9 |
| 13 | Ladyfish, *Elops saurus*, Elopidae | 25 |
| 14 | Hardhead catfish, *Ariopsis felis*, Ariidae | 10 |
| 15 | Pigfish, *Orthopristis chrysoptera*, Haemulidae | 26 |
| 16 | Black rockfish, *Sebastes melanops*, Sebastidae | 10 |
| 17 | Gag, *Mycteroperca microlepis*, Serranidae | 21 |
| 18 | Brown rockfish, *Sebastes auriculatus*, Sebastidae | 14 |
| 19 | Red snapper, *Lutjanus campechanus*, Lutjanidae | 26 |
| 20 | Pacific halibut, *Hippoglossus stenolepis*, Pleuronectidae | 13 |
| 21 | Red drum, *Sciaenops ocellatus*, Sciaenidae | 25 |
| 22 | Bocaccio, *Sebastes paucispinis*, Sebastidae | 10 |
| 23 | Lingcod, *Ophiodon elongates*, Hexagrammidae | 14 |
| 24 | Spotted seatrout, *Cynoscion nebulosus*, Sciaenidae | 26 |
| 25 | Pacific Jack Mackerel, *Trachurus symmetricus*, Carangidae | 14 |
| (III) Harvest decreasing for both sectors ($\theta$ values range: $180^\circ < \theta < 270^\circ$) | | |
| 26 | Atlantic menhaden, *Brevoortia tyrannus*, Clupeidae | 26 |
| 27 | Alewife, *Alosa pseudoharengus*, Clupeidae | 26 |
| 28 | American shad, *Alosa sapidissima*, Clupeidae | 25 |
| 29 | Skipjack tuna, *Katsuwonus pelamis*, Scombridae | 26 |
| 30 | English sole, *Parophrys vetulus*, Pleuronectidae | 12 |
| 31 | Copper rockfish, *Sebastes caurinus*, Sebastidae | 14 |
| 32 | Spot, *Leiostomus xanthurus*, Sciaenidae | 26 |
| 33 | Starry Flounder, *Platichthys stellatus*, Pleuronectidae | 13 |
| 34 | Pacific barracuda, *Sphyraena argentea*, Sphyraenidae | 14 |
| 35 | Rainbow smelt, *Osmerus mordax*, Osmeridae | 22 |
| 36 | Yellowtail rockfish, *Sebastes flavidus*, Sebastidae | 14 |
| 37 | Canary Rockfish, *Sebates pinniger*, Sebastidae | 14 |
| 38 | Summer flounder, *Paralichthys dentatus*, Paralichthyidae | 26 |
| 39 | Black grouper, *Mycteroperca bonaci*, Serranidae | 23 |
| 40 | Chilipepper rockfish, *Sebastes goodei*, Sebastidae | 14 |
| 41 | King mackerel (Atlantic), *Scomberomorus cavalla*, Scombridae | 26 |
| 42 | Tautog, *Tautoga onitis*, Labridae | 26 |
| 43 | Atlantic cod, *Gadus morhua*, Gadidae | 26 |
| 44 | Weakfish, *Cynoscion regalis*, Sciaenidae | 26 |
| 45 | Chub mackerel, *Scomber japonicus*, Scombridae | 10 |
| 46 | Winter flounder, *Pseudopleuronectes americanus*, Pleuronectidae | 26 |
| 47 | American eel, *Anguilla rostrata*, Anguillidae | 26 |
| 48 | Bluefish, *Pomatomus saltatrix*, Pomatomidae | 26 |
| 49 | Blueback herring, *Alosa aestivalis*, Clupeidae | 7 |
| 50 | Black seabass, *Centropristis striata*, Serranidae | 26 |
| 51 | Rock sole, *Lepidopsetta bilineata*, Pleuronectidae | 14 |
| (IV) Commercial harvest becoming more important ($\theta$ values range: $270^\circ < \theta < 360^o$) | | |
| 52 | Pacific hake, *Merluccius productus*, Merlucciidae | 13 |
| 53 | California halibut, *Paralichthys californicus*, Paralichthyidae | 14 |
| 54 | Scup, *Stenotomus chrysops*, Sparidae | 18 |
| 55 | Atlantic mackerel, *Scomber scombrus*, Scombridae | 26 |

### 2.2. Multivariate ordination

We used principal components analysis (PCA) to analyze both biological characteristics of individual species and characteristics of the fisheries exploited on those species. The application of PCA described here was somewhat distinctive in that much of the redundancy among variables was removed prior to the analysis (see below), whereas PCA is commonly used as a preliminary data analysis technique to organize the variability inherent in the data and to identify the redundant variables in the data set (McGarigal et al., 2000). The utility of the approach used here is that it allowed us to more easily examine the relationships among the variables by limiting the noise in the analysis.

