Abstract—Recreational fisheries in the waters off the northeast U.S. target a variety of pelagic and demersal fish species, and catch and effort data sampled from recreational fisheries are a critical component of the information used in resource evaluation and management. Standardized indices of stock abundance developed from recreational fishery catch rates are routinely used in stock assessments. The statistical properties of both simulated and empirical recreational fishery catch-rate data such as those collected by the National Marine Fisheries Service (NMFS) Marine Recreational Fishery Statistics Survey (MRFSS) are examined, and the potential effects of different assumptions about the error structure of the catch-rate frequency distributions in computing indices of stock abundance are evaluated. Recreational fishery catch distributions sampled by the MRFSS are highly contagious and overdispersed in relation to the normal distribution and are generally best characterized by the Poisson or negative binomial distributions. The modeling of both the simulated and empirical MRFSS catch rates indicates that one may draw erroneous conclusions about stock trends by assuming the wrong error distribution in procedures used to developed standardized indices of stock abundance. The results demonstrate the importance of considering not only the overall model fit and significance of classification effects, but also the possible effects of model misspecification, when determining the most appropriate model construction.

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The statistical properties of recreational catch rate data for some fish stocks off the northeast U.S. coast

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Major recreational fisheries in the waters off the northeast U.S. coast target a wide variety of pelagic and demersal fish species (NMFS, 1995, 1996). Fishery data collected in the National Marine Fishery Service (NMFS) Marine Recreational Fishery Statistics Survey (MRFSS) are the basis of fishery catch and effort estimates for most of these recreational fisheries and for indices of population abundance used in stock assessments (USDOC, 1992, 2001). For some stocks, reliable fishery-independent data such as research trawl survey indices are not available, and therefore the recreational fishery data are essential for tracking stock abundance. The intercept (creel sampling) portion of the MRFSS is an interview-type survey of recreational fishing trips and is conducted at public fishing sites such as marinas, launching ramps, fishing piers, and beaches. MRFSS catch estimates are made by expanding intercept survey sample catch rates in numbers, calculated on a per trip basis, by the estimated total number of recreational fishing trips. The estimated total number of fishing trips is calculated from data collected in a MRFSS telephone survey of households located in coastal counties. The U.S. Department of Commerce (USDOC, 1992, 2001) has provided overviews of the MRFSS intercept and telephone survey methods and catch estimation procedures.

In many cases recreational and commercial catch rates used as abundance indices are standardized by using general linear models that assume a lognormal error distribution (Gulland, 1956; Robson, 1966; Gavaris, 1980; Kimura, 1981). Commercial fishery catch-rate data generally meet tests of normality when log-transformed (Gulland, 1956; O'Brien and Mayo, 1988). Because of the efficiency and "integrating" property of commercial fishing gear (including trawls, fixed nets, and longlines), even catch rates on a per tow or per set basis are usually lognormally distributed (Taylor, 1953). An important characteristic of commercial data is that catch rates of zero (tows or sets with no catch of the target species) are rare.

With the assumption that there is an underlying lognormal error distribution, general linear models have often been used to standardize recreational fishery catch rates and compute indices of abundance. This approach has been used in the assessments of bluefin tuna (Brown and Browder, 1994), summer flounder (Terceiro[1]), black sea bass (NEFSC[2]), tautog (NEFSC[2]), winter flounder (NEFSC[3]), and bluefish

[1] Terceiro, M. (ed.). 1993. Assessment of summer flounder (*Paralichthys dentatus*), 1993: report of the stock assessment workshop summer flounder working group. Northeast Fisheries Science Center reference document 93-14, 72 p. Northeast Fisheries Science Center, Woods Hole, MA 02543.

[2] NEFSC (Northeast Fisheries Science Center). 1996a. Report of the 20th northeast regional stock assessment workshop (20th SAW): Stock Assessment Review Committee (SARC) consensus summary of assessments. Northeast Fisheries Science Center reference document 95-18, 210 p. Northeast Fisheries Science Center, Woods Hole, MA 02542.

[3] NEFSC. 1996b. Report of the 21st northeast regional stock assessment workshop (21st SAW): Stock Assessment Review Committee (SARC) consensus summary of assessments. Northeast Fisheries Science Center reference document 96-05d, 200 p. Northeast Fisheries Science Center, Woods Hole, MA 02543.

(NEFSC[4]; Gibson and Lazar[5]). However, Bannerot and Austin (1983) noted that the sampling distribution of recreational catch data is often highly skewed with a longer right-hand tail than might be expected even from a lognormal distribution. Furthermore, depending on the way the catch rate is defined (i.e. catch per trip, day, or hour), recreational fishery catch-rate distributions may contain a high proportion of zero catches.

Hilborn (1985) presented a frequency distribution of numbers of salmon caught per trip in the British Columbia sport fishery that appears to be best characterized by the negative binomial distribution, with a catch per hour frequency best characterized by the Poisson distribution. Jones et al. (1995) investigated the statistical properties of recreational fishery sampling data collected in angler surveys in Virginia and noted that the non-normality of recreational fishery data may violate assumptions of lognormality in methods used to develop indices of abundance, and especially the validity of confidence intervals. Power and Moser (1999) expressed similar concerns about sampled distributions of fish and plankton collected by research trawl nets, noting that the assumption of an underlying normal or lognormal distribution for these types of data is commonplace, and perhaps in error, and that distributions such as the Poisson or negative binomial may be more appropriate. Smith (1990, 1996) recommended various nonparametric resampling methods (e.g. bootstrap confidence intervals) for characterizing the dispersion of highly skewed research trawl survey catch distributions having a large proportion of zero catches. Smith (1999) modeled angling success for salmon, expressed as the catch after the first hour of angling, using a negative binomial distribution model.

In addition to the Poisson and negative binomial, alternatives to the lognormal error model for recreational fishery catch rates also include the delta-lognormal and delta-Poisson error models. These models are combinations of the delta distribution (Pennington, 1983) and lognormal or Poisson model approaches. The delta distribution has been used in modeling fish and plankton abundance indices from research trawl survey data, which are characterized by highly skewed distributions with a relatively high proportion of zero catches (Pennington, 1983). In the combined delta-lognormal and delta-Poisson approaches, indices of abundance are modeled as a product of binomially distributed probabilities of a positive catch and lognormal or Poisson distributed positive catch rates. The delta-lognormal model has been used in modeling fish-spotter data (Lo et al., 1992) and in the standardization of recreational fishery catch rates for bluefin tuna (Brown and Porch, 1997; Turner et al., 1997; Brown, 1999; Ortiz et al., 1999), both characterized by a highly contagious spatial distribution and a large proportion of zeroes. Bluefin and yellowfin tuna catch rates in the commercial and recreational fisheries have also been standardized by using Poisson (Brown and Porch, 1997), negative binomial (Turner et al., 1997), and delta-Poisson error distributions (Brown, 2001; Brown and Turner, 2001) to address these distributional characteristics.

In this study I first examine the statistical properties of recreational fishery catch-rate data as sampled by the MRFSS. Next, I examine the goodness of fit to different statistical distributions of empirical MRFSS catch rates, on both per trip and per hour bases. I then explore the effects of five different assumptions about the error structure of the catch-rate frequency distributions (lognormal, delta-lognormal, Poisson, delta-Poisson, and negative binomial) in deriving standardized indices of abundance with general linear models, using simulated recreational fishery and empirical MRFSS catch per trip (zero catches included) data.

Materials and methods

Overview of statistical methods

This work focuses on catch number per trip sampled in the MRFSS as the index of abundance. The distributional properties of MRFSS catch-per-hour rates are also examined, in order to explore whether the general conclusions reached for catch-per-trip rates are likely to be similar to catch-per-hour rates. Directed trips are defined as those for which interviewed anglers indicated that they were intending to catch a particular species as a primary or secondary target, whether successful or not (zero catches included). In analyses of trips for all species, all trips were used regardless of target or success (zero catches included). Catch rates were expressed as integer (natural) numbers of fish per trip or per hour.

A value of 1 was added to all observations when applying a lognormal transformation to allow inclusion of the zero catch rate observations (this constant was subtracted upon retransformation to the original scale). Expected sample values for the lognormal distribution were calculated by using the normal distribution and log-transformed catch rates (Sokol and Rohlf, 1981). Previous work on MRFSS catch-per-trip data has shown that the value of 1 is the appropriate constant to be added (Terceiro[1]; NEFSC[3]) because it tends to minimize the sum of the absolute value of skew and kurtosis for these distributions (Berry, 1987). The standard logarithmic transform bias correction was applied to express results in the original arithmetic scale (Finney, 1951; Bradu and Mundlak, 1970). No constant was added when data were analyzed under the assumption of binomial, Poisson, or negative binomial error distributions.

The binomial distribution is a discrete frequency (probability) distribution of the number of times an event occurs in a sample in which some proportion of the members possess some variable attribute (Snedecor and Cochran, 1967). Each event is assumed independent of other prior

[4] NEFSC. 1997. Report of the 23rd northeast regional stock assessment workshop (23rd SAW): Stock Assessment Review Committee (SARC) consensus summary of assessments. Northeast Fisheries Science Center reference document 97-05, 191 p. Northeast Fisheries Science Center, Woods Hole, MA 03543.

[5] Gibson, M. R., and N. Lazar. 1998. Assessment and projection of the Atlantic coast bluefish using a biomass dynamic model. A report to the Atlantic States Marine Fisheries Commission Bluefish Technical Committee and Mid-Atlantic Fishery Management Council Scientific and Statistics Committee, 29 p. Rhode Island Division of Fish and Wildlife, Jamestown, RI 02835

Table 1

Descriptive statistics for MRFSS (Marine Recreational Fishery Statistics Survey) 1981, 1988, and 1996 northeast U.S. coast catch per trip, including zero catches. Catch is given in numbers of fish. CV is the coefficient of variation (%). D is the Kolmogorov test statistic for normality. Test statistics significant at the 1% level (P<0.01) are shown by **, indicating rejection of the null hypothesis that catch rates follow a normal distribution.

