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Short communication

Estimation of recreational bag limit noncompliance using contact creel survey data

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ABSTRACT

Bag limits are commonly used to manage recreational fisheries, but the effect of noncompliance with these regulations is rarely evaluated. I developed a method to estimate noncompliance with recreational bag limits using creel survey data. This approach allowed for two populations of angler trips, compliant and potentially noncompliant, and estimated the proportion of potentially noncompliant trips. The model included a mixture of a negative binomial distribution for potentially noncompliant trips and a truncated negative binomial distribution for compliant trips. The method was applied using four separate models with different assumptions about noncompliance to harvest angler^{-1} trip^{-1} data from the recreational king mackerel (*Scomberomorus cavalla*) fishery in North Carolina, U.S. The model that estimated a single potential noncompliance parameter had the lowest (best) Akaike's Information Criterion value, and the estimated proportion of potentially noncompliant trips was about 36%. However, only about 1% of trips exceeded the bag limit because few trips reached the bag limit, which resulted in about 7% of harvest due to noncompliance. Studies that evaluate the likely consequences of bag limits on harvest and fishing mortality should include effects of noncompliance.

1. Introduction

The effectiveness of most fisheries management relies on compliance with regulations. Enforcement and compliance with fishery regulations is usually not a top priority of management (Randall, 2004), and evaluations of the effects of regulations are usually based on the assumption of 100% compliance. However, compliance with regulations is rarely universal, and noncompliance can severely reduce or eliminate intended effects of the regulation (Gigliotti and Taylor, 1990; Byers and Noonburg, 2007). In fact, the level of compliance with regulations can change the optimal regulatory instrument (Hansen et al., 2008). In order to accurately predict the effects of a management action, noncompliance with regulations needs to be considered.

Bag limits (or creel limits) are one of the most commonly used management tools for recreational fisheries (Porch and Fox, 1990; Radomski et al., 2001). Bag limits set a maximum number of fish of a species or group of species that can be harvested by an individual angler during a specified amount of time. The primary purposes of bag limits are typically to reduce fishing mortality and to provide more equitable distribution of the harvest (Porch and Fox, 1990). The size of bag limits for many species has declined over time as more conservation concerns have arisen in recreational fisheries, but the rationale for changes in bag limits and analysis of probable effects of changes are often lacking (Cook et al., 2001). In many fisheries, bag limits are not thought to be effective management tools because few anglers reach the bag limit (Radomski et al., 2001).

Simulation methods can be used to estimate the effects of a bag limit on harvest and fishing mortality, and these methods often rely on creel survey data (Porch and Fox, 1990, 1991). Many fishery management agencies conduct contact creel surveys to estimate catch and effort in many recreational fisheries (Pollock et al., 1994). These data often contain information on noncompliance because most creel surveys are designed to sample the angling population instead of serving as a law enforcement tool (Pollock et al., 1994). However, estimating the probable effect of a change in bag limit usually does not include effects of possible noncompliance. My objective was to develop a model to allow estimation of angler noncompliance with bag limits from contact creel survey data. The method was applied to data from the recreational fishery for king mackerel (*Scomberomorus cavalla*) in the southeastern U.S.

2. Methods

2.1. Model description

Angler trips were divided into two populations, compliant and potentially noncompliant. The term potentially noncompliant was