The data used in the PCA originated from a diverse collection of 129 sources (Appendix), including published literature, web-based resources (e.g., FishBase.org), stock assessments, species profiles and conference proceedings. PCA was conducted on the correlation matrix. McGarigal et al. (2000) recommend that the number of observations (species) should be at least three times the number of variables analyzed. As sufficient data were available for only 51 US marine fish species, we reduced the variable set used for the PCA using both *a priori* and *post hoc* approaches. Because PCA requires a full dataset, a variable (i.e., a fishery or life history characteristic) was excluded if information on that variable was not available for each of the 51 species or could not be estimated from closely related species. Highly correlated variables were removed *a priori* as well. If two variables had >70% correlation, the variable containing more unique information (i.e., had correlations with fewer variables) was retained. After PCA, variables were removed that did not contribute with an eigenvalue loading >0.3 to the important principal components (PCs; relative to the latent root criterion as described by McGarigal et al. (2000), i.e., PCs with eigenvalues >1), and the PCA was re-analyzed. Ultimately, 17 variables (6 fishery-related characteristics and eleven life history characteristics) were retained for analysis (Table 2).

Of the 17 variables included in the PCA, life history variables were largely based on those described by Winemiller and Rose (1992). The fishery variables were designed to distinguish the range of characteristics of marine fisheries in the US: the types of gear and vessels employed, and the predominant fishing goal (e.g., harvest for food, catch for sport only, etc.; see Table 2 for full descriptions of variables). Trend vector parameters $\theta$ and vector length (year$^{-1}$), as defined above, were also included in the PCA. Variables used were evenly split between continuous (9) and ordinal (8) variable types. Ordinal variables were ordered such that larger numbers correspond to states that were thought to be more vulnerable to fishing pressure. For any particular ordinal variable, when an individual species was characterized equally well by multiple states of ordinal rankings, an intermediate or average score was used.

To determine whether certain classes of species identified through PCA were more vulnerable to fishing pressure, we used the current assessed status of species as a measure of vulnerability. We considered a species especially vulnerable to fishing pressure if its fishery is currently assessed as overfished (see Brodziak et al., 2008) or closed. Categories of vulnerability were overlaid with the PCA classifications of species to infer correspondence between vulnerability, life history, and fisheries attributes.

## 3. Results

### 3.1. Analysis of harvest data

Of 110 US marine species for which some harvest data were available, only 55 had more than seven years of harvest data available for both sectors in corresponding years. When harvest trend