Species	No. of trips	Mean	Median	Variance	CV	Skew	D
1981							
Bluefish	4615	3.80	0.00	155.09	328	27.78	0.380**
Summer Flounder	3135	1.88	0.00	14.69	204	4.71	0.312**
Atlantic cod	509	2.55	1.00	13.49	144	2.48	0.244**
Scup	269	8.44	2.00	275.10	196	4.08	0.305**
All species	20,280	3.45	0.00	355.94	547	65.48	0.427**
1988							
Bluefish	7294	1.60	0.00	18.65	270	6.42	0.355**
Summer Flounder	4779	2.26	0.00	18.48	190	3.70	0.300**
Atlantic cod	1558	4.56	2.00	21.55	154	3.68	0.258**
Scup	960	9.28	3.00	312.65	190	4.48	0.300**
All species	48,423	2.29	0.00	43.66	289	8.94	0.365**
1996							
Bluefish	5457	1.20	0.00	13.12	301	8.40	0.370**
Summer Flounder	7047	2.33	1.00	13.49	157	3.40	0.263**
Atlantic cod	1099	3.97	1.00	43.34	166	3.29	0.273**
Scup	643	13.83	4.00	524.60	165	3.44	0.273**
All species	81,057	2.57	0.00	47.32	268	10.45	0.354**

events in the same sample (Sokal and Rohlf, 1981). In the present study, the binomial distribution was used only to model the probabilities of a positive catch (as opposed to a zero catch; thus the variable attribute of the observation is either catch or no catch) in the combined delta-lognormal and delta-Poisson models.

The Poisson distribution is also a discrete frequency distribution of the number of times an event (such as catching a fish during a trip) occurs in a sample and is characterized by a small mean value in relation to the observed maximum number of events within the sample (Sokal and Rohlf, 1981). For a Poisson distribution, the expected variance is equal to its mean, and Poisson frequency distributions are more highly skewed than normal or lognormal distributions (Bliss and Fisher, 1953).

The negative binomial is a discrete frequency distribution with a higher degree of dispersion than the Poisson distribution, such that the variance is significantly larger than the mean. A negative binomial distribution will converge to a Poisson as the variance approaches the mean (Bliss and Fisher, 1953). Although not as widely applied as the Poisson in the analysis of count data, there is a growing literature describing the properties of negative binomial regression methods to be used when analyzing "over-dispersed Poisson" frequency distributions (Manton et al., 1981; Lawless, 1987). The dispersion parameter of the negative binomial distribution, k, is a positive exponent relating the mean and variance of the distribution such that as the variance of a distribution exceeds the mean, the value of k decreases and the "over-dispersion" of the distribution in relation to a Poisson distribution increases. The most efficient estimate of the sample parameter, k', is estimated by maximum likelihood (Bliss and Fisher, 1953).

Descriptive statistics and frequency distributions of MRFSS catch per trip and catch per hour observations were compiled by using the SAS FREQ and UNIVARIATE procedures (SAS, 2000). Tests of normality were made with the Kolmolgorov-Smirnov D-statistic for normality (test significance expressed as probability < D; SAS, 2000). Evaluation of the most appropriate distributional fit to the data was based on inspection of the frequency distribution plots, the parametric chi-square (χ^2) and G-statistic goodness-of-fit tests, and the nonparametric Kolmogorov-Smirnov (D-statistic) goodness-of-fit test for an intrinsic hypothesis (because the expected distributions were calculated from the observed sample moments; Sokol and Rohlf, 1981). For the chi-square and G-tests, when intervals (classes) of catch per trip with fewer than 3 expected instances occurred, expected and observed frequencies for these intervals were pooled with the adjacent intervals to obtain a joint class with an expected frequency of occurrence of 3 or more (Sokol and Rohlf, 1981). Because of the large sample sizes involved (>>100), the G-test correction suggested by Williams (1976) proved to be very small in a few test calculations and therefore was not routinely applied. Unrealistic (for recreational fishery catch-rate data) negative expected values computed for the lognormal distributions were excluded, and the remaining positive distribution was raised to the observed sample total, so that the expected proportions at each interval summed to 1.0.

Standardized annual indices of abundance derived from the simulated recreational and empirical MRFSS data were calculated by using maximum likelihood estimation to fit generalized linear models with the SAS GENMOD procedure (SAS, 2000). The SAS (2000) defaults for model specification were generally followed. An identity link function was used under the lognormal distribution assumption (catch rates were ln-transformed prior to analysis). A logistic link function was used under the binomial distribution assumption applied for the probability of positive catch component in the delta-lognormal and delta-Poisson model approaches. A logarithmic link function was used under the Poisson and negative binomial assumptions (SAS, 2000). Type-3 general linear models were fitted in all cases because the results of this type of analysis do not depend on the order in which the terms of the model are specified. The significance of the individual classification effects (factors) in the models was judged by the chi-square statistic (Searle, 1987; SAS, 2000).

The overall goodness of fit of the standardization models was evaluated by using the deviance and log-likelihood statistics. The deviance is defined to be twice the difference between the maximum achievable log likelihood and the log likelihood at the maximum likelihood estimates of the model parameters (McCullagh and Nelder, 1989). The deviance has a limiting chi-square distribution, and so significance is judged by comparison to critical values of the chi-square distribution. The scale parameter (i.e. for normal distributions) was held fixed at 1 for all models to facilitate evaluation of goodness of fit and the degree of overdispersion for models with different error distribution assumptions. Holding the scale parameter fixed has no effect on the estimated intercept or model regression coefficients (e.g. in the study, the year coefficients that serve as the annual indices of abundance), but allows equivalent calculation among models of a "dispersion estimate" (SAS, 2000). This "dispersion estimate," measured after model fitting as the deviance divided by the degrees of freedom (deviance/df), is used to judge whether the data are overdispersed or underdispersed with respect to the error distribution used in model fitting and is therefore useful in evaluating whether the correct error distribution assumption has been used in the model (McCullagh and Nelder, 1989; SAS, 2000).

Descriptive statistics for MRFSS catch rates

The descriptive statistics (mean, median, variance, skewness, and Kolmolgorov-Smirnov (D) normality test statistic) and frequency distributions of MRFSS sample catch rates for 1981, 1988, and 1996 were examined for four species from U.S. Atlantic coast waters (Maine to the east coast of Florida), and in aggregate for all species sampled along the U.S. Atlantic coast. The following individual species were considered: bluefish (*Pomatomus saltatrix*, an example of a Atlantic coast predatory "gamefish"); summer flounder (*Paralichthys dentatus*, a Mid Atlantic Bight demersal flatfish); Atlantic cod (*Gadus morhua*, a New England demersal roundfish); and scup (*Stenotomus*

Table 2

Descriptive statistics for MRFSS (Marine Recreational Fishery Statistics Survey) 1981, 1988, and 1996 northeast U.S. coast catch per trip, positive catches only. Catch is given in numbers of fish. CV is the coefficient of variation (%). D is the Kolmogorov test statistic for normality. Test statistics significant at the 1% level ($P<0.01$) shown by **, indicating rejection of the null hypothesis that catch rates follow a normal distribution.

Species	No. of trips	Mean	Median	Variance	CV	Skew	D
1981							
Bluefish	2288	7.66	4.00	283.32	220	22.02	0.340**
Summer Flounder	1380	4.26	2.67	23.21	113	3.87	0.222**
Atlantic cod	298	4.36	3.00	15.19	89	2.26	0.188**
Scup	165	13.76	7.33	375.88	141	3.39	0.262**
All species	9484	7.33	3.00	732.27	368	47.02	0.395**
1988							
Bluefish	2445	4.75	2.33	40.35	133	4.40	0.254**
Summer Flounder	2326	4.64	3.00	26.92	112	2.94	0.209**
Atlantic cod	1065	6.67	4.00	58.02	114	3.46	0.219**
Scup	614	14.52	7.67	413.03	140	3.88	0.245**
All species	19,094	5.76	3.00	90.39	165	6.49	0.278**
1996							
Bluefish	1666	3.93	2.00	32.26	144	5.61	0.258**
Summer Flounder	4196	3.91	2.66	16.46	104	3.13	0.203**
Atlantic cod	679	6.43	4.00	54.39	115	2.85	0.210**
Scup	438	20.31	12.50	638.90	124	3.05	0.220**
All species	39,094	5.30	2.67	83.43	172	8.35	0.286**

Table 3

Descriptive statistics for MRFSS (Marine Recreational Fishery Statistics Survey) 1981, 1988, and 1996 northeast U.S. coast catch per hour, including zero catches. Catch is given in numbers of fish. CV is the coefficient of variation (%). *D* is the Kolmogorov test statistic for normality. Test statistics significant at the 1% level ($P<0.01$) shown by (**), indicating rejection of the null hypothesis that catch rates follow a normal distribution.

Species	No. of trips	Mean	Median	Variance	CV	Skew	*D*
1981							
Bluefish	4615	0.77	0.00	5.57	305	12.21	0.371**
Summer Flounder	3135	0.36	0.00	0.64	221	6.43	0.325**
Atlantic cod	509	0.38	0.17	0.43	172	4.04	0.280**
Scup	269	1.59	0.44	7.96	178	2.79	0.287**
All species	20,280	0.74	0.00	13.23	491	40.11	0.419**
1988							
Bluefish	7294	0.39	0.00	1.26	287	7.26	0.363**
Summer Flounder	4779	0.45	0.00	0.82	200	6.11	0.309**
Atlantic cod	1558	0.96	0.50	1.99	147	3.32	0.249**
Scup	960	2.12	0.67	14.03	177	3.60	0.286**
All species	48,423	0.54	0.00	3.07	325	15.18	0.379**
1996							
Bluefish	5457	0.34	0.00	1.23	322	7.73	0.378**
Summer Flounder	7047	0.52	0.22	0.729	164	4.17	0.271**
Atlantic cod	1099	0.86	0.28	1.99	165	3.12	0.272**
Scup	643	3.06	1.17	27.78	172	3.79	0.281**
All species	81,057	0.62	0.00	4.51	341	35.84	0.385**

Table 4

Descriptive statistics for MRFSS (Marine Recreational Fishery Statistics Survey) 1981, 1988, and 1996 northeast U.S. coast catch per hour, positive catches only. Catch is given in numbers of fish. CV is the coefficient of variation (%). *D* is the Kolmogorov test statistic for normality. Test statistics significant at the 1% level ($P<0.01$) shown by (**), indicating rejection of the null hypothesis that catch rates follow a normal distribution.