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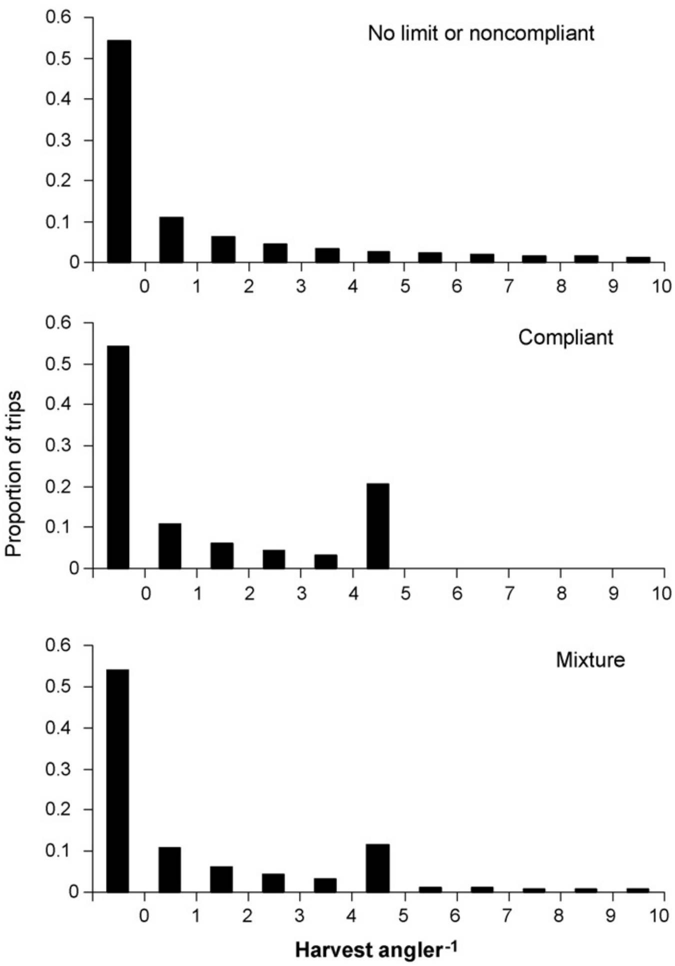

Fig. 1. General pattern of recreational harvest angler^{-1} with no bag limit (or complete noncompliance), a bag limit of five fish angler^{-1} day^{-1}, and mixture of compliance and noncompliance with 50% potential noncompliance.

used because harvest must exceed the bag limit in order to actually be noncompliant. The model described harvest angler^{-1} trip^{-1} as a mixture of a negative binomial distribution and a truncated negative binomial distribution (Fig. 1),

$$P(h) = xP_n(h) + (1 - x)P_c(h),$$

where variable definitions are provided in Table 1.

Harvest angler^{-1} trip^{-1} followed a negative binomial distribution for potentially noncompliant angler trips (or catch per angler trip with no bag limit),

$$P_n(h) = \frac{\Gamma(k+h)}{\Gamma(k)h!}\left(\frac{m}{m+k}\right)^h\left(\frac{k}{m+k}\right)^k,$$

and a truncated negative binomial distribution with the probability mass for harvests above the bag limit added to the bag limit for compliant angler trips,

$$P_c(h) = \begin{cases} P_n(h) & \text{for } h < b \\ \sum_{i=b}^{\infty} P_n(i) & \text{for } h = b \\ 0 & \text{for } h > b \end{cases}.$$

The negative binomial distribution has been suggested as an appropriate model for harvest angler^{-1} trip^{-1} (Porch and Fox, 1990) and has been used in previous studies (e.g., Bannerot and Austin, 1983). The model does not assume that an individual angler or angler party will always be compliant or noncompliant nor did it estimate of the proportion of anglers that are noncompliant.

The parameters of the model, m, k, and x, are estimated by minimizing the negative log likelihood function,

$$-LL = \sum_h n_h \log P(h).$$

In this description, the model has been described for a single year and angler party size. Multiple years of data are often available, and angler catches, particularly when fishing by boat, are frequently aggregated, thus not allowing for analysis of individual angler's catches. Given informative data, these parameters could be estimated for each year and each angler party size. The proportion of angler trips that are noncompliant (i.e., have catches above the bag limit) are a function of m, k, and x and can be easily estimated using this model,

$$P(h > b) = x\left(1 - \sum_{i=0}^{b} P_n(i)\right).$$

Table 1
Variable definitions.