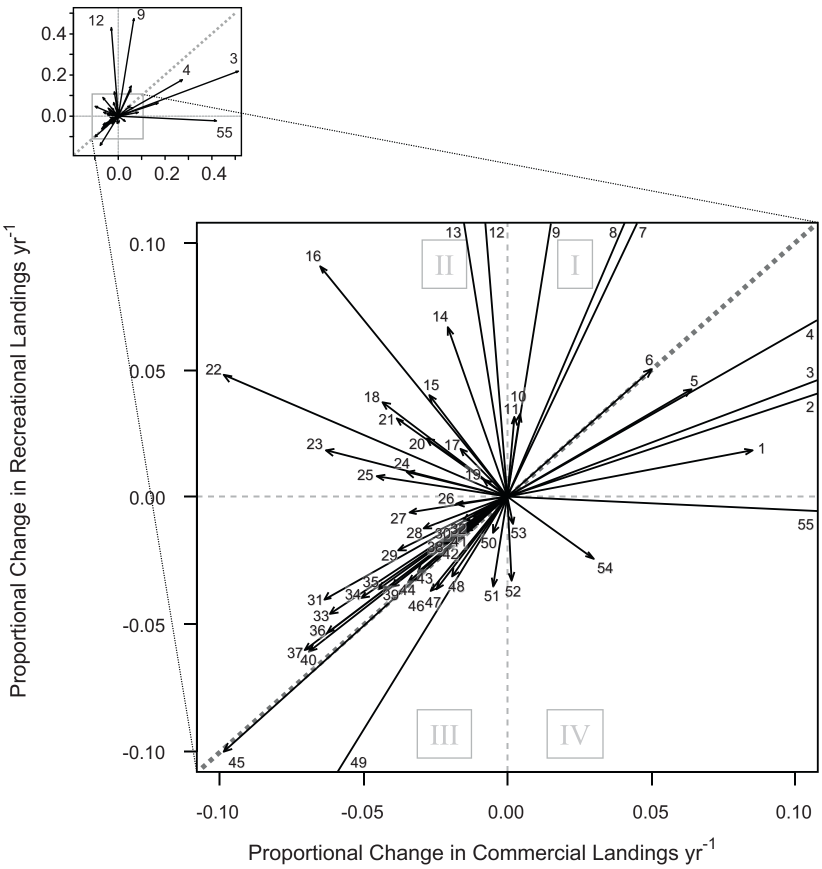


**Fig. 1.** Overlay of trend vectors that indicate relative harvest change between the recreational and commercial sectors for each of 55 marine species for which more than 7 corresponding years of harvest data were available for each sector. Significantly more ($\chi^2$ test; $p = 0.0019$) species (71%, 39 species) indicated an increase in the proportion of recreational harvest during the time series (i.e., trend vectors orientated above the diagonal, dotted line). Insert shows the relative magnitude of the five species (3, 4, 9, 12 and 55) that experienced the greatest change during the time series. Species names associated with the plotted numbers are given in Table 1. Orientation of the vector in different quadrants (roman numerals) indicates different trends: quadrant I – increase in harvest for both sectors; II – increasing importance of recreational harvest (i.e., proportional increase in recreational harvest relative to commercial harvest); III – decrease in harvest for both sectors; IV – decrease in importance of recreation harvest (i.e., proportional increase in commercial harvest relative to recreational harvest).

vectors were plotted together for these 55 species (Fig. 1 and Table 1), results indicate that the recreational harvest is increasingly important for the majority (71%) of marine species examined ($p = 0.0019$). Five species (northern anchovy, red grouper, striped bass, Pacific cod, and Atlantic mackerel) demonstrated exceptionally large harvest changes that were between three and five times the mean length (0.095 proportional change year$^{-1}$) of the trend vectors of all 55 species (Fig. 1).

Species were not uniformly distributed into the four vector quadrants ($p = 0.00037$) and far more species (26/55) experienced decreasing harvest over the time series (quadrant III) than would be expected for a null distribution. The second and third largest groups occupied quadrant II (14) and quadrant I (11), respectively. Only four species experienced an increase in the relative magnitude of commercial harvest during the time series (quadrant IV). Significantly more species were classified in quadrant II than IV ($p = 0.018$), indicative that significantly more species had increased in the relative magnitude of recreational harvests than commercial harvests. A wide variety of species demonstrated an increase in recreational harvest relative to commercial harvest; including species commonly harvested recreationally, species commonly harvested commercially, species targeted as bait for other fisheries, as well as species generally considered "bycatch" (i.e., non-targeted but retained catch). A range of trophic levels was also represented, including omnivores (4), invertebrate feeders (9), mixed invertebrate feeders and piscivores (19), and piscivores (7) (trophic classification follows Winemiller and Rose, 1992). The distribution of vectors was similar between Pacific and Atlantic coast species ($p = 0.22$), between benthic and pelagic species ($p = 0.16$), and between species harvested primarily by the commercial and recreational sectors ($p = 0.36$). Using the binary classification of $\theta$, more species indicated evidence of an increasing importance of recreational harvest (39 species; Fig. 1 – species with vectors terminating above the diagonal) than commercial harvest (16 species) over the available time series ($p = 0.0019$).

