Atlantic States Marine Fisheries Commission

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Healthy, self-sustaining populations for all Atlantic coast fish species or successful restoration well in progress by the year 2015.

Special Report to the ASMFC Atlantic Sturgeon Management Board:

ESTIMATION OF ATLANTIC STURGEON BYCATCH IN COASTAL ATLANTIC COMMERCIAL FISHERIES OF NEW ENGLAND AND THE MID-ATLANTIC

August 2007

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PROBLEM

Bycatch remains an important issue in the recovery of Atlantic sturgeon populations throughout their range (ASMFC 1998). This issue is also given highest priority by the National Marine Fisheries Service (NMFS) Proactive Program for Atlantic sturgeon restoration. The Atlantic States Marine Fisheries Commission (ASMFC) requires jurisdictional reporting of Atlantic sturgeon bycatch, but the quality of available data varies. Further, in New England and Mid-Atlantic coastal waters, regions where the NMFS Northeast Fisheries Science Center (NEFSC) Sea Sampling (Observer) Program data is available, recent analyses have resulted in substantially differing estimates of bycatch and related incidental mortality (i.e., Stein *et al*. 2004; Chris Hager, Virginia Institute of Marine Science, pers. comm.). As a principal recommendation from the 2006 ASMFC Atlantic Sturgeon Bycatch Workshop, the Sturgeon Technical Committee (TC) has recommended a focused assessment of the NEFSC Observer Database, which principally covers fisheries in New England and the Middle Atlantic state waters.

BYCATCH WORKSHOP PARTICIPANTS

During 24-25 April 2007, ASMFC and NMFS sponsored a workshop at the NMFS NEFSC, Woods Hole, Massachusetts.

Participants included:

Gary Shepherd (Host, NMFS NEFSC)
Tim Miller (NMFS NEFSC)
Christine Lipsky (NMFS NEFSC)
Jim Armstrong (Mid-Atlantic Fishery Management Council)
Chris Hager (Virginia Institute of Marine Science)
Andy Kahnle (NY State Department for Environmental Conservation, TC member)
Kathy Hattala (NY State Department for Environmental Conservation)
Erika Robbins (ASMFC, Atlantic sturgeon FMP Coordinator)
Dave Secor (Univ. MD Center for Environmental Science, TC Chair)
Kelly Place (workshop observer, ASMFC commissioner proxy)

WORKSHOP GOALS

1. Estimate Atlantic sturgeon bycatch rates and numbers caught by fishery, state, and season for the period 2001-2006 using data from the NEFSC observer database. Develop an interpolation model based upon recent fishing behaviors that allows estimation of bycatch among fisheries, regions, and seasons.
2. From the NEFSC Observer Database, estimate bycatch mortality rates by fishery, state, season, and fishing behavior (e.g., soak time).

REPORT STRUCTURE

This report contains six sections:

1. Estimation of Atlantic sturgeon bycatch and bycatch deaths from the NEFSC Observer Dataset (Gary Shepherd, lead)
2. Current level of coastal bycatch mortality and recovery of Atlantic sturgeon populations (Dave Secor, lead)
3. Spatial distribution of observed sturgeon encounters in commercial sink gillnets and sink gillnet fishery effort (Jim Armstrong, lead)
4. Factors associated with mortality of incidentally caught sturgeon in the Northwest Atlantic Ocean (Tim Miller, lead)
5. Presence:absence analysis of factors associated with Atlantic sturgeon bycatch (Dave Secor, lead)
6. Sink gillnet fisheries and descriptions of factors that can contribute to higher or lower interaction and retention rates (Chris Hager, lead)

PRINCIPAL FINDINGS

Estimates of Bycatch and Bycatch Deaths (2001-2006)

1. Sink Gillnets
    - 1.1. The approach adopted by the group to model bycatch for the recent period 2001-2006 is different from the method of Stein *et al*. (2004), which estimated bycatch for the period 1989-2000 using interpolation and a ratio method.
    - 1.2. Modeled bycatch of Atlantic sturgeon ranged between 2,752 (2002) and 7,904 (2006) with a mean of 5,143.
    - 1.3. Modeled deaths ranged between 352 (2006) and 1,286 (2004) with a mean of 649. Estimated mortality of intercepted sturgeon averaged 13.8%.
    - 1.4. Modeled bycatch was similar in magnitude to that estimated by a different approach for the 1989-2000 period (~4500 per year; Stein *et al*. 2004), but deaths were approximately two-fold less (649 per year for recent period v. approximately 1000 per year estimated by Stein *et al*. 2004). Similarly, mean mortality rate estimated for the recent period was less than that estimated for the earlier period (13.8% v. 22%).
    - 1.5. Because alternate methods were used for the earlier 1989-2000 and later 2001-2006 period, bycatch estimates reported here and in Stein *et al*. (2004) are not directly comparable, but similar amplitude in estimates indicate bycatch mortality of hundreds per year.

2. Otter Trawl
    - 2.1. Modeled bycatch of Atlantic sturgeon ranged 2,167 in 2005 to 7,210 in 2002 with a mean of 3,829.
    - 2.2. Sturgeon deaths (n=3) were rarely reported in the otter trawl observer dataset. This indicates low mortality rates. Because deaths were infrequent in the dataset they could not be modeled for the otter trawl gear.

2.3. Sturgeon bycatch is substantially lower than estimated for the 1989-2000 period (Stein *et al*. 2004): approximately 4,000 v. 12,000. The same caveat applies in comparing past and more recent period estimates in that different analytical approaches were used.

Current Bycatch Levels and Atlantic Sturgeon Recovery

1. To remain stable or grow, populations of Atlantic sturgeon can sustain only very low anthropogenic sources of mortality (<4% per year).
2. For one of the most abundant populations, the Hudson River population, current level of bycatch deaths is most likely retarding or curtailing recovery.
3. For many likely scenarios of contribution to coastal bycatch and recruitment levels, bycatch mortality for the Hudson River population exceeds those levels believed to lead to a stable or growing population. Only scenarios of low contribution rates of the population to coastal bycatch in concert with high and intermediate recruitment levels would lead to a stable or slow-growing population.
4. Other populations contribute to the coastal bycatch and populations smaller than the Hudson River population are expected to be affected to a larger degree by bycatch deaths because proportional removals have larger negative effects on less productive populations.
5. The results of the scenarios run for the Hudson River population are likely under-estimates because not all sources of mortality are included in the NMFS observer data estimate. These include unreported bycatch, poaching, and ship strikes.
6. Because deaths in New England and Mid-Atlantic waters are principally attributed to the monkfish sink gillnet fishery, changes in effort in this fishery are expected to lead to proportional changes in bycatch deaths. Similarly, means to reduce bycatch mortality in this and other sink gillnet fisheries through modification of gear deployments (e.g., soak time, presence of tie-downs) could result in substantial reductions in sturgeon deaths.

Spatial Distribution of Sink Gillnet Bycatch

1. Coverage of the NEFSC Observer Database is generally consistent with the distribution of fishery effort. However the Observer Program coverage in the southern Mid-Atlantic (mouth of Chesapeake through Cape Hatteras) is disproportionately high relative to reported effort.
2. Sturgeon encounters tend to occur in waters shoal of 50 meters. Although seasonal patterns exist, sturgeons are encountered in sink gillnets throughout the year.
3. Sink gillnet deployments and sturgeon bycatch were concentrated in several regions: off Cape Hatteras, the mouth of the Chesapeake, Maryland's coastal waters, the northern shore of New Jersey and New York Bight, Rhode Island coastal waters, and Cape Cod through Gulf of Maine

Factors Associated with Atlantic Sturgeon Bycatch Mortality in Sink Gillnets

1. The strongest gear factor associated with mortality was the increase with mesh size when tie-downs were used regardless of whether monkfish or groundfish were targeted.
2. A significant positive association of water temperature to mortality was detected when tie-downs were used regardless of whether monkfish or groundfish were targeted.
3. A significant positive association between soak time to mortality was detected when monkfish were targeted (tie-downs used).