Species	No. of trips	Mean	Median	Variance	CV	Skew	*D*
1981							
Bluefish	2288	1.56	0.75	10.00	203	9.48	0.317**
Summer Flounder	1380	0.82	0.50	1.07	126	5.35	0.229**
Atlantic cod	298	0.65	0.45	0.56	115	3.64	0.220**
Scup	165	2.56	1.67	10.41	125	2.16	0.242**
All species	9484	1.58	0.67	26.96	328	29.00	0.381**
1988							
Bluefish	2445	1.16	0.63	2.85	145	4.91	0.253**
Summer Flounder	2326	0.93	0.60	1.24	120	5.45	0.212**
Atlantic cod	1065	1.40	1.00	2.29	108	3.14	0.196**
Scup	614	3.31	1.71	17.98	128	3.09	0.223**
All species	19,094	1.37	0.67	6.67	188	11.08	0.301**
1996							
Bluefish	1666	1.13	0.55	3.15	157	4.80	0.270**
Summer Flounder	4196	0.87	0.58	0.90	109	3.93	0.198**
Atlantic cod	679	1.39	0.80	2.49	114	2.68	0.205**
Scup	438	4.49	2.73	34.38	131	3.38	0.228**
All species	39,094	1.29	0.63	8.49	226	28.09	0.331**

Table 5

Summary of goodness of fit tests for 1996 MRFSS (Marine Recreational Fishery Statistics Survey) catch per trip distributions, including zero catches, for bluefish, summer flounder, Atlantic cod, scup, and all species.

Species	Expected number of intervals	Degrees of freedom	χ^2 statistic	G statistic	$\chi^2_{0.01}$	D statistic	$D_{0.01}$
Bluefish							
Mean = 1.20							
Variance = 13.12							
n = 5457							
Lognormal	9	6	7314	5722	17	0.462	0.014
Poisson	7	5	5315	4251	15	0.394	0.014
Negative binomial	23	20	68	27	38	0.007	0.014
Summer flounder							
Mean = 2.33							
Variance = 13.49							
n = 7047							
Lognormal	11	8	8654	4714	20	0.281	0.012
Poisson	10	8	10,902	5772	20	0.307	0.012
Negative binomial	22	19	139	101	36	0.011	0.012
Atlantic cod							
Mean = 3.97							
Variance = 43.34							
n = 1099							
Lognormal	12	9	2138	1068	22	0.360	0.031
Poisson	12	10	8284	2212	23	0.425	0.031
Negative binomial	25	22	48	22	40	0.015	0.031
Scup							
Mean = 13.83							
Variance = 524.60							
n = 643							
Lognormal	28	25	389,173	3850	44	0.541	0.041
Poisson	25	23	6.67e+07	6391	42	0.544	0.041
Negative bionomial	51	48	305	235	74	0.053	0.041
All species							
Mean = 2.57							
Variance = 47.32							
n = 81,057							
Lognormal	14	11	180,754	83,230	25	0.382	0.004
Poisson	13	11	306,000	129,928	25	0.440	0.004
Negative binomial	51	48	1577	1146	74	0.020	0.004

chrysops, a Mid-Atlantic demersal schooling roundfish, likely to yield a relatively high catch per trip). These species were selected as examples because they occur over a broad range along the northeast U.S. coast, are among the most frequently caught by recreational fishermen, and their catch-rate distributions are representative of most species caught by recreational fishermen in the northeast U.S (USDOC, 1992). Four configurations of catch rate distributions were examined: 1) catch per trip distributions including zero catches, 2) catch per trip distributions with positive catches only, 3) catch per hour distributions including zero catches, and 4) catch per hour distributions with positive catches only.

Goodness-of-fit statistics for the lognormal, Poisson, and negative binomial distributions were calculated for the four individual species and for all species to help judge which error structure best characterized the MRFSS catch-rate data. A single year (1996) is presented because of the similarity of the catch distributions across species and time. Given the results of the Kolmogorov-Smirnov D tests from the descriptive statistics work, which indicated that none of the catch rates were normally distributed (see "Results" section), that error structure was not examined further. As with the descriptive statistics analysis, both catch-per-trip and catch-per-hour rates were examined in the goodness-of-fit exercise, both for

Table 6

Summary of goodness-of-fit tests for 1996 MRFSS (Marine Recreational Fishery Statistics Survey) catch per trip distributions, positive catches only, for bluefish, summer flounder, Atlantic cod, scup, and all species.

Species	Expected number of intervals	Degrees of freedom	χ^2 statistic	G statistic	$\chi^2_{0.01}$	D statistic	$D_{0.01}$
Bluefish							
Mean = 3.93							
Variance = 32.26							
n = 1666							
Lognormal	9	6	1803	1026	17	0.312	0.025
Poisson	11	9	2091	1211	22	0.312	0.025
Negative binomial	21	18	425	347	35	0.196	0.025
Summer flounder							
Mean = 3.91							
Variance = 16.46							
n = 4196							
Lognormal	10	7	6068	2863	18	0.270	0.016
Poisson	12	10	3821	2234	23	0.240	0.016
Negative binomial	20	17	699	587	33	0.143	0.016
Atlantic cod							
Mean = 6.43							
Variance = 54.39							
n = 679							
Lognormal	12	9	3376	962	22	0.379	0.040
Poisson	14	12	3419	925	26	0.365	0.040
Negative binomial	27	24	121	88	43	0.147	0.040
Scup							
Mean = 20.31							
Variance = 638.90							
n = 438							
Lognormal	30	27	3.74e+11	6565	47	0.543	0.049
Poisson	32	30	8.09e+07	3477	51	0.475	0.049
Negative binomial	50	47	204	147	72	0.089	0.049
All species							
Mean = 5.30							
Variance = 83.43							
n = 39,094							
Lognormal	11	8	70,234	24,957	20	0.254	0.001
Poisson	16	14	169,662	59,516	29	0.391	0.001
Negative binomial	50	47	12,293	10,217	72	0.201	0.001

all directed trips including zero catches and for positive catches only.

Simulated recreational fishery catch rates

To isolate the consequences of possible model misspecification in deriving standardized indices of abundance, negative binomial distributions with characteristics like those of MRFSS recreational catch-per-trip distributions were simulated by using the SAS RANTBL function (SAS, 2000). The simulated distributions were arranged to provide continuously decreasing, continuously increasing, and peaked (increasing to a peak and then decreasing) trends in an 11-year time series of catch per trip. For the decreasing trend, the simulation procedure began with year 1 set at a mean catch per trip = 3.0, maximum catch per trip of 50 fish per trip, and variance = 81.0, which are characteristic of the MRFSS catch-per-trip distributions for all species (Table 1). For year 1, this combination of mean and variance provided a maximum likelihood estimate of the negative binomial dispersion parameter, k, of 0.23.

The vector of expected probabilities of catch per trip for these initial moments, assuming a negative binomial distribution, was then used to randomly generate 1000

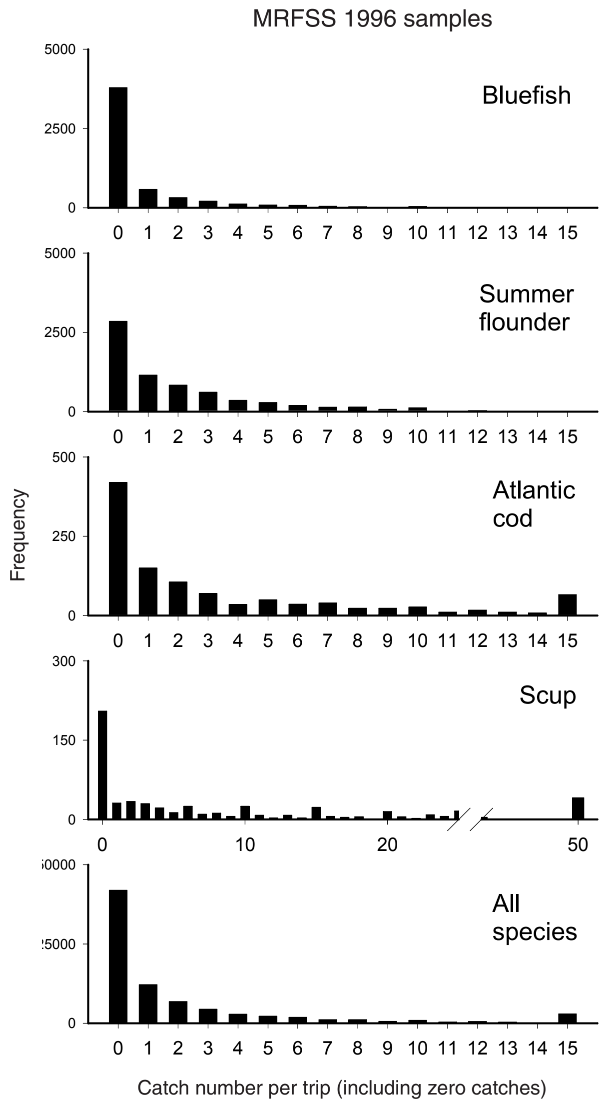

Figure 1

Marine Recreational Fishery Statistics Survey (MRFSS) 1996 sample data for bluefish, summer flounder, Atlantic cod, scup, and all species, Maine to the Florida east coast: catch number per trip (including zero catches). The 15 and 50 fish intervals are "plus groups" because they include totals for larger intervals.