### 3.2. Multivariate ordination

The PCA resulted in an acceptable ordination of the 17 fishery and life history variables (Table 3). The first six PCs were most important to the analysis and together explained 69% of the variability in the correlation matrix. Though the first two PCs explained only 33% of the variability in the data set, these PCs clearly separated the species into four groupings: (1) those that are commercially important, (2) those important to both sectors, (3) those that are primarily recreationally important and (4) a single species (Hardhead catfish) whose harvest is primarily an incidental bycatch (Fig. 2). Most life history variables were strongly related to PC 1, whereas most fishery-related variables were strongly correlated with PC 2. Life history variables that contributed most to PC 1 were average age at first maturity, egg size (ovum diameter), length of the spawning season, habitat, distribution in the water column, and the latitudinal range of individual species (Fig. 3). Fishery-related variables that contributed most to PC 2 included fishing goal, fish-

**Table 2**
Definitions of fishery and life history variables used in the principal components analysis. Abbreviations (in parentheses) correspond to labels used in Fig. 3.

| Name | Definition |
|---|---|
| *Fishery variables* | |
| Fishing goal (FishingGoal) | 5 progressive levels of intent by the angler (inferred from participating sectors): non-targeted bycatch (0), enjoyment only (1), enjoyment and some harvest for food (2), food only (3), commercial harvest (4) |
| Fishing mode (FishingMode) | Ranking of 6 generalized types of fishing effort that a fished population is exposed to, progressing from: shore fishing (0), small private boats (1), larger private boats, guides and charters (2), party or head boats (3), commercial vessels, non-targeted or mixed species, with significant bycatch (4), targeted commercial (5) |
| Proportion recreational harvest (PropRec) | Average proportion of the harvest attributable to the recreational sector, calculated over the most recent 5 years that harvest data were available for both sectors |
| Target (Target) | 5 progressive levels describing where fishing effort is directed on the fished population: effort evenly distributed along coast or by depth (0), effort diffuse but fish and effort concentrated in shallow coastal waters accessible by shore, pier, or with small boats (1), fish are associated with a particular habitat or behavior that is easily targeted by fishing effort, e.g. fish associated with structure, or fish school (2), effort directed on, or intercepts a migration pathway (3), effort directed on a spawning aggregation (4) |
| Trend angle, $\theta$ (Trend) | Angle of the trend vector, as defined by Eq. (1) |
| Trend vector length (VectorLen) | The magnitude of the length of the trend vector (proportional change year$^{-1}$) |
| *Life history variables* | |
| Age at maturity (AgeMat) | Mean age at maturity |
| Egg buoyancy (EggBouy) | Ranked values: demersal (0), neutrally buoyant (1), pelagic (2) |
| Habitat (Habitat) | Ranking for habitat of each species following Winemiller and Rose (1992) for marine species: caves or springs (0), small cold-water streams (1), small warmwater streams (2), river channels (3), river backwaters and lakes (4), estuaries (5), marine benthic (6), marine pelagic (7) |
| $L_\infty$ (Linf) | Average length at maximum age, estimated from von Bertalanffy growth model (Ricker, 1975) |
| Ovum diameter (OvumDia) | Mean diameter of mature oocytes to nearest .01 mm |
| Range in latitude (RangeLat) | Span of latitudes included in a species' range (in degrees), based on range maps and verbal accounts of species ranges (Winemiller and Rose, 1992) |
| Reproductive strategy (ReprodStrategy) | System of classification based on ovarian characteristics (Murua and Saborido-Rey, 2003) that groups fish species into 5 different categories: iteroparous, asynchronous, indeterminate batch spawner (0), iteroparous, asynchronous, determinate,batch spawner (1), iteroparous, group synchronous, determinate, batch spawner (2), iteroparous, group synchronous, determinate, total spawner (3), semelparous, synchronous, determinate total spawner (4) |
| Spawning season length (SpawningSeason) | Number of days that spawning or early larvae were reported; if information was available from multiple sources, average value was estimated |
| Time until eggs hatch (TimeHatch) | Mean time for eggs to hatch once exposed to the ocean environment, under average conditions (hours); does not include time to parturition (*Sebastes*) |
| Trophic level (TrophicLevel) | Ranking based on available diet information for adults: detritivore/herbivore (0), omnivore (1), invert-feeder (2), piscivore (3) |
| Water column (WaterCol) | Typical distribution of species in the water column: benthic (0), epibenthic (1), pelagic (2) |

ing mode, the proportion of harvest attributable to the recreational sector, and where fishing effort is directed on the fished population (target). Fishery variables tended to ordinate orthogonally to life history variables. Only one life history variable, $L_\infty$, was strongly related to PC 2.