4. A significant positive association of soak time to mortality was detected when groundfish were targeted without tie-downs.
5. A significant positive association of soak time to mortality was detected when striped bass were targeted without tie-downs.
6. A significant positive association of sturgeon length to mortality was detected when striped bass were targeted without tie-downs.

Presence:Absence Analysis of Factors Associated with Bycatch

1. For sink gillnet fisheries, higher incidence of sturgeon bycatch was associated with depths <40 meters, mesh sizes >10", and months April-May.
2. For otter trawl fisheries, higher incidence of sturgeon bycatch was associated with depths <30 meters.

Interaction and Retention of Atlantic Sturgeons in Sink Gillnets

1. The NEFSC sturgeon bycatch dataset based on observer coverage is not homogenous across or within fisheries, effort, target species, state, or areas of operation. However, patterns exist in data suggesting that interaction rates are driven by spatial and temporal variables and retention is gear dependent.
2. Increased regional movement and hence availability of migrating sturgeons increase the likelihood of interaction with sink gillnets of any type operating within migration corridors. Gear characteristics and fish size affect retention. Tie-down use appears to increase the overall size range of retained fish by increasing the susceptibility of smaller individuals.
3. Water temperature and soak time duration affect survival of sturgeons through physiological constraints regardless of capture method. Across the range of temperatures, incidence of death increased with rising temperatures. A clear relationship was apparent between increasing mortality and soak times, with soak times >24 hours resulting in a 40% incidence of death and those <24 hours resulting in a 14% incidence of death.
4. Longer soak times may also increase bycatch and related deaths by increasing the likelihood of an interaction and perhaps through a baiting effect.
5. Mortality rates appear to be unusually high in 12 inch mesh (e.g. the monkfish fishery); however, mesh size cannot be analyzed in isolation because these nets were also observed to contain tie-downs 98% of the time, and soak times over 24 hrs occurred 83% of the time for these monkfish fishery deployments.
6. Confounding gear attributes across fisheries and imprecise reporting of various gear characteristics known to affect fish retention, currently limit what can be learned from the NEFSC Observer Database regarding gear characteristics and their effect on sturgeon retention. Controlled experiments on captive fish suggest, however, that twine size, hanging ratio, and tie-down use all significantly increase the retention of fish that encounter sink gillnets.

RESEARCH RECOMMENDATIONS

1. Highest research priority should be given to evaluation of relative population contributions to regions of high bycatch. Molecular approaches are currently available to estimate these population contribution rates, but such studies should be undertaken through careful sampling designs to insure that genetic samples are representative of intercepted sturgeon.

2. Abundance and vital rate estimates are required for populations contributing to coastal bycatch to evaluate whether bycatch rates are sustainable on a population-specific basis.
3. The bycatch GENMOD modeling approach developed here should be used for analysis of historical bycatch (the 1989-2000 period). The model will need to be re-parameterized and refit. Also, changes in how data have been recorded by observers and within the vessel trip report (VTR) data prior to 2000 will need to be carefully considered.
4. State effort statistics related to sink gillnet and other fisheries that retain sturgeons should be combined with the VTR database to permit improved expansion of observer-based bycatch rates.
5. A detailed GIS analysis should be performed on the distribution of observed sturgeon bycatch to compare recent patterns of coastal habitat use by Atlantic sturgeon to historical ones (1989-2000). Although most sturgeon were caught as bycatch in waters <40 meters in gillnet and trawl fisheries, this depth association is expected to vary between New England and Mid-Atlantic regions and deserves additional analysis. The observer database (1989-present) could support habitat suitability mapping for Atlantic sturgeon in coastal waters of New England and the Mid-Atlantic.
6. Controlled mesocosm-scale experiments on sink gillnet interactions and retention of sturgeon, such as those recently conducted at VIMS (C. Hager, pers. comm.), should continue to investigate gear factors associated with bycatch. Gear retention studies could be conducted in semi-field systems (large ponds) and permit estimates of catchability applicable to the field.

SECTION 1

ESTIMATION OF ATLANTIC STURGEON BYCATCH AND BYCATCH DEATHS FROM THE NMFS OBSERVER DATASET

Gary Shepherd, lead
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Introduction

An analysis was conducted to evaluate the bycatch of U.S. Atlantic sturgeon in coastal fisheries north of Cape Hatteras, NC. The intent of the work was a follow-up to a publication by Stein *et al*. (2004) that characterized Atlantic sturgeon bycatch from coastal fisheries in the Northeast for 1989 to 2000. That study concluded that bycatch was on the order of 260,000 lbs per year resulting in mortalities of 1,200 to 1,500 sturgeon (Table 1). Mortalities occurred in gillnet fisheries and were not estimated in trawl fisheries.

Table 1. Annual bycatch from 1989-2000 estimated from Stein et al. (2004). Estimates based upon observer bycatch expanded by landings for principal fisheries and mortality estimates of 22% in sink gillnet and 10% in drift gillnet fisheries.

Gear	Bycatch (000s lbs)	Mortalities (# per year)
Trawl	100	0
Sink Gill Net	125	1000
Drift Gill Net	35	385

Bycatch in commercial fisheries can be estimated using several methods. Commonly the ratio between observed discards and landings for a species can be used to expand to total species landings. However, this requires targeted landings or identifiable fisheries not restricted by quotas. Atlantic sturgeon are not subjected to a directed fishery and characterizing bycatch by fishery requires a subjective definition of a fishery. Fishing effort can also be used rather than landings, but gillnet effort recorded in vessel trip reports (NE Vessel Trip Report (VTR) data) has not been considered reliable (Palka and Rossman 2001). An alternative estimation method is development of a predictive model based on variables associated with bycatch, an approach used to estimate marine mammal bycatch. The encounter rate of marine mammals in coastal net fisheries is relatively infrequent, similar to Atlantic sturgeon. Estimation of sturgeon bycatch for 2001-2006 coastal fisheries was made using a log-linear model of Northeast Fisheries Science Center (NOAA Fisheries: NEFSC) observer data and commercial logbook records.

Approach

NEFSC observer data was queried for either Atlantic sturgeon or unknown sturgeon occurring in limited or regular trips using sink gillnets, anchor gillnets, or otter trawls. The spatial distribution was limited to trips within NMFS coastal statistical areas north of Cape Hatteras, NC (Figure 1). Sturgeon species, weight and length are recorded by observers on individual logs if observed and if unobserved the weight and length are estimated by the captain of the vessel. Since 2001, there have been 29 recorded shortnose sturgeon reported, (2003-3, 2004-12, 2005-3, 2007-11). If a fish is identified as a shortnose, a photo is taken and the audit requires that the data be double-checked and the photo used to confirm the identification. These records of shortnose sturgeon were excluded from analysis. The observer also records whether the sturgeon was dead or alive when released. Additional tow-by-tow information such as depth, and mesh size are recorded by the onboard observer. All trips by vessels fishing under a federal permit are required to maintain logbooks that includes trip information such as species landed, statistical areas fished, and effort.