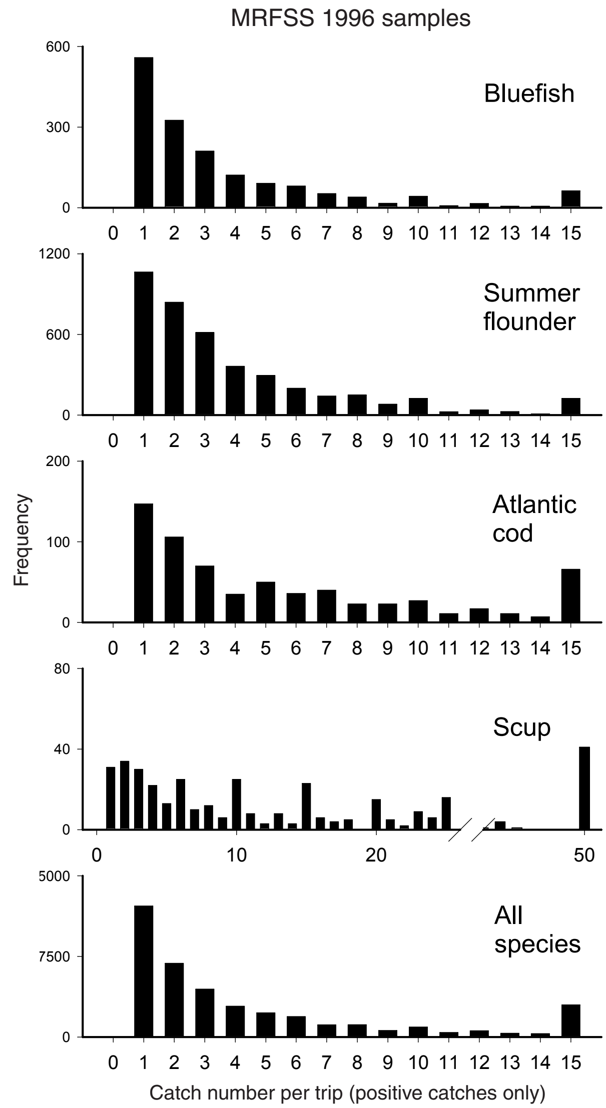

Figure 2

Marine Recreational Fishery Statistics Survey (MRFSS) 1996 sample data for bluefish, summer flounder, Atlantic cod, scup, and all species, Maine to the Florida east coast: catch number per trip (positive catches only). The 15 and 50 fish intervals are "plus groups" because they include totals for larger intervals.

observations of catch per trip (including zeroes) for year 1 (n=1000). The initial mean for year 2 was then set at 10 percent less than year 1 (i.e. 2.7) and the year 2 set of 1000 observations generated under the negative binomial assumption. The dispersion parameter, k, was held constant at the year 1 maximum likelihood estimate of 0.23, resulting in a decrease in variance, a relatively stable coefficient of variation (CV), and less frequent occurrence of large catch-per-trip values, as the mean decreased. These conditions were felt to best reflect the true changes in angler catch per trip as stock abundance declines. The exercise was repeated for years 3 to 11, providing a time series of decreasing simulated recreational fishery catch per trip. The simulated annual distributions, scaled (normalized) to the 11-year time series mean of 1.75, were re-ordered to create the increasing and peaked time series.

Standardized indices of abundance were then calculated from the simulated, trended series by using lognormal, Poisson, negative binomial, delta-lognormal, and delta-Poisson models, with year serving as the single classification vari-

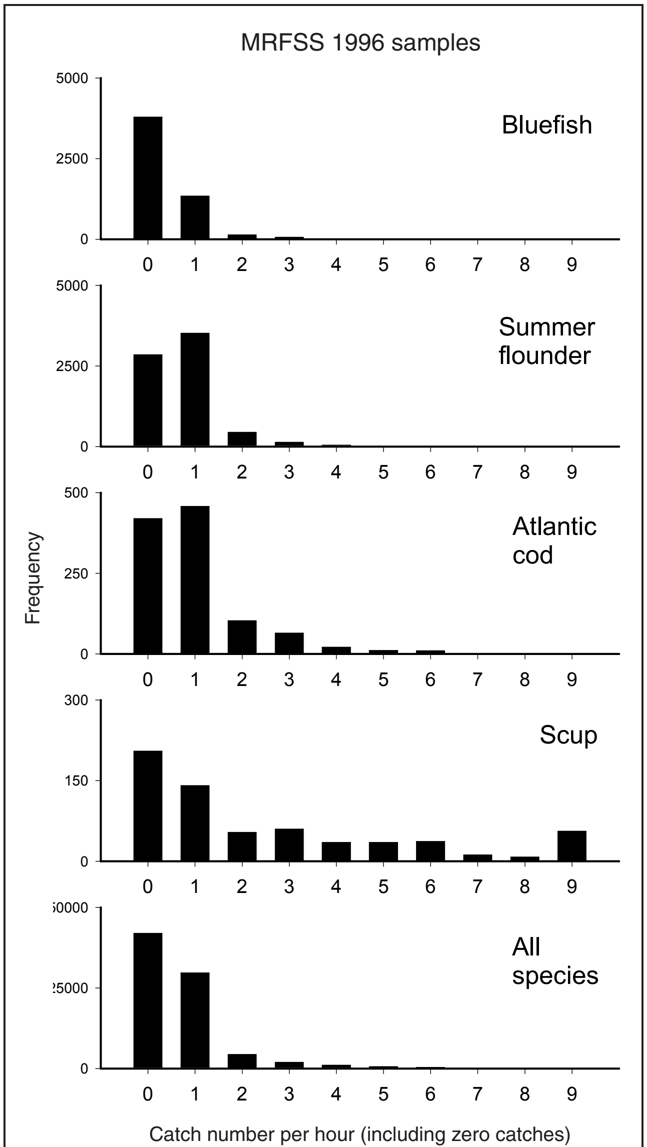

Figure 3

Marine Recreational Fishery Statistics Survey (MRFSS) 1996 sample data for bluefish, summer flounder, Atlantic cod, scup, and all species, Maine to the Florida east coast: catch number per hour (including zero catches). The 9 fish interval is a "plus group" because it includes totals for larger intervals.

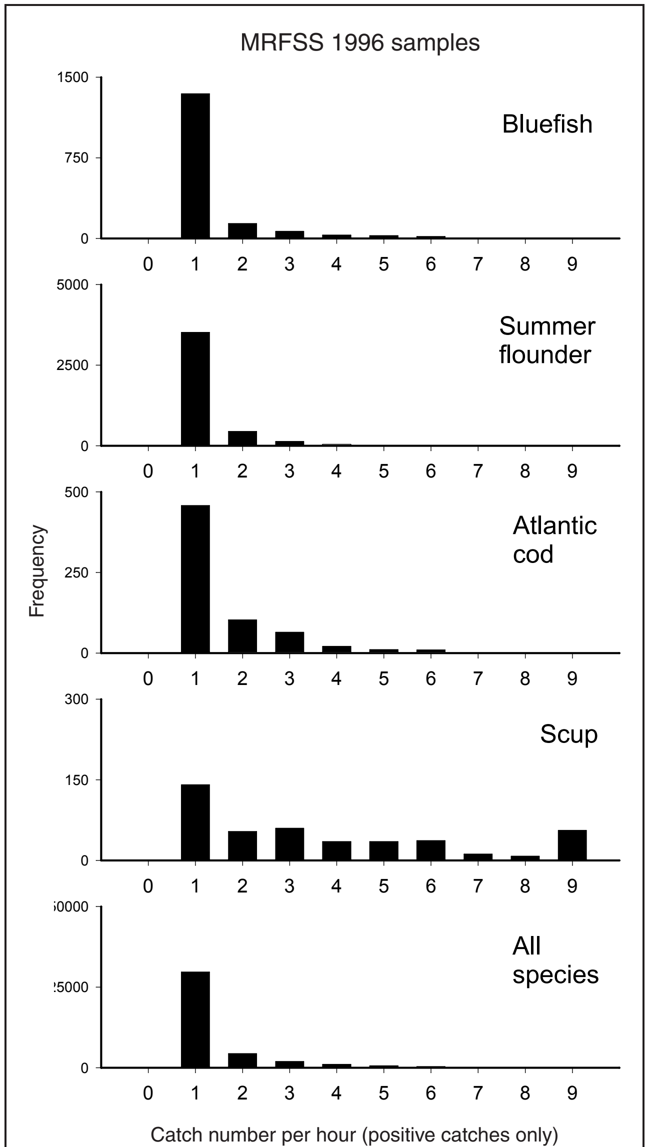

Figure 4

Marine Recreational Fishery Statistics Survey (MRFSS) 1996 sample data for bluefish, summer flounder, Atlantic cod, scup, and all species, Maine to the Florida east coast: catch number per hour (positive catches only). The 9 fish interval is a "plus group" because it includes totals for larger intervals.

able and index of abundance. Modeled in this way, the negative binomial model is expected to provide year-effect coefficients very close in absolute value to the unstandardized, mean simulated catch per trip of the true underlying negative binomial distribution because no other classification effects are present to account for variance from the unstandardized mean. The deviance of the year coefficients provided by the models, assuming the other error distributions, then provides an indication of the degree of model misspecification because virtually all the estimated variance in this particular exercise is due to model (process) error, except for the small amount generated by the random draw from the starting probability distributions.