Variable	Definition
h	Harvest per trip
x	Proportion of potentially noncompliant angler trips
$P(h)$	Probability of trips with harvest h from potentially compliant and noncompliant angler trips
$P_c(h)$	Probability of trips with harvest h from compliant angler trips
$P_n(h)$	Probability of trips with harvest h from potentially noncompliant angler trips
m	Mean parameter of the negative binomial distribution
k	Dispersion parameter of the negative binomial distribution
b	Daily bag limit for an individual angler or party of anglers
Γ	Gamma function
n_h	Number of observations of harvest h
−LL	Negative log likelihood

2.2. Application to king mackerel

The U.S. king mackerel fishery is managed as two stocks with one centered in the Gulf of Mexico and the other distributed along the southeastern U.S. Atlantic coast from Florida to North Carolina. For this study, I only considered the Atlantic migratory group in North Carolina. King mackerel is fished by recreational anglers and commercial fishers. The Atlantic migratory group of the king mackerel stock was considered overfished in the late 1980s (South Atlantic Fishery Management Council, 1989). As a result, substantial changes in regulations were adopted to reduce fishing mortality rates, such as gear restrictions and trip limits for commercial fisheries and increased size limits and reduced bag limits for recreational fisheries. The history of changes in bag limits for king mackerel has been five king mackerel angler^{-1} day^{-1} during 1991–1994 and three king mackerel angler^{-1} day^{-1} since 1995.

I compared four models: 1) a null negative binomial model (i.e., no compliance with bag limits), 2) a model with almost complete compliance with bag limits (the noncompliance parameter was set to 1%), 3) a model with a single noncompliance parameter that was constant over time, and 4) a model that estimated a noncompliance parameter for each year. For each model, separate m and k parameters were estimated for each year. The model with 1% noncompliance was arbitrarily chosen to represent the case of almost no noncompliance because the negative log likelihood function is undefined for a model with complete compliance, but observations of anglers over the bag limit. An additional model that estimated separate m and k parameters for compliant and potentially noncompliant trips was also attempted, but parameter estimates were not uniquely identifiable. The maximum likelihood estimates of the parameters of each model were found using AD Model Builder (Otter Research Limited, 2000). AD Model Builder is a superset of C++ libraries that facilitates development of nonlinear statistical models. It implements a quasi-Newton search algorithm that relies on exact (to machine precision) derivatives calculated using a reverse-mode automatic differentiation algorithm. Models were compared with the Akaike's Information Criterion corrected for small sample size (AIC_c) and Akaike weights (AIC_c weights), which estimate the relative evidence of one model among a set of models (Burnham and Anderson, 2002).

I fitted the model to data from the contact creel survey portion of the Marine Recreational Fisheries Statistics Survey (MRFSS) from 1991 to 2007. MRFSS is a large-scale creel survey in the U.S., which is designed to estimate catch, harvest, species composition, catch per unit effort (CPUE), and effort in marine recreational fisheries. MRFSS consists of a telephone-based survey to estimate total effort and in-person dockside interviews in public fishing areas to estimate CPUE and species composition. Data are collected from dockside interviews of completed fishing trips and include information on number fish and species harvested, sizes of harvested