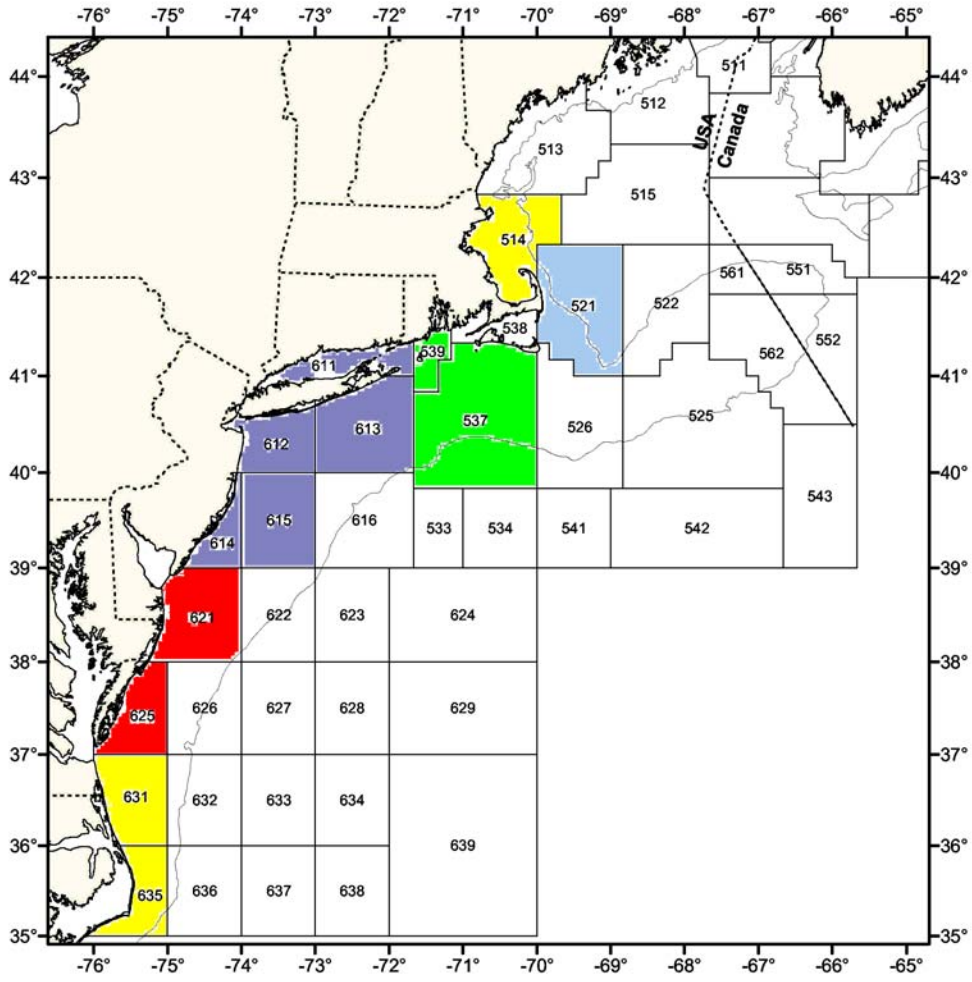

Figure 1. **NEFSC commercial statistical areas. Similar color (shaded) areas define a division in the sturgeon analysis.**

Observed trip data with sturgeon bycatches were combined with all observed trips within similar months, areas and depths for gillnet and trawl gear. These data were evaluated using a log-linear model for each gear type with months grouped by quarter and areas grouped into division. A variety of model error structures were evaluated (log-normal, negative binomial, poisson, and quasi-poisson) using the count of sturgeons as the dependent variable. The quasi-poisson model with a log link was chosen as the most appropriate for count data. The model incorporated year, quarter and division as class variable and landed weight ($\log_e$ of total weight across all species), depth (fathoms), and mesh size as covariates. Model parameters were estimated using SAS Proc GENMOD.

Final model configuration was:

$$\text{Sum sturgeon \#} = \log_e(U) + (B_1*(\log_e(\text{landed wt})) + (B_2*(\text{mesh}) + (B_3*\text{depth}) + \text{yr} + \text{qtr} + \text{div} + \text{error}$$

Separate model parameters were estimated for all sturgeon caught with gillnet, dead sturgeon in gillnet, all sturgeon in trawls and dead sturgeons in trawls. The model for dead sturgeon in trawls did not converge implying an estimate of zero. Total numbers of sturgeon taken as bycatch were predicted using the sum of landings within comparable cells determined from VTR data. The total landings within the VTR data are a subset of total landings represented by dealer reported data. The total bycatch estimate was adjusted based on a modified ratio of VTR to dealer data as reported in Wigley *et al*. (2004). Model parameter estimates and their diagnostics are presented at end of this section.

Results

Observer Dataset

During the period 2001-2006, a total of 67 and 511 Atlantic sturgeon were observed in otter trawl and gillnet fisheries respectively (Tables 2 and 3). Observed bycatch varied across divisions (statistical areas), as emphasized in greater detail in Section 3. For both gear types, most bycatch was observed in the second quarter (Tables 4 and 5). On a proportionate basis of all observed trips, 2.9 to 6.1% of gillnet trips encountered sturgeon and 0.5 to 2.0% of trawl trips encountered sturgeon (Table 6). The landings dataset by which expansions were made are shown in Tables 7 and 8.

Table 2. Observed sturgeon in gillnet bycatch – by Division (months combined), 2001-2006.

Year	Division						
	51	**52**	**53**	**61**	**62**	**63**	**Total**
2001	9		2		31	42	**84**
2002	14	2	4	8	4	18	**50**
2003	15	6	1	4	8	29	**63**
2004	25	12	5	86	7	8	**143**
2005	11	2	6	25	1	22	**67**
2006	4	3	2	40	15	40	**104**
Total	**78**	**25**	**20**	**163**	**66**	**159**	**511**

Table 3. **Observed sturgeon in otter trawl bycatch – by Division (months combined), 2001-2006.**

Year	**Division**						
	51	**52**	**53**	**61**	**62**	**63**	**Total**
2001	0	0	0	6	0	0	**6**
2002	0	1	0	0	1	0	**2**
2003	1	1	0	0	1	3	**6**
2004	2	0	4	10	0	0	**16**
2005	1	1	1	8	0	1	**12**
2006	2	0	0	14	4	5	**25**
Total	**6**	**3**	**5**	**38**	**6**	**9**	**67**

Table 4. **Observed sturgeon in gillnet bycatch – by quarter, 2001-2006.**

Year	**Quarter**				
	1	**2**	**3**	**4**	**Total**
2001	22	54	0	9	**85**
2002	6	24	4	16	**50**
2003	19	28	0	16	**63**
2004	14	52	12	71	**149**
2005	11	17	5	36	**69**
2006	37	68	8	7	**120**
Total	**109 (20%)**	**243 (45%)**	**29 (5%)**	**155 (29%)**	**536**

Table 5. **Observed sturgeon in otter trawl bycatch – by quarter, 2001-2006.**

Year	**Quarter**				
	1	**2**	**3**	**4**	**Total**
2001	0	4	0	2	**6**
2002	0	0	0	2	**2**
2003	4	2	0	0	**6**
2004	1	7	3	5	**16**
2005	1	5	4	2	**12**
2006	8	11	1	5	**25**
Total	**8 (21%)**	**29 (43%)**	**8 (12%)**	**16 (24%)**	**67**

Table 6. **Sturgeon observed bycatch as proportion of all observed trips, 2001-2006.**

Year	Gillnet Number of Trips	Gillnet Trips with Sturgeon	Otter Trawl Number of Trips	Otter Trawl Trips with sturgeon
2001	1,005	61 (6.1%)	286	4 (1.4%)
2002	720	33 (4.6%)	438	2 (0.5%)
2003	879	39 (4.4%)	580	5 (0.9%)
2004	1,657	89 (5.4%)	981	12 (1.2%)
2005	1,484	43 (2.9%)	1128	11 (1.0%)
2006	947	55 (5.8%)	601	12 (2.0%)

Table 7. **Landings data for all species, sink gillnet in thousands of mt, 2001-2006.**