MRFSS standardized indices of abundance, 1981–98

The potential effect of the assumed error structure on the calculation of standardized indices of abundance was further explored with empirical examples using the 1981–98 MRFSS time series of catch-per-trip rates (zero catches

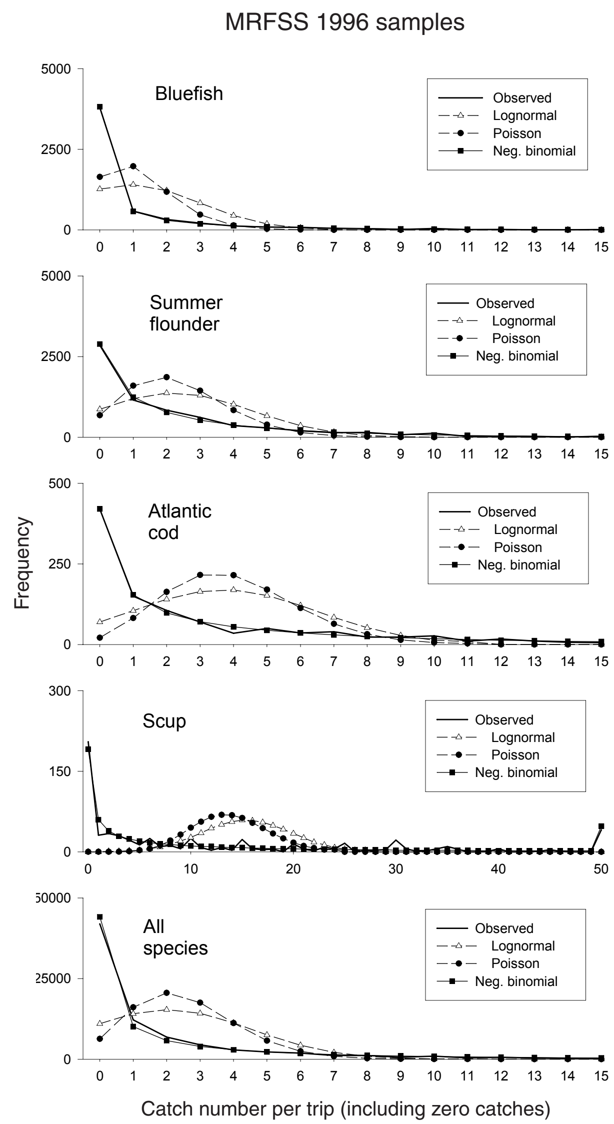

Figure 5

Observed and expected catch number per trip (including zero catches) frequency distributions for bluefish, summer flounder, Atlantic cod, scup, and all species, Maine to the Florida east coast. The 15 and 50 fish intervals are "plus groups" because they include totals for larger intervals.

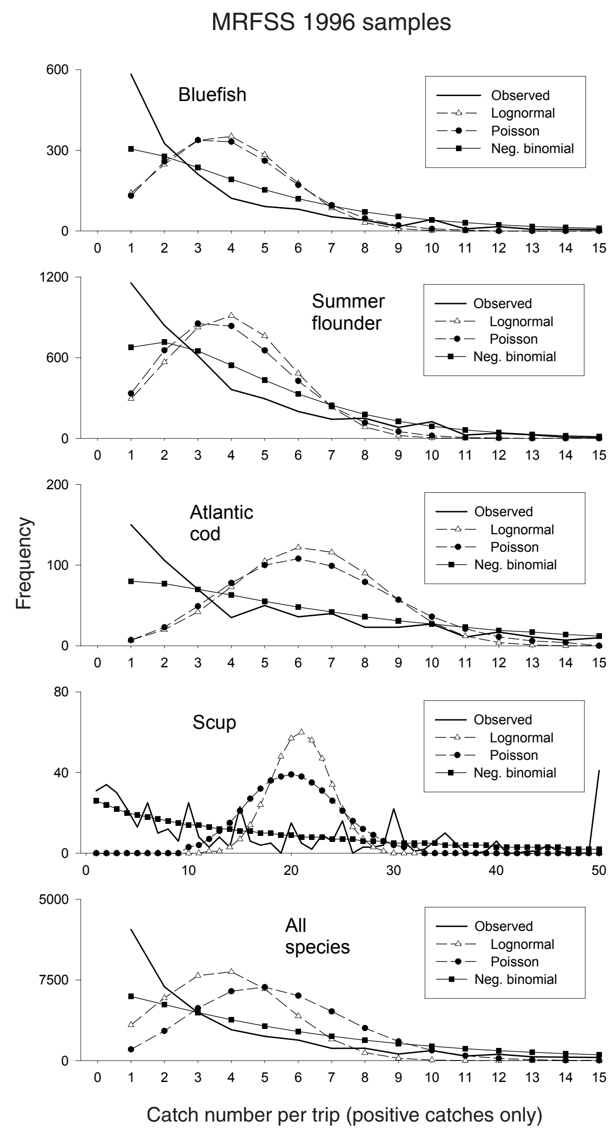

Figure 6

Observed and expected catch number per trip (positive catches only) frequency distributions for bluefish, summer flounder, Atlantic cod, scup, and all species, Maine to the Florida east coast. The 15 and 50 fish intervals are "plus groups" because they include totals for larger intervals.

included) for bluefish, summer flounder, Atlantic cod, scup, and for all species. Annual indices of stock abundance were developed from these MRFSS catch rate data following procedures in previous Atlantic coast bluefish and summer flounder stock assessments (Terceiro[1]; NEFSC[3]; Gibson and Lazar[5]). Standardized indices were calculated by applying lognormal, Poisson, negative binomial, delta-lognormal, and delta-Poisson models, using the main effects classification variables determined in these stock assessments to be statistically significant factors: year, fishing mode (shore, private or rental boat, party or charter boat), state of landing (Maine to Florida), fishing wave (two-month sampling period, e.g. Jan–Feb), fishing area (>3 miles from shore, ≤3 miles from shore), and days12, the angler-reported days of saltwater fishing during the previous 12 months (a proxy for angler avidity, experience, or skill, or a proxy for all three characteristics). The retransformed, bias-corrected (when necessary) year coefficients serve as the annual indices of stock abundance. Calculation and evaluation of the MRFSS standardized indices followed the general procedures described in the "Overview of statistical methods" in the "Materials and methods" section.

Table 7

Summary of goodness-of-fit tests for 1996 MRFSS (Marine Recreational Fishery Statistics Survey) catch per hour distributions, including zero catches, for bluefish, summer flounder, Atlantic cod, scup, and all species.

Species	Expected number of intervals	Degrees of freedom	χ^2 statistic	G statistic	$\chi^2_{0.01}$	D statistic	$D_{0.01}$
Bluefish							
Mean = 0.35							
Variance = 1.23							
n = 5457							
Lognormal	6	3	2806	3047	11	0.323	0.014
Poisson	5	3	514	41	11	0.028	0.014
Negative binomial	5	2	514	41	9	0.028	0.014
Summer flounder							
Mean = 0.52							
Variance = 0.72							
n = 7047							
Lognormal	7	4	2022	2430	13	0.245	0.012
Poisson	5	3	1408	1209	11	0.193	0.012
Negative binomial	5	2	1408	1209	9	0.193	0.012
Atlantic cod							
Mean = 0.86							
Variance = 2.00							
n = 1099							
Lognormal	7	4	289	300	13	0.243	0.031
Poisson	5	3	51	11	11	0.051	0.031
Negative binomial	5	2	51	11	9	0.051	0.031
Scup							
Mean = 3.06							
Variance = 27.78							
n = 643							
Lognormal	11	8	546	346	20	0.312	0.041
Poisson	10	8	1209	583	20	0.347	0.041
Negative binomial	19	16	54	39	32	0.032	0.041
All species							
Mean = 0.62							
Variance = 4.51							
n = 81,057							
Lognormal	13	10	144,556	126,529	23	0.575	0.004
Poisson	7	5	54,675	72,657	15	0.036	0.004
Negative binomial	7	4	54,675	72,657	13	0.036	0.004

Results

Descriptive statistics for MRFSS catch rates

Descriptive statistics of MRFSS catch rates for the four catch rate configurations, four individual species, and for all species are presented for the years 1981, 1988, and 1996 (Tables 1–4). These three years are characteristic of the 1981–2002 time series of MRFSS data. Given the similarity among these years, frequency distributions are plotted only for 1996 (Figs. 1–4). Catch rate means, both with and without zero catches, are generally much higher than medians, variances are much larger than the means, skewness is always much larger than zero, and there is a high proportion of zero catch and one-fish catch-rate observations. In all cases, the Kolmogorov-Smirnov D test statistics were significant at the 1% level. All of these factors indicate that MRFSS catch-rate distributions are highly contagious and overdispersed in relation to the normal distribution (Sokol and Rohlf, 1981). Scup has highest frequency of high catch rates (Figs. 1–4). The scup and Atlantic cod samples exhibit modes at regular intervals of high catch-per trip rates (e.g. 10, 15, 20, 25, and 30 fish per trip) that may indicate some degree of digit bias in the sampling.

Table 8

Summary of goodness of fit tests for 1996 MRFSS (Marine Recreational Fishery Statistics Survey) catch per hour distributions, positive catches only, for bluefish, summer flounder, Atlantic cod, scup, and all species.

Species	Expected number of intervals	Degrees of freedom	χ^2 statistic	G statistic	$\chi^2_{0.01}$	D statistic	$D_{0.01}$
Bluefish							
Mean = 1.13							
Variance = 3.15							
n = 1666							
Lognormal	6	3	1508	1462	11	0.446	0.025
Poisson	5	3	590	590	11	0.269	0.025
Negative binomial	5	2	590	590	9	0.269	0.025
Summer flounder							
Mean = 0.87							
Variance = 0.90							
n = 4196							
Lognormal	6	3	3005	3146	11	0.416	0.016
Poisson	5	3	838	921	11	0.210	0.016
Negative binomial	5	2	838	921	9	0.210	0.016
Atlantic cod							
Mean = 1.39							
Variance = 2.49							
n = 679							
Lognormal	6	3	414	368	11	0.356	0.040
Poisson	5	3	145	113	11	0.213	0.040
Negative binomial	5	2	145	113	9	0.213	0.040
Scup							
Mean = 4.49							
Variance = 34.38							
n = 438							
Lognormal	10	7	601	292	18	0.270	0.049
Poisson	11	9	725	324	22	0.280	0.049
Negative binomial	17	14	127	99	29	0.166	0.049
All species							
Mean = 1.29							
Variance = 8.49							
n = 39,094							
Lognormal	7	4	38,171	33,641	13	0.434	0.001
Poisson	8	6	31,475	16,429	17	0.270	0.001
Negative binomial	8	5	31,475	16,429	15	0.270	0.001

For the catch-per-trip configurations, catch rates were best characterized by the negative binomial distribution (Tables 5–6, Figs. 5–6). Note that the calculated chi-square, *G*-, and *D*-test statistics were generally significant at the 1% level, so that based on strict interpretation of these results, the null hypothesis that the observed distributions come from one of the theoretical distributions was rejected in all cases. However, the calculated test statistics for the negative binomial distributions were at least an order of magnitude smaller than those for the Poisson and lognormal distributions, suggesting that an underlying negative binomial distribution was much more likely. The distributions of the catch-per-hour rates generally had a truncated range compared to the catch-per-trip rate configurations (Figs. 1–4). For most of the catch-per-hour distributions, the maximum likelihood solution for the negative binomial k parameter occurred at very large values (>1000). The expected frequencies for the negative binomial distribution therefore converged to those expected for a Poisson distribution, resulting in identical test statistic values and indicating that the catch-per-hour rates are best characterized by the Poisson distribution (Tables 7–8, Figs. 7–8).