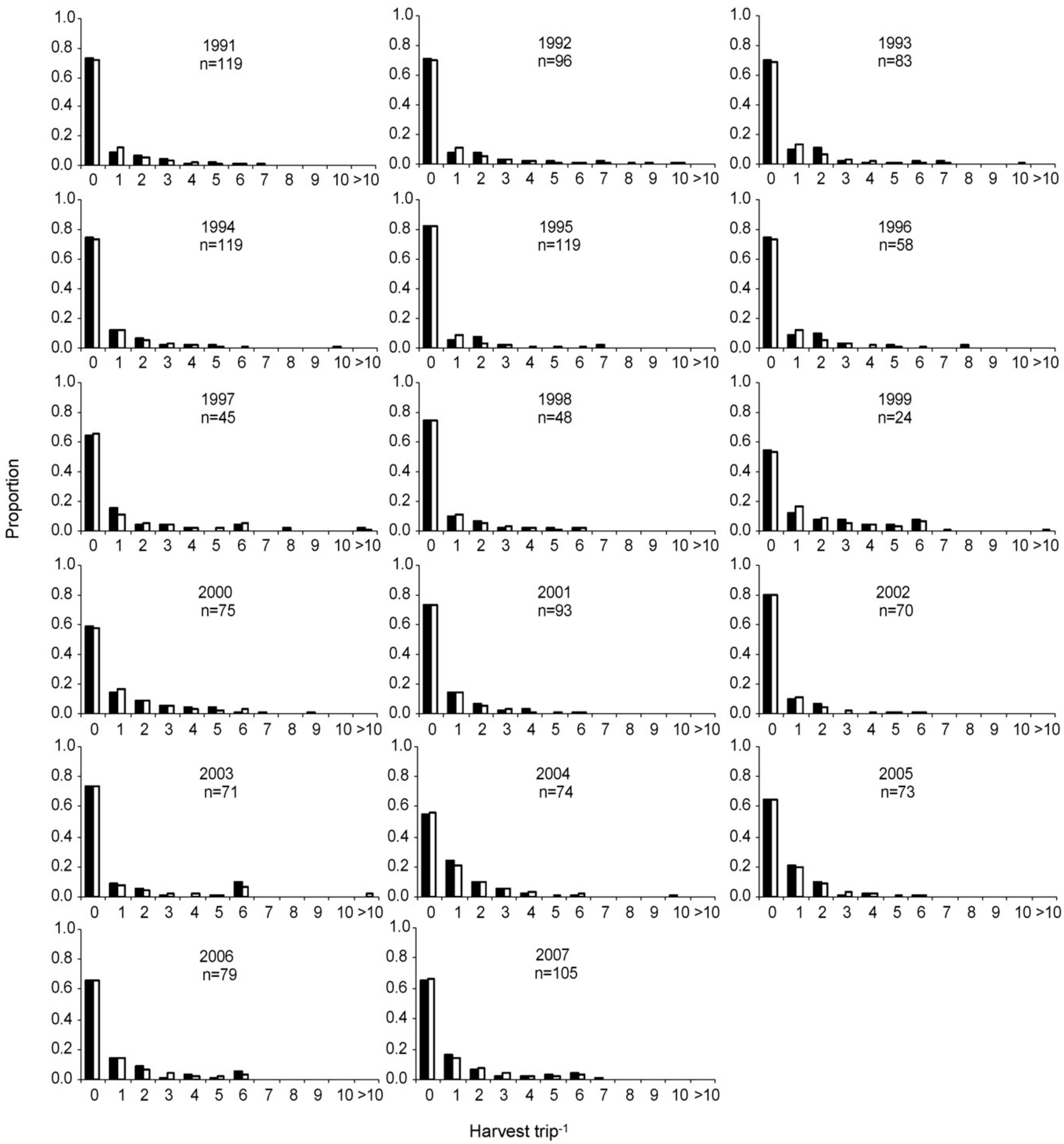

Fig. 2. Observed (black bars) and predicted harvest trip^{-1} for model with constant potential noncompliance (white bars) for a party size of two. Year and sample size (n) are indicated in each panel.

fish, number of fish released, and target species of the fishing trip. This study only used information from the in-person dockside interviews. Data were selected from private and rental boat anglers in North Carolina who stated they targeted king mackerel on their fishing trip. Data were sorted by party size, and this application uses a party size of two because this was the most frequent party size for trips targeting king mackerel (47% of trips and 37% of harvest; MRFSS, unpublished data). The censoring of data resulted in 1351 observations during 1991–2007. For a party size of two, the effective bag limit for a trip was 10 king mackerel angler^{-1} trip^{-1} during 1991–1994 and six king mackerel angler^{-1} trip^{-1} since 1995. Using a party size of two allows the model to be substantially simplified from considering parties of all sizes because only a single bag limit and set of m and k parameters are used in each year.

3. Results and discussion

Harvest per trip ranged from zero to twelve for trips with two anglers, with harvest of zero being the most common outcome (Fig. 2). Few trips reached the bag limit when it was five fish angler^{-1} day^{-1} during 1991–1994, but achieving the bag limit became more common since it was reduced to three fish angler^{-1} day^{-1}. Observed trips over the bag limit were rare and comprised only 0.8% of the observations.