Year	Quarter 1	2	3	4	Total
2001	2.5	4.5	4.0	5.6	**16.6**
2002	3.9	4.1	4.0	4.5	**16.5**
2003	3.4	5.3	4.8	5.1	**18.6**
2004	3.9	4.6	4.4	3.7	**16.7**
2005	2.5	4.7	4.3	3.8	**15.3**
2006	3.4	3.6	4.2	4.3	**15.5**
Total	**19.6**	**26.9**	**25.7**	**27.0**	**99.2**

Table 8. **Landings data for all species, otter trawl in thousands of mt, 2001-2006.**

Year	Quarter 1	2	3	4	Total
2001	24.0	20.0	22.2	26.1	**92.3**
2002	26.4	18.5	19.8	20.2	**84.7**
2003	27.6	14.3	18.0	21.5	**81.4**
2004	26.7	23.4	31.6	20.9	**102.7**
2005	26.3	19.9	21.6	18.9	**86.6**
2006	31.1	15.5	23.0	19.0	**88.5**
Total	**162.1**	**111.6**	**136.2**	**126.4**	**536.2**

Bycatch Estimates

Results of the model (unadjusted for VTR under-reporting) produced estimates of sturgeon bycatch in gillnets ranging from 1,135 in 2001 to 2,617 in 2004 (Table 10). The model using only sturgeon noted as dead when captured produced estimates of 318 fish in 2006 to 1,163 in 2004 (Table 10). Estimated trawl caught sturgeon numbered 2,167 in 2005 to 7,210 in 2002 (Table 12). However, in the observer data for 2001 through 2006 there were only a total of 3 dead sturgeon implying that survival is likely very high.

An alternative approach using the ratio of observed sturgeon bycatch to landings per cell (year, quarter, division, mesh, and depth) produced similar results, although generally lower than the model results (Tables 10 and 12). The 2006 trawl bycatch estimate was abnormally large due in part to the presence of a cluster of sturgeon discards in a cell (division 61, qtr 4, 2”mesh, 70-80 fathoms) with low observed landings. The resulting expansion to total landings in the cell creates unusually high bycatch estimates.

Final estimates of sturgeon bycatch were raised by 10.6% to account for total landings not represented in VTR logbook data (this expansion from an independent analysis conducted by NEFSC). The estimated total number of sturgeon mortalities from coastal fisheries ranged from 1,286 in 2004 to 352 in 2006 (Table 13).

Table 9. Gillnet landings and bycatch summary, 2001-2006.

Year	Observed Landings	All Observed Sturgeon	Dead Observed Sturgeon	Frequency of Trips	Total Landings (lbs)
2001	1,309,013	84	25	66,351	35,905,851
2002	1,010,286	50	12	65,304	34,958,179
2003	1,389,213	63	13	70,014	39,407,816
2004	2,386,838	143	70	69,168	35,235,041
2005	2,212,164	67	21	66,026	32,136,445
2006	1,295,780	104	13	65,785	32,523,536

Table 10. Gillnet sturgeon bycatch estimates, 2001-2006.

Year	Sturgeon Bycatch Estimate	Ratio Method (all)	Dead Sturgeon Bycatch Estimate
2001	1,135	316	451
2002	1,767	1,912	598
2003	2,587	1,679	607
2004	2,617	1,643	1,163
2005	1,331	935	383
2006	1,980	1,523	318

Table 11. Otter trawl landings and bycatch summary, 2001-2006.

Year	Observed Landings	All Observed Sturgeon	Dead Observed Sturgeon	Frequency of Trips	Total Landings (lbs)
2001	3,460,014	6		168,391	200,642,099
2002	2,598,338	2		173,928	177,395,979
2003	2,419,910	6		162,159	170,848,708
2004	2,373,397	16		154,144	210,931,478
2005	2,501,287	11	1	152,331	175,448,183
2006	3,170,686	23	2	144,632	188,613,390

Table 12. Otter trawl sturgeon bycatch estimates, 2001-2006.

Year	Sturgeon Bycatch Estimate	Ratio Method (all)	Dead Sturgeon Bycatch Estimate
2001	3,200	225	**Model did not converge**
2002	7,210	60	
2003	2,007	874	
2004	3,226	945	
2005	2,167	613	
2006	**5,166**	**5,777**	

Table 13. Total sturgeon bycatch estimates (count) following adjustment to total landings, 2001-2006.

Year	Ratio	Model All	Model Dead	% Dead
2001	598	4,795	498	10.4%
2002	2,181	2,752	662	24.1%
2003	2,824	5,081	671	13.2%
2004	2,862	6,462	1,286	19.9%
2005	1,712	3,869	424	10.9%
2006	8,074	7,904	352	4.4%

SECTION 2

DOES THE CURRENT LEVEL OF COASTAL BYCATCH MORTALITY CURTAIL OR PROHIBIT RECOVERY OF ATLANTIC STURGEON POPULATIONS?

David Secor, lead
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Introduction

To provide context on the likely consequences of the recent estimate of bycatch mortality (~650 Atlantic sturgeon per year) in New England and mid-Atlantic waters, an analysis was conducted using parameters from the Hudson River population (Kahnle *et al*. 2007). Where important uncertainty in parameter variables existed, a likely range of values was used. The larger analysis was ordered in a series of sequential questions and analyses.

What Do We Know?

From analyses conducted in this report for the period 2001-2006, we can conclude:

1. Most observed sturgeon deaths occur in sink gillnet fisheries. Among targeted species, the monkfish fishery accounts for the majority of sturgeon bycatch deaths. Although overall bycatch of sturgeons in trawl fisheries are similar to sink gillnet fisheries, observers recorded very few deaths (n=3).
2. Modeled bycatch deaths for sink gillnet fisheries averaged ranged between 352 (2006) and 1,286 (2004) with a mean of 649.
3. Sink gillnet fisheries and sturgeon bycatch deaths occur over a wide region of U.S. mid-Atlantic and New England waters (Section 3). Thus, they are expected to intercept Atlantic sturgeon from several populations.
4. Fish over 120 cm are fully vulnerable to coastal sink gillnet bycatch. Fish >200 cm are rarely observed. This corresponds to an age range of 11 to 20 years (Stevenson and Secor 2000; Kahnle *et al*. 2007).

From the scientific literature, we can support:

1. The Hudson River population is a major contributor to bycatch sturgeon in the New England and Mid-Atlantic regions. A genetic analysis performed in the late 1990s on fish caught in sink gillnets in mid-Atlantic waters classified the majority of fish as Hudson River population (Waldman *et al*. 1996). The Hudson River is also likely the largest population in these regions (Kahnle *et al*. 2007). Still, sampling and genetic analyses are limited in New England and mid-Atlantic waters and Atlantic sturgeon are known to disperse widely (Eyler 2006). Thus, systems other than the Hudson systems are expected to contribute to coastal sturgeon numbers.
2. Atlantic sturgeon populations can withstand only low rates of anthropogenic (e.g., fishing, bycatch) mortality. For instance, sustainable fishing rates on adult Atlantic sturgeon are 5% per year, and sustainable fishing rates for sub-adults are lower still (Boreman 1997; ASMFC 1998; Kahnle *et al*. 2007). Thus, even small rates of bycatch mortality (<5%) on sturgeon populations could retard or curtail recovery.
3. A recent abundance estimate for age-1 Hudson River Atlantic sturgeon was 4,300 in 1995 (Peterson *et al*. 2000). Estimates for adult numbers during the period 1986-1995 were 600 males and 270 females (Kahnle *et al*. 2007). No other published estimates of abundance for Atlantic

sturgeon populations exist, although sturgeon studies do indicate that yearling abundances tend to fluctuate less than 5-fold on a year-to-year basis (Nilo *et al*. 1997; Woodland and Secor 2007).