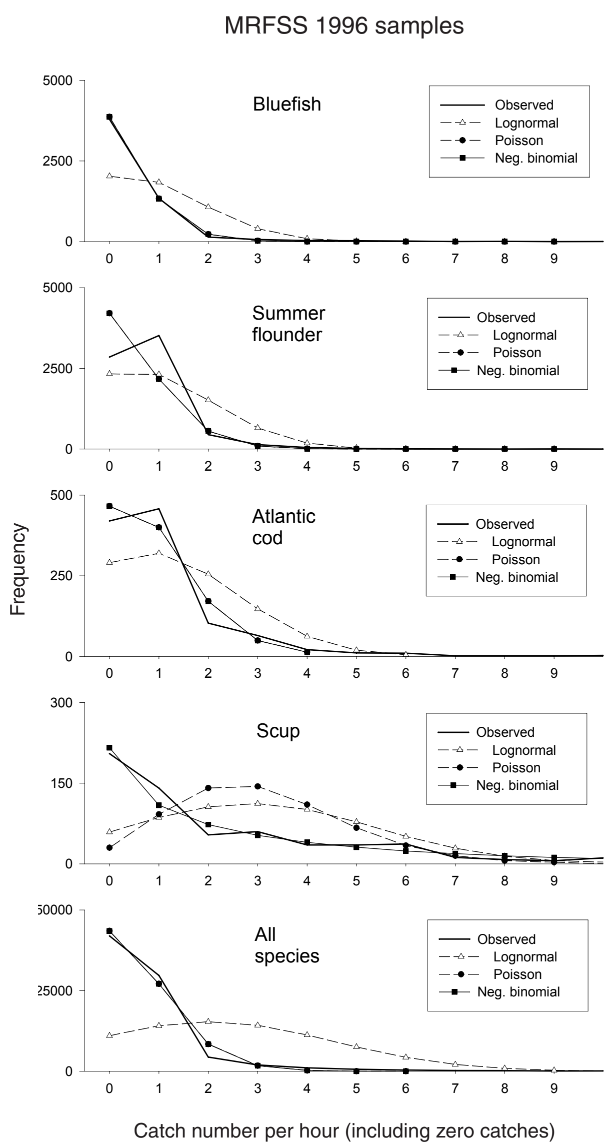

Figure 7

Observed and expected catch number per hour (including zero catches) frequency distributions for bluefish, summer flounder, Atlantic cod, scup, and all species, Maine to the Florida east coast. The 9 fish intervals is a "plus group" because it includes totals for larger intervals.

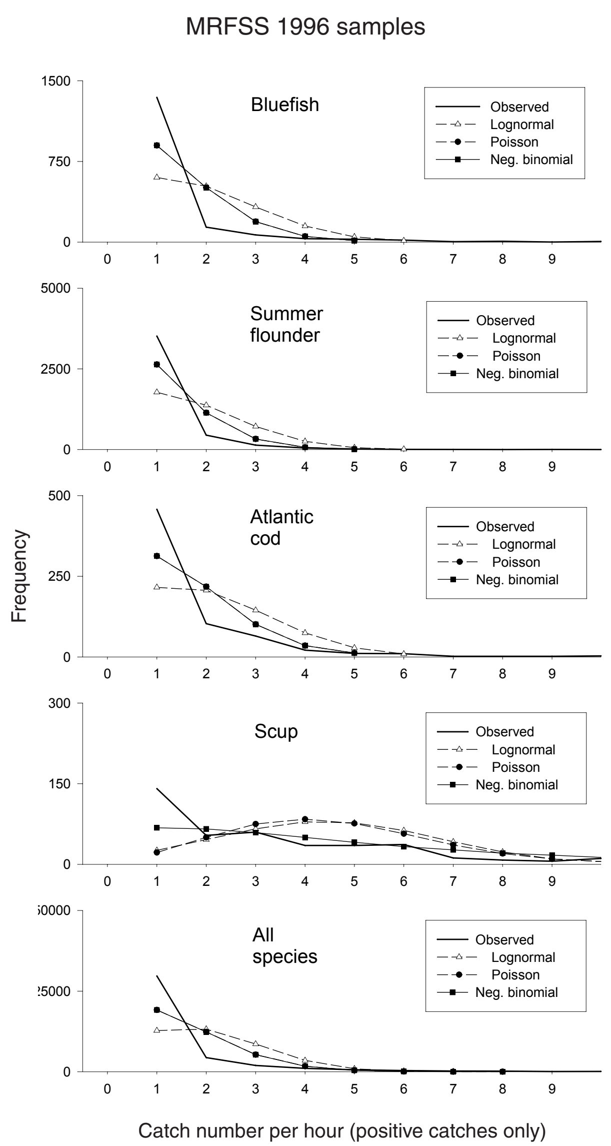

Figure 8

Observed and expected catch number per hour (positive catches only) frequency distributions for bluefish, summer flounder, Atlantic cod, scup, and all species, Maine to the Florida east coast. The 9 fish intervals is a "plus group" because it includes totals for larger intervals.

Simulated recreational fishery catch rates

The eleven simulated distributions of catch per trip had means ranging from 2.80 to 0.98 fish per trip, variances ranging from 31.81 to 4.39, and CVs of about 200%. Simulated variance decreased as the simulated mean decreased because the negative binomial dispersion parameter, k, was held constant at 0.23. The resulting unstandardized, simulated index of abundance declined by 65% over the 11 year series (Table 9).

All standardization model fits were highly significant ($P<0.001$), as characterized by the chi-square statistics for the year effect (Table 10). The three different time series trends had no effect on the results, and therefore only the results for the decreasing series are reported. The Poisson and negative binomial models generated year coefficients as standardized indices of abundance that were very similar to each other and, as expected, virtually identical to the unstandardized annual means, indicating a 65% decline over the time series (Fig. 9). Interestingly, the diagnostic

Table 9

Summary statistics for the simulated recreational fishery catch per trip assuming a negative binomial distribution, configured to decline by 10% in successive time periods (years). For year 1, starting maximum catch per trip was 50 fish per trip, mean was 3.0, variance was 81.00, coefficient of variation (CV) of 300%, and the dispersion parameter of the negative binomial distribution, k, was 0.23. In years 2–11, k was held constant at the year-1 value of 0.23, allowing the variance to decrease as the mean catch declined. Annual simulated means were scaled to the 11 year time series mean (1.75) for comparability with standardized indices calculated for decreasing, increasing, and peaked time series trends.

Year	Simulated mean catch per trip	Simulated maximum catch per trip	Simulated variance	Simulated CV (%)	Scaled simulated catch per trip
1	2.80	47	31.81	201	1.60
2	2.49	39	24.75	200	1.42
3	2.27	37	20.97	202	1.30
4	2.05	34	17.23	203	1.17
5	1.85	31	14.24	204	1.06
6	1.67	29	11.84	206	0.95
7	1.49	26	9.65	209	0.85
8	1.32	21	7.36	206	0.75
9	1.21	21	6.47	211	0.69
10	1.09	19	5.38	213	0.62
11	0.98	17	4.39	215	0.56

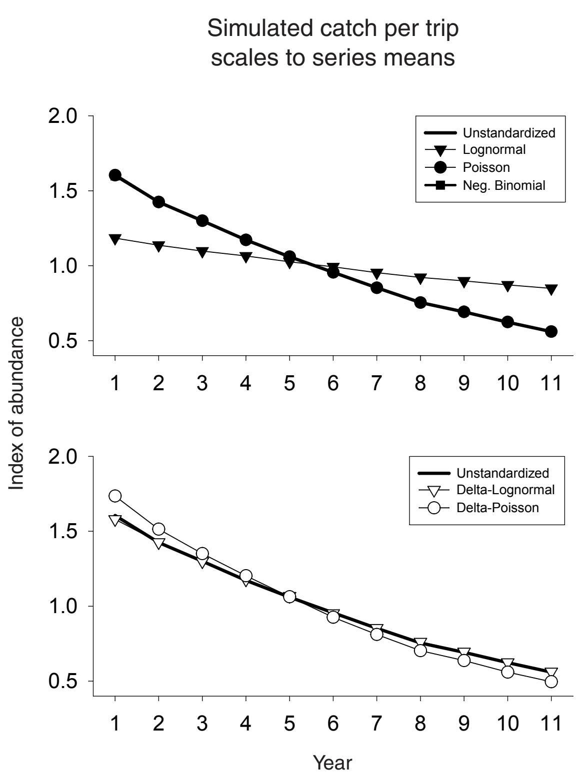

Figure 9

Simulated recreational fishery indices of abundance modeled under different error distribution assumptions.

statistics indicated a better determined year effect (more precise year coefficients) for the Poisson than for the negative binomial. However, the dispersion estimate (deviance/df) for the Poisson model was much greater than 1.0, indicating that the input data were overdispersed with respect to the Poisson distribution (Table 10). The latter was the expected result, given that the variance of the annual simulated data sets was much larger than the mean. The results indicated that the negative binomial was a more appropriate model, with a dispersion estimate closer to 1.0, which was also the expected result given the true negative binomial distribution of the simulated data (SAS, 2000).

The consequence of assuming a lognormal model for the true underlying negative binomial distribution was a more extreme smoothing of the true time series trends than with the other model assumptions, with a decline of only 28% over the time series (Fig. 9). The diagnostic statistics for the lognormal model indicated a significant model fit, but the dispersion estimate was much less than 1.0, indicating that the input data were underdispersed with respect to the lognormal distribution (Table 10). This finding is reflective of the large number of 0 and 1 catch-per-trip observations, and a lack of observations near the mean of the input probability distribution (SAS, 2000). In this simulation exercise, therefore, the lognormal model dispersion estimate of much less than 1.0 is indicative of model misspecification.