All of the models fit the data reasonably well. However, models with complete noncompliance and little noncompliance had much lower AIC$_c$ weights than models that estimated noncompliance, indicating that models that estimated noncompliance were substantially better than those that did not (Table 2). Further, the model with a single noncompliance parameter had a substantially higher AIC$_c$ weight than the model with annual noncompliance parameters. Because the model with a single estimated noncompliance parameter was superior the other models, only detailed results from this model are presented.

Estimates of the m and k parameters varied over time, but did not show an obvious trend (Fig. 3). The estimated proportion of potentially noncompliant trips was about 36% for the model with a single noncompliance parameter. Estimated noncompliance (anglers harvesting more than the bag limit) was only about 1% and was much lower than potential noncompliance because relatively few angler trips reached the bag limit (Fig. 4). The cause of the discrepancy between potential and actual noncompliance occurred because less than 3% of trips were estimated to reach the bag limit in most years, and about 1% were estimated to have harvested more than the bag limit, which suggests that the bag limit affects only a small proportion of anglers.

An additional analysis was conducted to estimate effects of noncompliance on harvest by jointly considering parties from one to four private and rental boat anglers in North Carolina who stated they targeted king mackerel on their fishing trip. This range of party sizes composed more than 97% of the interviews during 1991–2007. In this analysis, separate m and k parameters were estimated for each party size and each year, but a common potential noncompliance parameter was estimated across years and party sizes. For computational stability, a small constant (0.0001) was added to the

Table 2
Negative log likelihood (−LL), number of parameters, corrected Akaike's Information Criterion (AIC$_c$), and AIC$_c$ weights for models of king mackerel harvest trip^{-1} for a party size of two during 1991–2007. The number of observations for calculation of AIC$_c$ was 1351.

Model	−LL	# parameters	AIC$_c$	AIC$_c$ Weight
Single noncompliance	1463.1	35	2998.1	0.992
Annual noncompliance	1450.9	51	3007.9	0.008
100% noncompliance	1480.1	34	3030.0	0.000
1% noncompliance	1490.6	34	3051.0	0.000

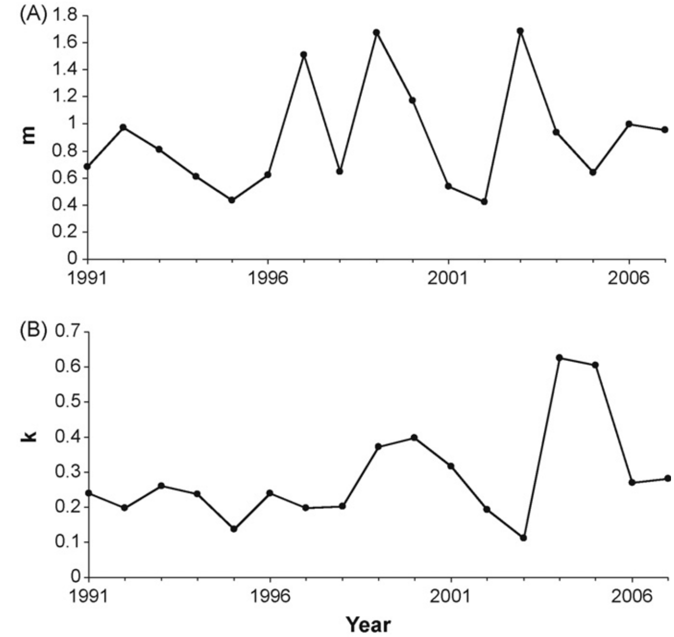

Fig. 3. Annual maximum likelihood estimates of mean (m; panel A) and dispersion (k; panel B) parameters for the model with constant potential noncompliance over time for the recreational Atlantic king mackerel fishery off North Carolina during 1991–2007.

probability while calculating the likelihood. The estimate of potential noncompliance was about the same as in the analysis of parties of two, 38%, and the estimated proportion of anglers that were noncompliant was about 1%. As in the analysis of two-angler parties, few trips reached the bag limit, and this caused noncompliance to be low. Although a small proportion of angler trips were estimated to have harvested more than the bag limit, illegal (above the bag limit) harvest accounted for about 7% of the total from this sector during 1995–2007. This occurred because trips that were over the bag limit had substantially higher harvest than average.