4. Estimated annual natural mortality for New England and mid-Atlantic sturgeon is M=0.07 (Kahnle *et al*. 2007).

From important sources of uncertainty, we stipulate:

1. Levels of Hudson River contribution to the coastal bycatch in New England and the Mid-Atlantic region at three levels: 25%, 50%, and 75%.
2. Levels of age-1 Hudson River abundance of 1,000, 5,000, and 10,000.

What Can We Estimate?

We can now estimate percent Hudson River population bycatch mortality under scenarios of percent contribution of the Hudson River population to coastal bycatch and population recruitment levels using the following calculation:

$$\%\text{HR bycatch mortality}=C*D/N$$

where,
C= contribution of HR fish; stipulated at 25%, 50%, and 75%
D= bycatch deaths at age 11 years; stipulated at 88 (total bycatch deaths/number of vulnerable age classes adjusted for annual mortality of 0.07; 650/7.4)
N=Abundance of age-class of HR fish, which is fully vulnerable to sink gillnet.
Estimated as $R*\exp^{-0.07*t}$, where R=1,000, 5,000, or 10,000 yearling recruits and t=10, the mean period of time before yearlings are fully vulnerable to sink gillnets (i.e., 50% of yearlings survive to age 11).

This procedure only estimates bycatch mortality for the Hudson River population. In doing so, we first need to consider how much of the coastwide sink gillnet bycatch consists of this particular population (10, 20, 50%). We then need to know how many fish die in the bycatch for a given year-class. This is important because the biological reference point for sustainable bycatch (<4%) applies to each year-class on an annual basis. In contrast to the reference point, total bycatch deaths in any given year are distributed across numerous size and age-classes. To determine bycatch mortality in a year-class we chose year-class age 11, the first year estimated to fully recruit to the sink gillnet fishery. We assumed that knife-edge recruitment of Atlantic sturgeon occurred at 11 years of age and a constant rate of bycatch occurred until 20 years of age. This may be unrealistic because sink gillnets do show a degree of selection for smaller sized sturgeon (see Sections 4 and 6). Still, we do not have sufficient information to derive selectivity coefficients. Total bycatch was divided by number of vulnerable age-classes adjusted for natural mortality. If adjustments could be made based upon size-selectivity in our calculations, we expect that these modifications would tend to narrow the age-range of bycatch losses; thus scenario results are conservative (under-estimates of true bycatch losses at age 11). Finally, it's necessary to match population abundances to losses (D/N). To do this, we applied a natural mortality rate to a range of yearling abundances (1,000, 5,000, 10,000) for a ten year period to estimate abundance at age 11, just as sturgeon become vulnerable to coastal sink gillnet bycatch.

Tabulating across scenarios,

% HR Contribution	HR Recruitment	% HR Bycatch Mortality
50%	1,000	8.8
	5,000	1.8
	10,000	0.9
25%	1,000	4.4
	5,000	0.9
	10,000	0.4
10%	1,000	1.7
	5,000	0.4
	10,000	0.2

What Inferences do Reasonable Scenarios Support?

For scenarios of low recruitment (1,000 yearlings), percent bycatch mortality for the Hudson River population exceeded those believed to lead to a stable or growing population (bycatch mortality rates <4%; Kahnle *et al.* 2007). In a substantial number of scenarios, bycatch mortality was a substantial fraction of allowable anthropogenic mortality (e.g., in excess of 1%). Only low contribution rates of the population to coastal bycatch in concert with high and intermediate recruitment levels would lead to stable or slow growing populations. This set of scenarios suggests that for one of the most abundant populations of Atlantic sturgeon, current level of bycatch deaths could be retarding or curtailing recovery.

Implications

To remain stable or grow, populations of Atlantic sturgeon can sustain only very low anthropogenic sources of mortality (Boreman 1997; Secor and Waldman 1997; ASMFC 1998; Gross *et al.* 2000; Kahnle *et al.* 2007). This drives the implications of the simulations, where most reasonable scenarios led to bycatch mortality that exceeded 3%. Errors related to other input parameters—natural mortality, size at vulnerability, and bycatch death estimates—would have to be quite large to change this overall finding.

The results of the scenario are conservative (likely under-estimates) because not all sources of mortality are included in the NMFS Observer Database estimate. Observer programs do not operate in most inland or bay waters. Other sources include poaching and ship strikes. For instance, a single poaching event in Virginia during 1999 resulted in the deaths of 95 Atlantic sturgeon; ship strikes can also account potential for dozens of deaths each year that are not part of the observer program estimate (Blankenship 2007; D. Fox, Delaware State University, pers. comm.). We remind readers that the analysis is specific to New England and Mid-Atlantic waters where broad observer coverage supports an analysis of sturgeon bycatch. No such observer program exists in southeastern U.S. Atlantic waters.

Other populations contribute in unknown ways to the coastal bycatch, but populations smaller than the Hudson River population would be expected to be disproportionately affected by bycatch as proportional removals have larger negative effects on less productive populations (Policansky and Magnuson 1998).

Because deaths are principally attributed to the monkfish sink gillnet fishery, changes in effort in this fishery are expected to result in proportional changes in bycatch deaths. Similarly, means to reduce bycatch in this and other sink gillnet fisheries through modifications of gear deployments (e.g., soak time, tie-downs) could result in substantial reductions in sturgeon bycatch and sturgeon bycatch deaths (see Sections 4 and 6).

SECTION 3

SPATIAL DISTRIBUTION OF OBSERVED STURGEON ENCOUNTERS IN COMMERCIAL SINK GILLNETS AND SINK GILLNET FISHERY EFFORT

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Introduction

The purpose of this exercise was to use GIS analysis to exhibit the locations of sturgeon encounters in comparison to the overall range of observed sink gillnet fishery coverage by the NEFSC Sea Sampling (Observer) Program (Observer Program). Further, seasonal distributions of observed live and dead sturgeons were examined along with their distribution across statistical divisions and depths.

Approach

Effort was made to ensure that the subset of Observer Program records used for the maps was consistent with that used in the statistical analyses and modeling exercises described elsewhere in this report (timeframe: Jan 1, 2001–Dec 31, 2006; 6,472 observed sink gillnet trips totaling 28,543 sets; 511 individual sturgeon encountered). Typically, trips comprised multiple sets (mean N_sets/trip = 4.41; range = 1 to 31; Figure 1.). A “set” consisted of a string of connected nets (mean nets/string = 8.93; "range" = 1 to ~50 nets; 8 sets with over 50 nets, 16 sets with no values; Figure 2.).

Points displayed on each of the maps correspond to the latitudes and longitudes recorded by observers at the beginning of each string retrieval. A limitation of the information conveyed by the maps is overlap of points for sets where multiple sturgeon were encountered. This occurred in 76 of the total 386 sets that caught sturgeon (mean N_sturgeon/set when sturgeon were captured was 1.32). Locations reflect all observed sink gillnet sets (green), live sturgeon releases (blue) and dead sturgeon discards (red) (Figure 3). Additionally, the order in which the points are layered is such that dead discards overlay live discards and zero encounters are at the bottom. In order to mitigate the masking effect of this approach, point sizes decrease conversely with layering. This allows a location where both live and dead discards occurred to be displayed (appears as a red point with a blue “halo”). While all the maps show consolidated data from 2001 to 2006, monthly maps were created to explore temporal shifts in the spatial distribution of encounters and mortalities (Figures 4-15). A single map shows observed sets and encounters across months (Figure 3).

Three additional maps were created to display (1) sink gillnet fishery effort (Figure 16); (2) effort in comparison with observer coverage (Figure 17); and (3) fishery effort, observer coverage, and observed sturgeon encounters (Figure 18). For the last map, live discards are in green to contrast with the blue shading used for effort (this is noted here to avoid confusion with green used in observer data maps to indicate sets with no sturgeon).