As noted in the “Materials and methods” section, the indices of abundance from the delta models are calculated as the product of the year-effect coefficients from the two component models. The interaction of the year coefficients from the binomial proportion positive catches and lognormal or Poisson positive catches components of the delta models

Table 10

Summary of model fits for simulated recreational fishery catch per trip (including zero catches) with a decreasing time series trend. Total model degrees of freedom were 10,989; for the positive catches component of the delta models, degrees of freedom were 4,184. Year-model-effect degrees of freedom were 10, and the year-model effect was highly significant (P<0.0001) in all five models.

Criterion	Value	Dispersion estimate (value/df)
Lognormal model		
Deviance	7330	0.6670
Log-likelihood	–13,773	
Year chi-square	183	
Poisson model		
Deviance	51,719	4.7064
Log-likelihood	–7483	
Year chi-square	2049	
Negative binomial model		
Deviance	10,699	0.9736
Log-likelihood	7524	
Year chi-square	239	
Delta models: binomial proportion positive catch		
Deviance	14,546	1.3237
Log-likelihood	–7273	
Year chi-square	78	
Delta-lognormal model: lognormal positive catches		
Deviance	3474	0.8303
Log-likelihood	–5557	
Year chi-square	119	
Delta-Poisson model: Poisson positive catches		
Deviance	15,822	3.7815
Log-likelihood	10,466	
Year chi-square	936	

Table 11

Summary of model fits for estimating indices of abundance from empirical MRFSS (Marine Recreational Fishery Statistics Survey) bluefish catch per trip (including zero catches), 1981–98. Total model degrees of freedom (df) were 130,300; for the positive catches component of the delta models, degrees of freedom were 48,447. All model fits and classification effects were highly significant (P<0.001).

Criterion	Value	Dispersion estimate (value/df)
Lognormal model		
Deviance	84,150	0.6458
Log-likelihood	–156,444	
Year chi-square	1835	
Poisson model		
Deviance	675,791	5.1864
Log-likelihood	–19,680	
Year chi-square	20,604	
Negative binomial model		
Deviance	99,393	0.7628
Log-likelihood	190,140	
Year chi-square	2104	
Delta models: binomial proportion positive catch		
Deviance	157,674	1.2101
Log-likelihood	–78,837	
Year chi-square	854	
Delta-lognormal model: lognormal positive catches		
Deviance	39,963	0.8249
Log-likelihood	–64,129	
Yera chi-square	1240	
Delta-Poisson model: Poisson positive catches		
Deviance	249,112	5.1419
Log-likelihood	193,660	
Year chi-square	10,501	

provided some interesting results in this simulation exercise. The binomial model component, common to both delta models, provided a highly significant year effect and indicated a 41% decline in abundance over the time series. The dispersion estimate indicated some overdispersion of the data with respect to the binomial distribution (Table 10).

The lognormal positive catches component of the delta-lognormal model also provided a highly significant year effect and indicated a 39% decline in abundance over the time series, producing a smoothing effect similar to that observed for the lognormal model of catch per trip including zeroes. The dispersion estimate indicated some underdispersion of the data with respect to the lognormal distribution (Table 10). The product of the annual year coefficients from the two delta-lognormal model components, which individually indicated less decline than the unstandardized indices, provided final indices of abundance that declined 64% over the time series (due to the product of two positive fractional values <1 providing a even smaller value <1)—nearly identical to the unstandardized, Poisson, and negative binomial series (Fig. 9).

The Poisson positive catches component of the delta-Poisson model provided a highly significant year effect and indicated a 51% decline in abundance over the time series. The dispersion estimate was much greater than 1.0, indicating overdispersion of the data with respect to the Poisson model (Table 10). The product of the annual year coefficients from the two delta-Poisson model components provided indices of abundance that declined 71% over the time series, a slightly greater decrease than for the other models (Fig. 9). Note again that the delta-lognormal and delta-Poisson models share the same binomial proportion positive catch model components, and therefore annual year coefficients for this component. The decrease estimated by the delta-Poisson model was greater than that for the delta-lognormal because the year coefficients from the Poisson positive catch model were all smaller, and more closely matching the unstandardized positive catch series, than the comparable

Table 12

Summary of model fits for estimating indices of abundance from empirical MRFSS (Marine Recreational Fishery Statistics Survey) summer flounder catch per trip (including zero catches), 1981–98. Total model degrees of freedom (df) were 102,162; for the positive catches component of the delta models, degrees of freedom were 52,507. All model fits and classification effects were highly significant (P<0.001).

Criterion	Value	Dispersion estimate (value/df)
Lognormal model		
Deviance	66,452	0.6505
Log-likelihood	–122,989	
Year chi-square	2663	
Poisson model		
Deviance	444,657	4.3525
Log-likelihood	–14,827	
Year chi-square	14,053	
Negative binomial model		
Deviance	96,698	0.9465
Log-likelihood	97,777	
Year chi-square	2560	
Delta models: binomial proportion positive catch		
Deviance	130,341	1.2758
Log-likelihood	–65,171	
Year chi-square	2498	
Delta-lognormal model: lognormal positive catches		
Deviance	36,780	0.7005
Log-likelihood	–65,202	
Year chi-square	1203	
Delta-Poisson model: Poisson positive catches		
Deviance	183,019	3.4856
Log-likelihood	115,991	
Year chi-square	5675	

Table 13

Summary of model fits for estimating indices of abundance from empirical MRFSS (Marine Recreational Fishery Statistics Survey) Atlantic cod catch per trip (including zero catches), 1981–98. Total model degrees of freedom (df) were 20,629; for the positive catches component of the delta models, degrees of freedom were 13,160. All model fits and classification effects were highly significant (P<0.001).

Criterion	Value	Dispersion estimate (value/df)
Lognormal model		
Deviance	19,425	0.9416
Log-likelihood	–28,697	
Year chi-square	380	
Poisson model		
Deviance	142,834	6.9239
Log-likelihood	54,501	
Year chi-square	4090	
Negative binomial model		
Deviance	21,824	1.0579
Log-likelihood	98,335	
Year chi-square	323	
Delta models: binomial proportion positive catch		
Deviance	24,997	1.2117
Log-likelihood	–78,837	
Year chi-square	191	
Delta-lognormal model: lognormal positive catches		
Deviance	11,657	0.8858
Log-likelihood	–17,920	
Year chi-square	353	
Delta-Poisson model: Poisson positive catches		
Deviance	75,359	5.7264
Log-likelihood	88,239	
Year chi-square	2805	

lognormal positive catch year coefficients over the course of the time series. For example, the year-11 coefficient from the binomial proportion positive catches model was 0.59; the year-11 lognormal positive catches coefficient was 0.61, providing a product for the year-11 index of 0.36. In contrast, the year-11 Poisson positive catches coefficient was 0.49, providing a product for the year-11 index of 0.29. When these and the other annual coefficients were scaled to the respective series means, the delta-Poisson model indicated a slightly greater decline over the time series.

MRFSS standardized indices of abundance, 1981–98

All standardization models of the MRFSS catch per trip (including zero catches), for the four individual species and for all species, fitted well. In part because of the large number of observations, the overall model fits and the individual classification effects (year, mode, state, wave, and days12) were all highly significant. Only the year effect chi-square statistics are tabulated because the year effect coefficients serve as the annual indices of abundance (Tables 11–15). The year effect was generally the second or third most important effect in the models, after mode and state. The dispersion estimates (deviance/df) for the lognormal models indicated the data were generally underdispersed with respect to the lognormal; the dispersion estimates for the Poisson models indicated overdispersion with respect to that distribution. The dispersion estimates for the negative binomial models and binomial components of the delta models were generally close to 1.0, indicating appropriate model specification (Tables 11–15).

As in the simulated catch-rate exercise, the lognormal standardized abundance indices generally show lower

Table 14

Summary of model fits for estimating indices of abundance from empirical MRFSS (Marine Recreational Fishery Statistics Survey) scup catch per trip (including zero catches), 1981–98. Total model degrees of freedom (df) were 17,604; for the positive catches component of the delta models, degrees of freedom were 11,124. All model fits and classification effects were highly significant (P<0.001).

Criterion	Value	Dispersion estimate (value/df)
Lognormal model		
Deviance	32,270	1.8331
Log-likelihood	–30,346	
Year chi-square	332	
Poisson model		
Deviance	375,924	21.3545
Log-likelihood	309,490	
Year chi-square	12,094	
Negative binomial model		
Deviance	18,668	1.0604
Log-likelihood	466,529	
Year chi-square	369	
Delta models: binomial proportion positive catch		
Deviance	22,027	1.2512
Log-likelihood	–11,013	
Year chi-square	174	
Delta-lognormal model: lognormal positive catches		
Deviance	14,340	1.2891
Log-likelihood	–17,225	
Year chi-square	350	
Delta-Poisson model: Poisson positive catches		
Deviance	212,250	19.0804
Log-likelihood	391,327	
Year chi-square	8793	

Table 15

Summary of model fits for estimating indices of abundance from empirical MRFSS (Marine Recreational Fishery Statistics Survey catch per trip for all species (including zero catches), 1981–98. Total model degrees of freedom (df) were 1,033,367; for the positive catches component of the delta models, degrees of freedom were 457,598. All model fits and classification effects were highly significant (P<0.001).

Criterion	Value	Dispersion estimate (value/df)
Lognormal model		
Deviance	861,881	0.8341
Log-likelihood	–1,372,576	
Year chi-square	7246	
Poisson model		
Deviance	8,048,246	7.7884
Log-likelihood	277,042	
Year chi-square	28,734	
Negative binomial model		
Deviance	870,357	0.8422
Log-likelihood	3,118,822	
Year chi-square	2243	
Delta models: binomial proportion positive catch		
Deviance	1,351,532	1.3079
Log-likelihood	–675,766	
Year chi-square	11,867	
Delta-lognormal model: lognormal positive catches		
Deviance	466,644	1.0198
Log-likelihood	653,838	
Year chi-square	655	
Delta-Poisson model: Poisson positive catches		
Deviance	3,773,909	8.2472
Log-likelihood	2,414,210	
Year chi-square	10,785	

rates of change in abundance than do the unstandardized, Poisson, or negative binomial indices, with the CV of the lognormal series about 25–50% of the CV of the unstandardized indices (Figs. 10–14). In effect, the lognormal standardization of MRFSS per trip catch rates had an unintended (and undesirable) smoothing effect on the independent annual indices abundance. The Poisson and negative binomial models generally provided interpretations of the trend and annual changes in abundance very similar to those of the unstandardized indices.