Species considered especially vulnerable to fishing pressure were evenly distributed throughout the data-space ordinated by the first two PCs (Fig. 2; bold numbers). Similarly, stocks considered healthy (i.e., fisheries not considered overfished or closed) were also evenly distributed (not shown). Thus, vulnerability to fishing pressure could not be identified using the fishery or life history variables used in this analysis.

## 4. Discussion

### 4.1. Implications of observed trends

Harvest data trends suggest that marine recreational fishing has increased in importance during the last several decades. Our analyses of harvest data show that 71% of species for which data were available showed an increase in the magnitude of recreational harvests relative to commercial harvests from 1981 to 2006. Thus, recreational fisheries merit increased attention by marine fisheries managers if sustainable marine fisheries are to be achieved.

Considering the relatively long time series and the diverse assortment of fish families represented in our analyses, it seems likely that the observed changes are the result of a complex interaction of factors that have affected harvests over time. For any individual vector drawn in Fig. 1 that exhibits an increase in the magnitude of recreational harvests, the same trend could result from an increasing recreational harvest, a decreasing commercial harvest or by a combination of both increasing and decreasing changes in harvest levels for the recreational and commercial sectors, respectively. The most common trend observed was one of decreasing harvests for both sectors, thus, this may suggest a decreasing abundance for some of these species. However, we caution that harvest trend vectors are not necessarily reliable indi-

**Table 3**
Eigenvalues, cumulative percentage variation and variable loadings (eigenvectors) for each significant principal component (PC), resulting from principal components analysis of 17 variables (6 fishery characteristics, 11 life history traits) for 51 species for which sufficient data were available. Variable loadings > 0.3 are in bold to facilitate pattern recognition. Variables are listed in alphabetical order according to variable type; "–" indicates there was no loading for that variable on a PC.

| | PC 1 | PC 2 | PC 3 | PC 4 | PC 5 | PC 6 |
|---|---|---|---|---|---|---|
| Eigenvalue | 1.739 | 1.594 | 1.400 | 1.238 | 1.223 | 1.072 |
| Cumulative percentage of variance | 17.80 | 32.75 | 44.27 | 53.29 | 62.09 | 68.84 |
| Loadings | | | | | | |
| *Fishery* | | | | | | |
| FishingGoal | 0.206 | **−0.477** | – | 0.114 | – | – |
| FishingMode | 0.255 | **−0.444** | −0.226 | – | – | −0.113 |
| PropRec | −0.103 | **0.492** | 0.159 | – | – | – |
| Target | – | 0.118 | 0.212 | **0.529** | 0.162 | −0.279 |
| Trend ($\theta$) | 0.144 | −0.162 | – | 0.24 | **−0.333** | **0.454** |
| VectorLen | – | – | **−0.323** | – | **0.480** | −0.130 |
| *Life history* | | | | | | |
| AgeMat | −0.259 | – | **−0.457** | 0.191 | −0.150 | −0.202 |
| EggBouy | **0.337** | 0.198 | 0.165 | – | **−0.323** | −0.185 |
| Habitat | **0.316** | – | −0.244 | – | 0.280 | **0.370** |
| Linf | 0.106 | **0.338** | **−0.357** | 0.214 | −0.272 | 0.112 |
| OvumDia | **−0.338** | 0.135 | −0.134 | **−0.394** | – | 0.141 |
| RangeLat | **0.303** | 0.110 | −0.284 | −0.187 | 0.150 | **−0.335** |
| ReprodStrategy | **−0.319** | – | −0.124 | **0.358** | – | −0.141 |
| SpawningSeason | **0.303** | – | – | **−0.306** | −0.251 | −0.265 |
| TimeHatch | −0.117 | −0.165 | −0.289 | – | – | **0.401** |
| TrophicLevel | 0.277 | 0.223 | **−0.303** | **0.341** | −0.111 | 0.128 |
| WaterCol | 0.281 | – | 0.203 | 0.124 | **0.490** | 0.231 |

cators of abundance since they also reflect changes in effort or management action over time – which clearly can drive harvest trends in US fisheries (Brodziak et al., 2008; Terceiro, 2001). Rather than any one simple explanation for any particular vector, it seems more likely that each species has been affected by a combination of changes in both sectors. Regardless of the reasons for the harvest trends observed for individual species over time, two conclusions can be generalized from the available data: the predominant trend observed is one of decrease in the harvest of both sectors, and recreational harvest is becoming relatively more important for most marine species in the US.