Sink gillnet fishery effort was calculated as a unitless product of net length (i.e., the amount of net in the water) and soak time. These data are available in the NMFS' vessel trip report (VTR) database:

Net length = nhaul*gearqty*gearsize
where, nhaul = # strings
gearqty = # nets per string
gearsize = mean length of nets in a string

Soak time = soakhr + (soakmin/60)

Effort = Net length * Soak time

Effort maps were created using a total 79,265 sink gillnet trips (Figures 16-18). These trips are a subset of the total number of sink gillnet trips (90,230) that met the gear, timeframe, and spatial limitations of the data used in the statistical analyses after extreme values for any variable and missing spatial data were culled.

In order to plot concentrations of fishing effort, calculated "effort" values for each trip were summed within ten minute squares (an area equal to 10x10 geographical minutes). The shading of ten-minute squares, then, reflects the distribution of the cumulative percent of total effort. Cumulative percent was used because the calculated "effort" values are unintuitive. Using cumulative percent, a relatively small number of darker shaded ten-minute squares contributed proportionally to much of the total effort and a large number of light shaded ten-minute squares contributed to the final 5%. Ergo, shading reflects where most of the effort is occurring.

Results and Discussion

The distribution of observed gillnets were concentrated off Cape Hatteras, the mouth of the Chesapeake, MD's coastal waters, northern shore of New Jersey and NY Bight, RI coastal waters, Cape Cod through Gulf of Maine (Figure 3). Sturgeon bycatch tended also to be concentrated in these areas without obvious spatial trends in mortality. Spatial concentrations in observer coverage and sturgeon bycatch were grossly similar to those reported for the 1989-2000 period by Stein *et al.* (2004). The large majority of sturgeon bycatch was observed in waters shoal of 50 fathoms. Indeed other analyses indicate that most sturgeon bycatch occurs in waters shoal of 50 meters (Stein *et al.* 2004; see Section 5).

Seasonal maps (Figures 4-15) showed higher bycatch incidence highest during April and May and lowest from August to October (see Section 5), but it is important to recognize that underlying these monthly depictions are specific fisheries that develop uniquely with respect to season and region, such that seasonal trends are confounded with fishery effects (see Sections 4 and 6).

The overlay of coverage and effort appears to show that observer coverage is generally consistent with the distribution of fishery effort (Figures 16-18). Note however that Observer Program coverage in the southern Mid-Atlantic (mouth of Chesapeake through Cape Hatteras) is disproportionately high relative to effort in the sink gillnet fisheries.

Results indicate that several concentrated regions of gillnet fisheries exist and that these all encounter sturgeons, which can contribute to their mortality. Sturgeon encounters tend to occur in waters shoal of 50 meters. Although seasonal patterns exist, sturgeons are encountered in sink gillnets throughout the year. A limitation of the present GIS analysis is that gillnets are combined across categories of fisheries and applications, even though the efficiency at which they encounter sturgeons are associated with target fishery and gear variables (see Sections 4 and 6). On the other hand, these illustrations give support to coarse inferences on the comparative distribution of effort and sturgeon encounters. If further integration of the statistical modeling exercises and GIS analyses were to be undertaken, mapping could be used to provide information on time/area combinations where certain types of sink gillnet fishery activity are likely to result in sturgeon captures. This type of information would have a clear practical application if a reduction in sturgeon bycatch is ultimately desired.

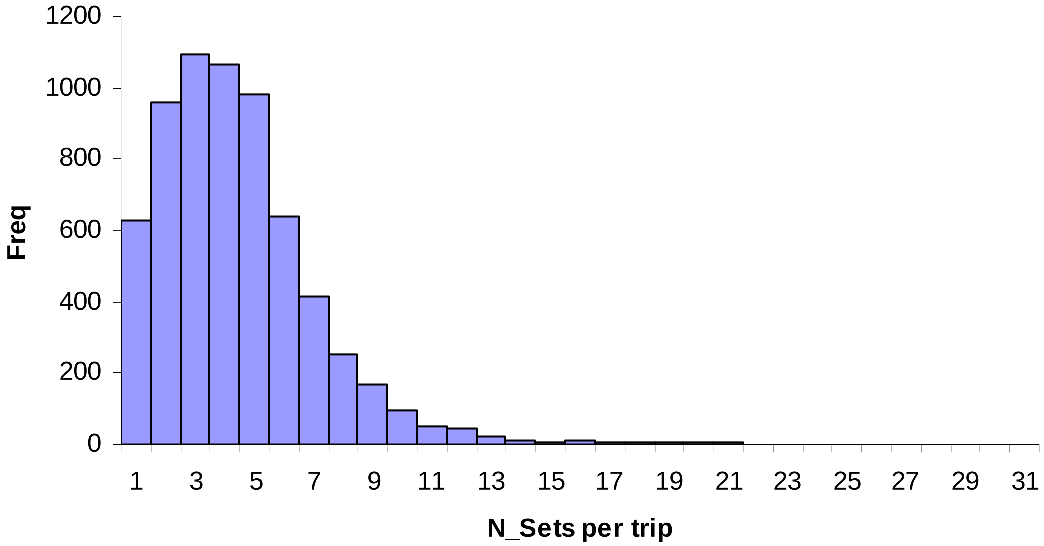

Figure 1. **Frequency distribution of sink gillnet sets per trip on observed trips, 2001-2006.**

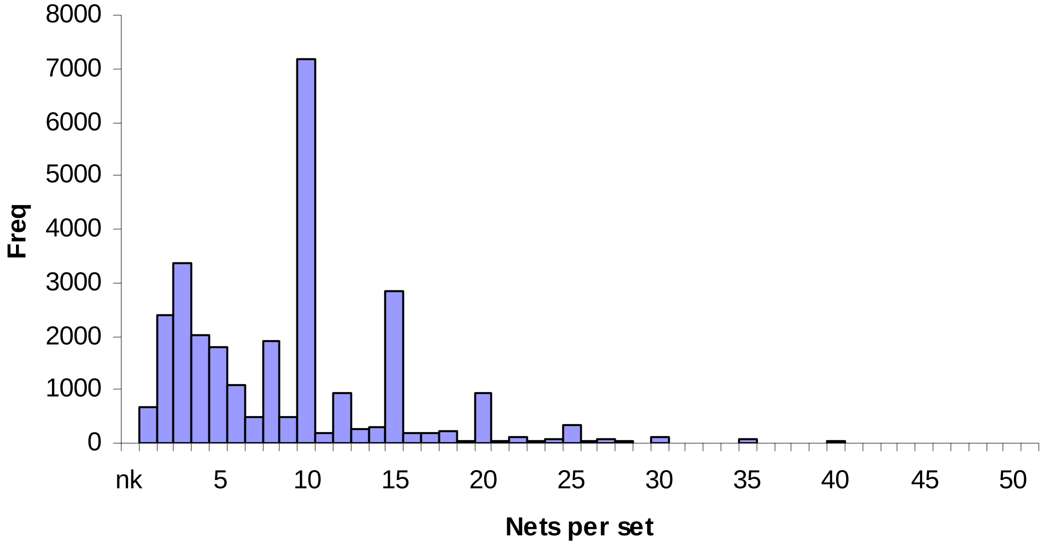

Figure 2. **Frequency distribution of nets per set on observed trips, 2001-2006.**