For bluefish, the delta-lognormal, and delta-Poisson models provided time series of indices with about the same variability and trend, but slightly different annual changes, as those from the unstandardized, Poisson, and negative binomial models. For summer flounder, Atlantic cod, scup, and all species, the delta-lognormal and delta-Poisson models provided time series of abundance indices that were more variable, with slightly different trends and annual changes, than the unstandardized, Poisson, and negative binomial series. This last result is comparable to that observed for the delta models used with the simulated data and is therefore likely due in part to model misspecification of the positive catch-per-trip component (recall that catch per trip for these examples is best characterized by the negative binomial distribution) and a comparable interaction of the binomial, lognormal, and Poisson model year coefficients.

Discussion

The frequency distributions of recreational fishery catch-rate data as sampled by the MRFSS are highly skewed, often with a significant proportion of zero catch observations. The present study indicates that MRFSS catch rates generally are not normally or lognormally distributed

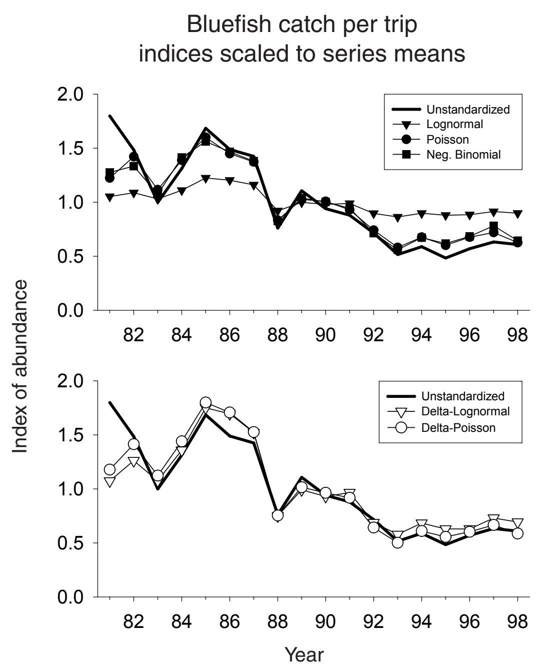

Figure 10

Indices of bluefish abundance (catch number per trip including zero catches) modeled under different error distribution assumptions, 1981–98.

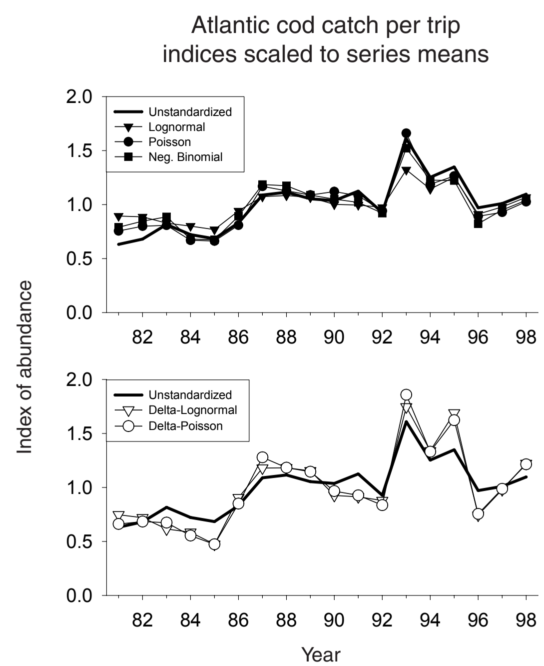

Figure 12

Indices of Atlantic cod abundance (catch number per trip including zero catches) modeled under different error distribution assumptions, 1981–98.

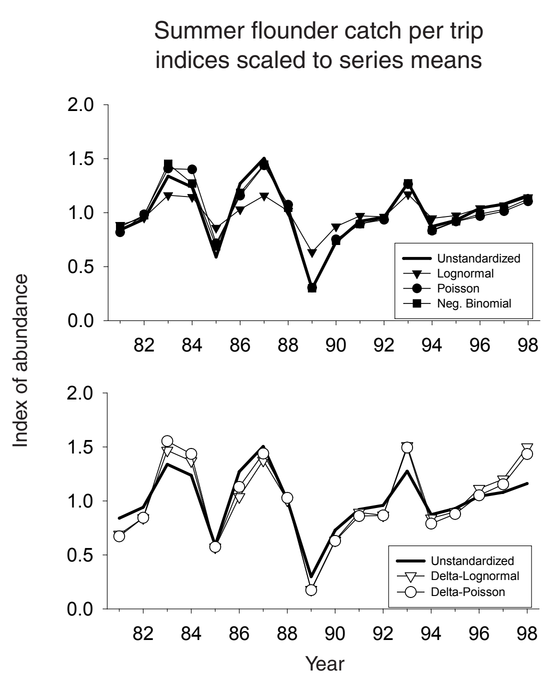

Figure 11

Indices of summer flounder abundance (catch number per trip including zero catches) modeled under different error distribution assumptions, 1981–98.

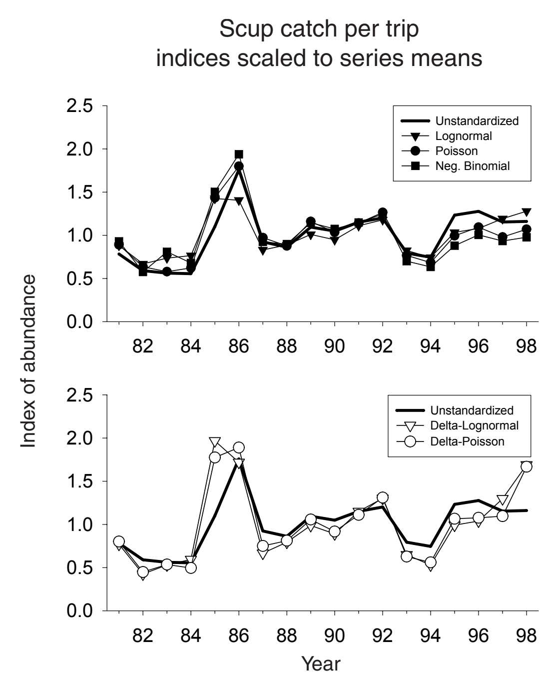

Figure 13

Indices of scup abundance (catch number per trip including zero catches) modeled under different error distribution assumptions, 1981–98.

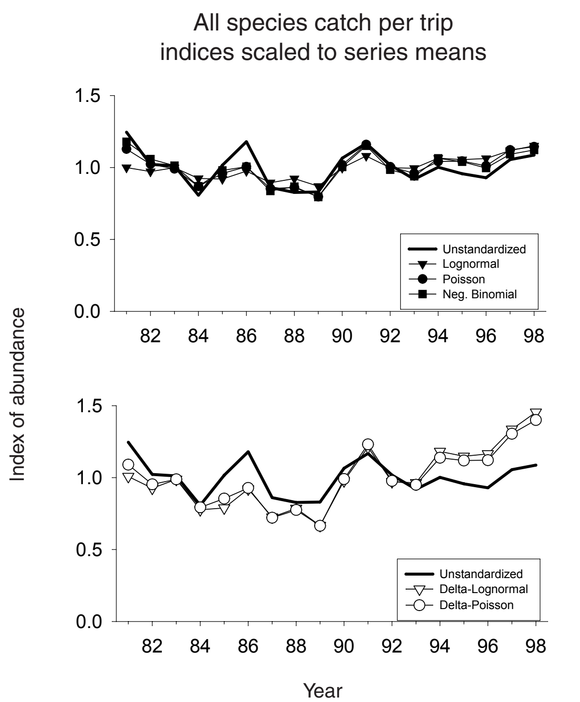

Figure 14

Indices of all species abundance (catch number per trip including zero catches) modeled under different error distribution assumptions, 1981–98.

but usually best characterized by the Poisson or negative binomial distribution, depending on the manner in which the catch rate is configured. This finding suggests that standardization methods for MRFSS catch-rate data where Poisson (in the case of per hour rates) or negative binomial (for per trip rates) error structures are assumed would usually be more appropriate than methods where normal or lognormal error structures are assumed.

The modeling of both the simulated and empirical MRFSS catch rates indicates that one may draw erroneous conclusions about stock trends by assuming the wrong error distribution in procedures used to developed standardized indices of abundance. The results demonstrate the importance of considering not only the overall model fit and significance of classification effects, but also the possible effects of model misspecification, when determining the most appropriate model construction. In particular, the simulation exercise indicates that assuming a lognormal model in the calculation of indices of abundance from recreational fishery catch-per-trip data with a true underlying negative binomial distribution will provide indices that will strongly underemphasize the true trends in the indices, and therefore in stock abundance. This underestimation applies equally to populations that may be declining or increasing faster than the lognormally standardized indices might indicate.

The MRFSS catch-per-trip indices standardized with the negative binomial model, which the descriptive statistics and goodness-of-fit results suggest should be the appropriate model, differ relatively little from the unstandardized indices, indicating that the model effects accounted for a low percentage of the variation in mean catch rate. The classification categories recorded in the general MRFSS sampling are broad, and even measures of angling avidity such as "angler-reported days of saltwater fishing during the previous 12 months" may not be adequate proxies for the real factors (besides stock abundance) that account for variation in recreational fishery mean catch rates. To make standardization analysis of MRFSS catch rate data potentially more useful, by accounting for a significantly larger part of the unexplained variance and thus providing more accurate indices of abundance, more information on the characteristics of individual fishing trips may be needed. Such information might include details on the type of equipment used, the skills, experience, avidity, and identity of the individual fishermen, and detailed temporal and spatial information about fishing trips. In the future, collection of detailed trip data for general recreational fisheries may be best accomplished by the identification and sampling of "test fleets" of known, individual fishermen.

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