The increasing importance of recreational harvest was a common feature of US marine fisheries, irrespective of the sector that dominates the fishery or species targeted. The primary sector, whether commercial or recreational, appears to be unimportant to the likelihood that recreational fishing pressure would increase during the study period. Important commercial species like pacific jack mackerel, pacific cod, pacific halibut and lingcod, and non-targeted bycatch species like hardhead catfish all demonstrated increasing proportional recreational harvest trends that were similar to commonly targeted recreational species like spotted seatrout, red drum and black rockfish.

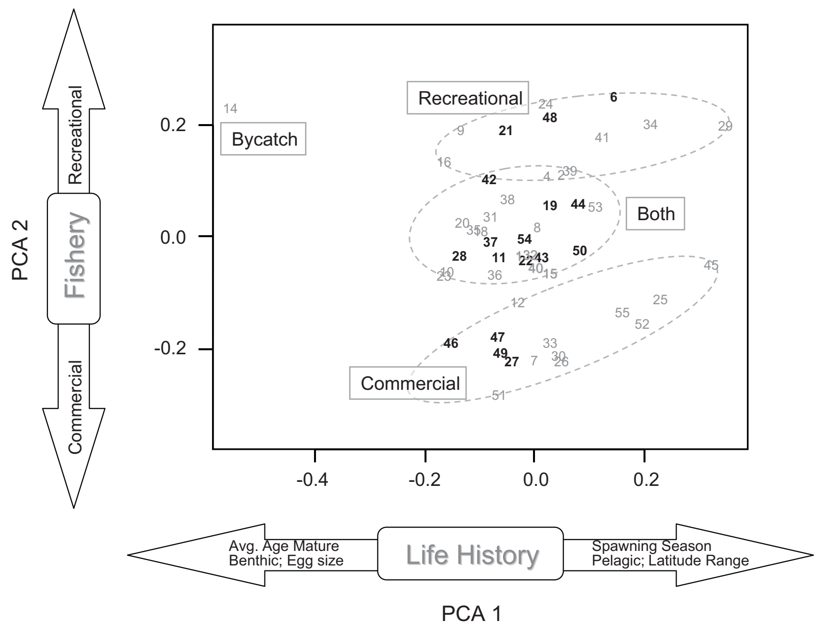


**Fig. 2.** Scatterplot of the first two principal components (PCs) from the principal components analysis (PCA). PC 1 (*x*-axis) is dominated by life history variables while PC 2 was dominated by Fishery-related variables. Numbers on plot are individual species. Species names that correspond to the numbers shown are given in Table 1. Numbers in bold are species currently assessed to be overexploited to some degree; i.e., species whose fisheries are classified by the National Marine Fisheries Service to be either overfished or closed.