The level of potential noncompliance estimated in this study is likely caused by an inability among many anglers to accurately identify species or a lack of awareness of regulations. In particular, small king mackerel can be mistaken for Spanish mackerel (*Scomberomorus maculates*). Page and Radomski (2006) found that anglers who were unaware of regulations were more likely to violate them. In addition, fisheries where the regulations have changed frequently have a higher proportion of anglers that are unfamiliar with the regulations (Page and Radomski, 2006).

In most cases this model will provide a minimum estimate of noncompliance because only observed noncompliance is used in the estimation. Creel survey data frequently contain observations of noncompliance because they are designed to estimate catch and

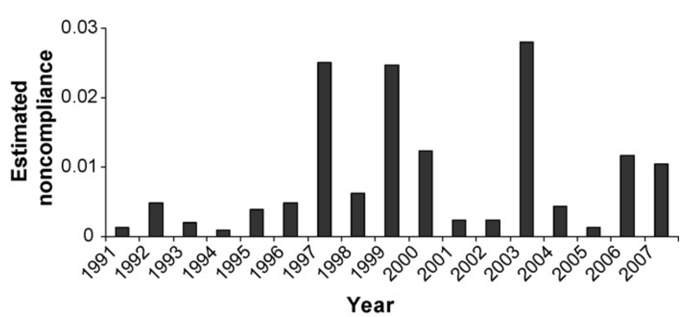

Fig. 4. Estimated proportion of noncompliant trips for king mackerel from the model with constant potential noncompliance for a party size of two during 1991–2007.

effort instead of being a law enforcement tool (Pollock et al., 1994), but these observations are probably of anglers who are unaware of the regulations. Anglers who intentionally harvest over the bag limit would probably avoid creel clerks or refuse to have their catches inspected. Additionally, anglers may harvest more than their daily bag limit by fishing multiple trips per day. Because the data for this model are observed harvest per trip, this sort of behavior would be considered compliant if the anglers did not exceed the bag limit on a given trip. Bag limit regulations may also affect angler choices of where to fish and what to fish for, which can alter the effectiveness of regulations (Beard et al., 2003).

This model may also be useful for standardizing fishery dependent indices of abundance when bag limits have changed over time. Recreational fishery data are often used in stock assessments, and CPUE is frequently used as an index of abundance. Changing regulations can affect catchability, thus causing fishery CPUE to not be proportional to abundance. This could be especially true if anglers continue to fish for other species after reaching their bag limit because the length of a fishing trip may not reflect the amount of time spent fishing for the original target species. Therefore, when bag limits change over time, CPUE in the fishery could change in a way that is not proportional to abundance. The model discussed in this paper, or one without noncompliance, could be used in a generalized linear model framework (McCullagh and Nelder, 1989; Maunder and Punt, 2004) to standardize recreational fishery CPUE and account for changes in bag limits when angler trips are thought to be a better measure of effort than angler hours. The m or k parameter from each year could provide an index of abundance. Alternatively, Bannerot and Austin (1983) suggested that the proportion of zero catches was the best index of abundance for a headboat fishery for yellowtail snapper (*Ocyurus chrysurus*).

Effects of noncompliance with proposed regulations should be included in analyses of effects of regulations on a fishery (Hansen et al., 2008). Although effects of noncompliance were likely low in this study, noncompliance will have a greater effect when a larger proportion of anglers reaches the bag limit. The method presented in this paper for estimating noncompliance with bag limits can be useful for determining likely effects of changes in bag limits, and can also be useful for determining whether additional enforcement or education may be necessary to achieve management objectives. This model could also be combined with the methods of Porch and Fox (1990) to estimate effects of reductions or increases in noncompliance on fishing mortality rates and catches, which could be useful for evaluating tradeoffs between increased education or law enforcement and additional regulations.

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