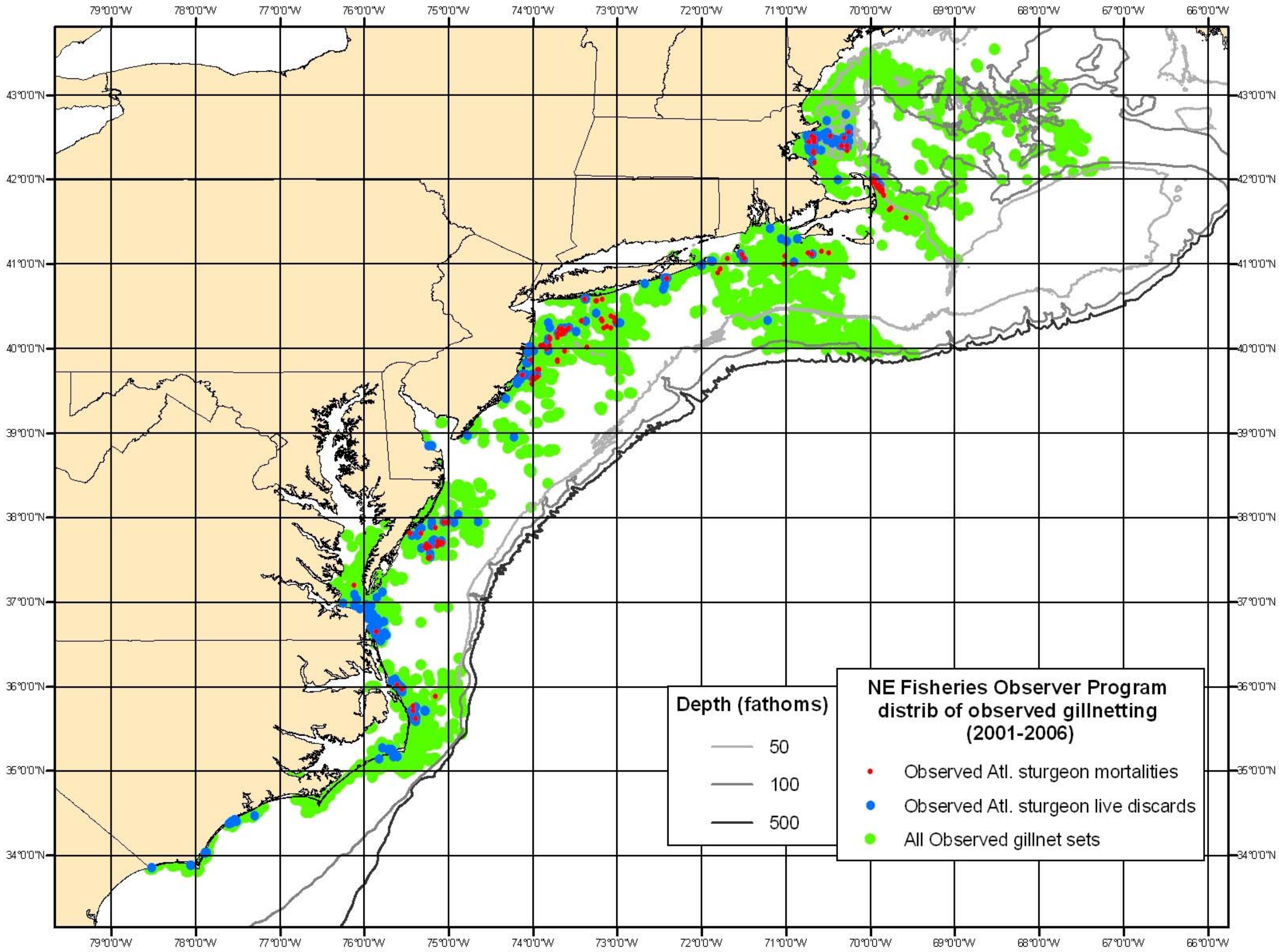

Figure 3. **All observed sturgeon bycatch, 2001-2006.**

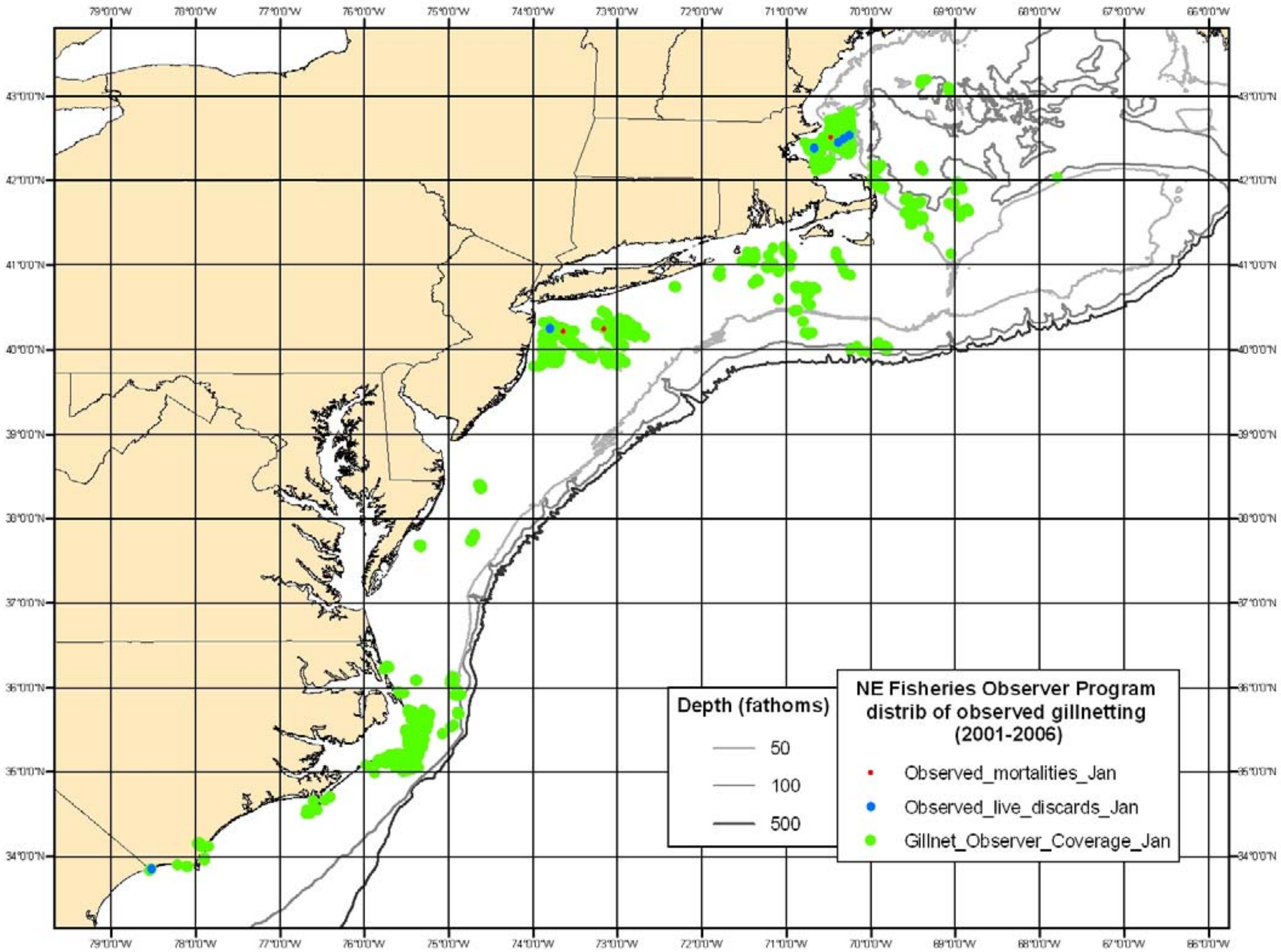

Figure 4. **Observed sturgeon bycatch, January 2001-2006.**