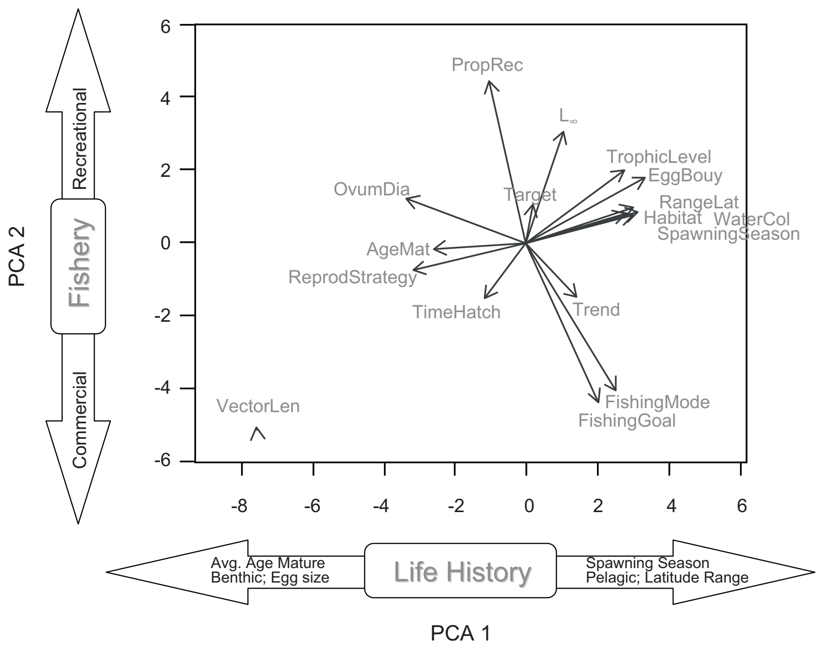


**Fig. 3.** Variable loadings on the first two principal components. Definitions of variable labels are presented in Table 2; variable loadings values are presented in Table 3. The length of the vector for VectorLen was negligible and this variable was orientated between PropRec and Target; it was plotted separately so it could be seen.

### *4.2. Multivariate ordination*

Our results suggest that fishery variables were largely independent of (i.e., orthogonal to) life history variables. Vulnerable species do not appear to exhibit any particular pattern along either the PC1 or PC2 axes. Thus, neither fishery nor life history characteristics were useful to classify species that are especially vulnerable to fishing. These results suggest that criteria based on fishery or life history characteristics – commonly applied by a variety of organizations around the world (e.g., fishery: Marine Stewardship Council (2010); life history: North America: seafoodwatch.org (Monterey Bay Aquarium), seachoice.org (a collaboration of variety of non-governmental organizations [NGOs]), Blue Ocean Institute; Europe and Africa: World Wildlife Fund "Seafood Guides"; Australia: Australian Marine Conservation Society "Sustainable Seafood Guide") to establish vulnerability of species to fishing pressure with the goal of letting consumers make menu choices that promote sustainability – may be less useful than expected. In light of these results, a precautionary approach to managing recreational species would be to assume that all targeted species are as vulnerable to fishing pressure as the most vulnerable fished species. Regardless of its life history or fishery characteristics, any species can be made vulnerable to modern fishing pressure.

Interpretation of our results with regard to vulnerability is incomplete because the status of so many marine species remains unknown. However, the distribution of vulnerable species identified in our analyses suggests our conclusions are likely valid despite this lack of information. We defined especially vulnerable species in terms of the NMFS assessed status. This information is clearly incomplete because many marine species remain unassessed, and while unassessed species are assumed healthy, this may not be the case. Cadrin and Pastoors (2008) reviewed species managed by both the International Council for the Exploration of the Sea (ICES) convention and those under US jurisdiction. They report that in 2006, 44% of US stocks had unknown or undefined status with respect to a biomass threshold and 59% had unknown or undefined status with respect to the fishing mortality limit. However, the relatively even distribution of especially vulnerable species across most fishery and life history characteristics in our analysis suggests that if more species were assessed the distribution of these would likely remain the same.

### *4.3. Alternative management strategies*

Our analyses indicate that the recreational sector is becoming increasingly important to marine fisheries in the US, so it seems appropriate for management to consider that new strategies may be needed for the management of these stocks. Further, it appears likely that the trends we identified will likely continue because the number of participants in the marine recreational fishery has been projected to continue to increase through 2025 in many areas of the US (Thunberg and Milton, 2002). However, the goals of fishery management have been developed largely for commercial fisheries (Smith, 1994), and maximizing optimal yield remains central to the goals of marine fisheries management in the US (Congress, 2006; Brodziak et al., 2008) Yet, yield-based goals may have little relevance to the management of recreational fisheries (Larkin, 1977). Consequently, if the increasing importance of recreational fisheries is a general trend for marine fisheries in the US as our analyses suggests, it seems appropriate to reconsider the management goals of US marine fisheries.

Maximizing various other quantities (e.g., economic yield, catch rate, and well-being) instead of the traditional biological yield performance measures has been suggested as alternative goals for marine fisheries management (Hilborn, 2007; Kirkegaard and Gartside, 1998; Pollnac et al., 2007; Tuomi, 1977). However, such goals may be affected by some of the same disadvantages as maximum optimal yield (Larkin, 1977). Additionally, the economic and societal data necessary to support decision making using such goals are imprecise (Kearney, 2002), and there is a widespread lack of valuation relevant to the recreational sector (McLeod, 1995). There is active debate about what constitutes "value" or "quality" for different individuals and for different fisheries (Holland and Ditton, 1992; McFadden, 1969; Pawson et al., 2008). Moreover, "value" for anglers has been found to change over time (Kearney, 2002; Schramm and Gerard, 2004). Consequently, widespread application of such strategies does not appear likely until these issues can be better resolved.

Freshwater fisheries have long been dominated by recreational fishing, and for these fisheries maximizing yield is rarely a management goal. Rather these fisheries are more often managed to provide opportunities to catch fish of a certain size. For species where harvests are still at a premium, the management goal often relates to achieving or maintaining a specific size structure. One common approach in the management of warmwater fisheries in North America relies on proportional size structure (PSS) policies (e.g., Guy et al., 2006; Willis et al., 1993). The policies, originally developed by Anderson (1976) to assess population status in largemouth bass (*Micropterus salmoides*), assess the proportion of the population size structure that are greater than some desired or "quality" length. PSS-based management is aimed at achieving a balanced population, in which sustainable abundances of larger, quality-sized fish is supported. Sampling gear used in estimation can bias PSS, as can shifts in underlying trophic ecology (Willis et al., 1993), but the approach has seen widespread acceptance by state and provincial managers. Interestingly, there are broad similarities between this approach and recent calls for fishery reference points for marine species that emphasize age diversity as an important factor regulating sustainability of marine fishes (Secor, 2007; Venturelli et al., 2009). Thus, considerations of both angler satisfaction and population sustainability may lead to adoption of age- and size-diversity reference points as a buffer to simple yield-based approaches in the marine realm.

The increasing importance of marine recreational fisheries will likely require management strategies that allow greater input from a larger and more diverse set of stakeholders. The recreational sector includes numerous subgroups that might include independent anglers, angler organizations, tournament anglers and organizers, and divers, among others. Consequently, as the marine recreational sector continues to become more important, fisheries managers will inevitably need to accommodate the input and involvement of a much larger group of stakeholders than has previously been required for the management of primarily commercial interests with relatively few participants. A variety of strategies to accommodate such need have previously been described (Cooke and Cowx, 2006; Granek et al., 2008; Mapstone et al., 2008; Sutinen and Johnston, 2003). Recently, we have had first-hand experience in such a collaborative effort to examine the king mackerel fishery on the east coast of the US, termed "Project FishSmart" (Ihde et al., 2011; Miller et al., 2010). Representative stakeholders included independent anglers, angler organizations, tournament anglers and organizers, charter captains, tackle shop owners, commercial fishers, state managers and biologists, and environmental NGOs. The process resulted in stakeholder recommendations that were formally presented to the management council by the stakeholders themselves (Project FishSmart Workgroup, 2008). Stakeholder recommendations were more conservative than that required by the recently reauthorized Magnuson–Stevens Fishery Conservation and Management Act (Congress, 2006). Thus, this type of process appears promising for future efforts to incorporate the diverse set of goals of marine recreational fisheries stakeholders into the management process.

## 5. Conclusion

Trends from harvest data suggest that, over the last several decades, recreational fishing has become increasingly important for marine fisheries in the US. Moreover, the evidence indicates that this is a general trend for most marine fisheries and not just for those fisheries already recognized as popular for recreation. Multivariate analysis of available data indicates that fishery characteristics are distinct from life history characteristics. Furthermore, neither fishery nor life history characteristics were useful to predict vulnerability in this study. Consequently, there appears to be little to predict vulnerability of populations to fishing efforts save that all fished species can be made vulnerable to overexploitation. The well-developed yield-based strategies, designed for commercial fisheries, are not likely to be effective in managing populations as the diverse recreational fishing sector becomes increasingly important. New strategies beyond traditional yield-based strategies are needed. Incorporating alternative strategies like size-based management goals, and stakeholder-based initiatives may be important to marine fisheries management as recreational fishing continues to grow in importance.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.fishres.2010.12.016.

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