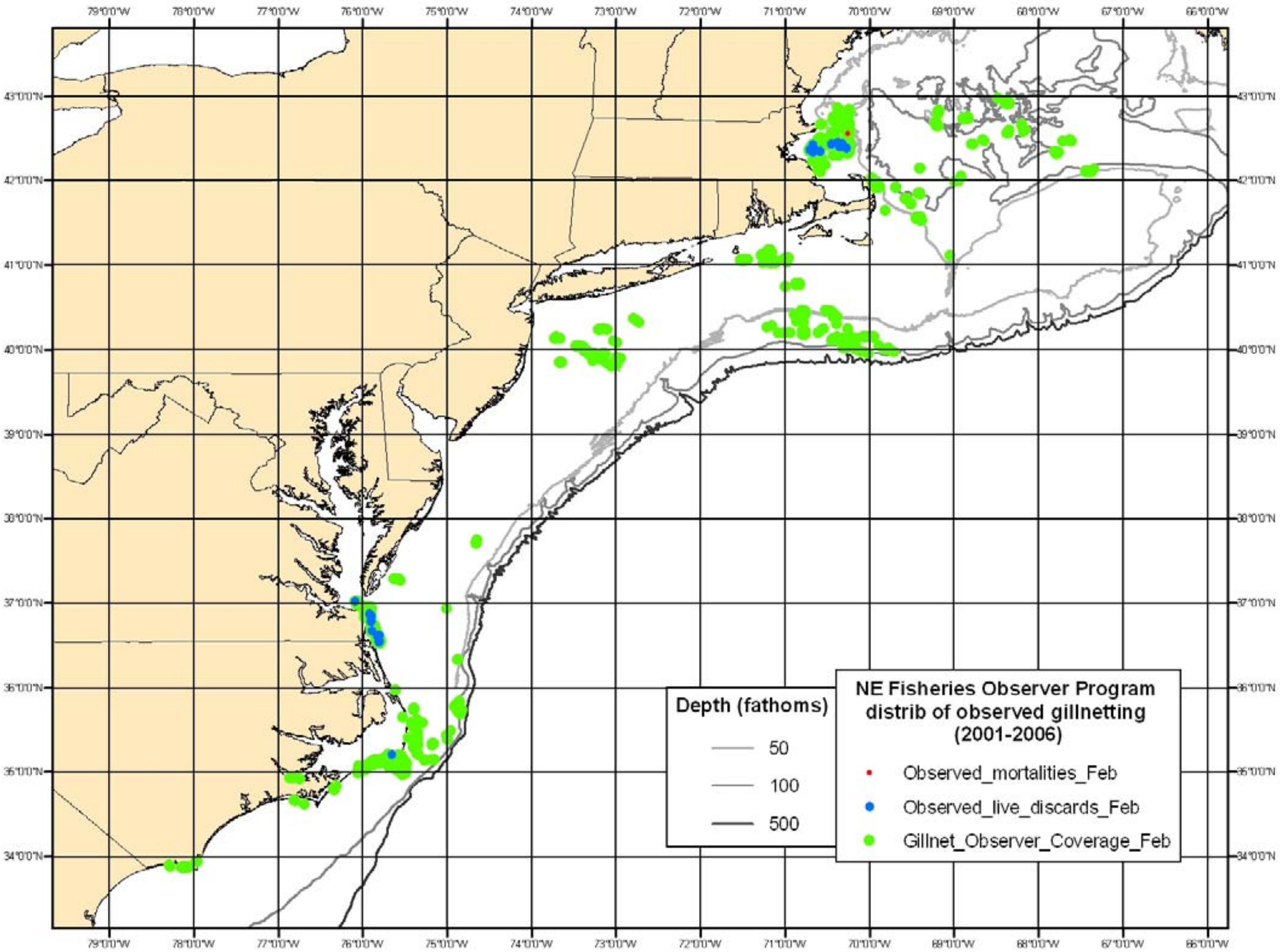

Figure 5. **Observed sturgeon bycatch, February 2001-2006.**

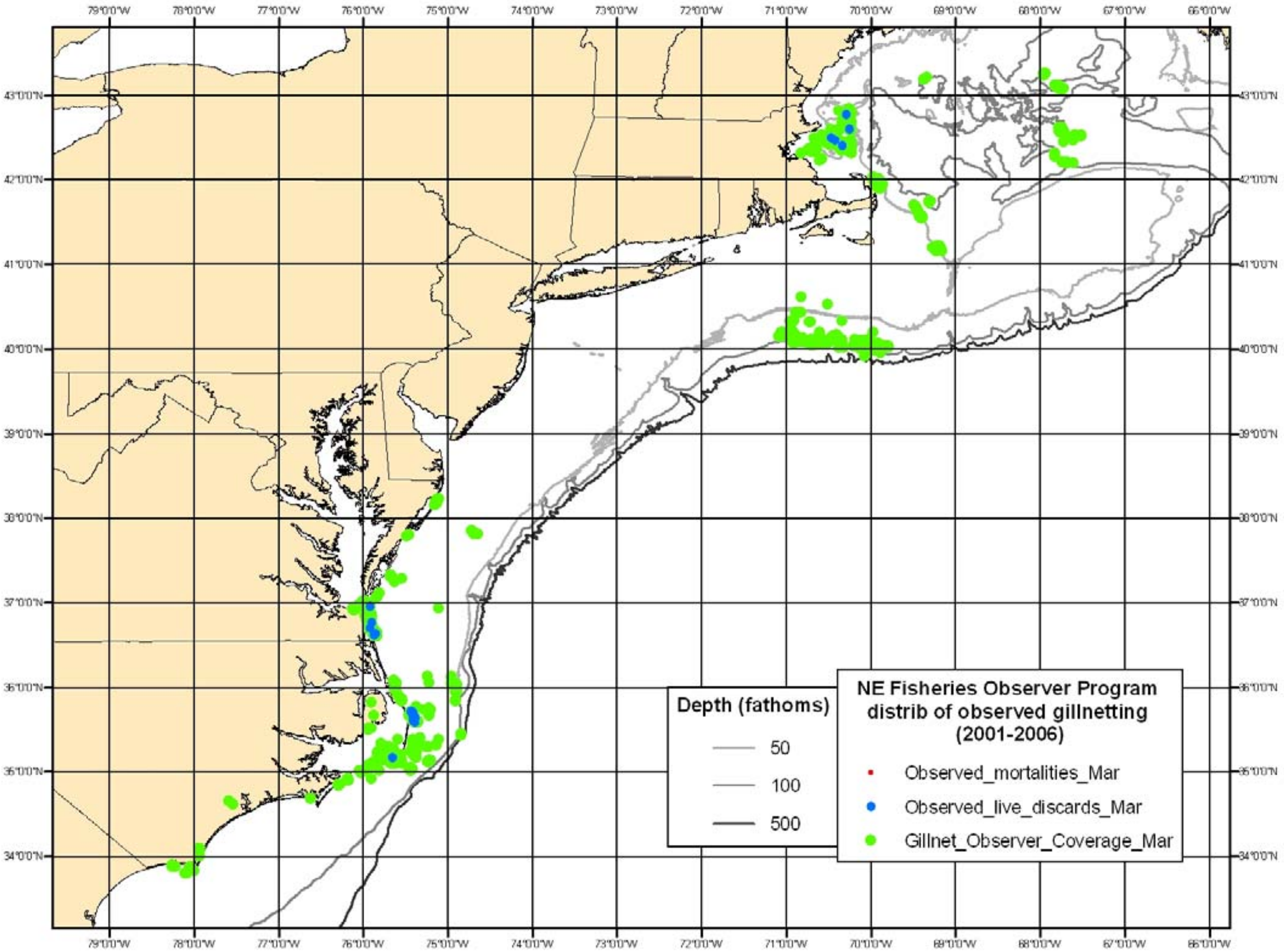

Figure 6. **Observed sturgeon bycatch, March 2001-2006.**

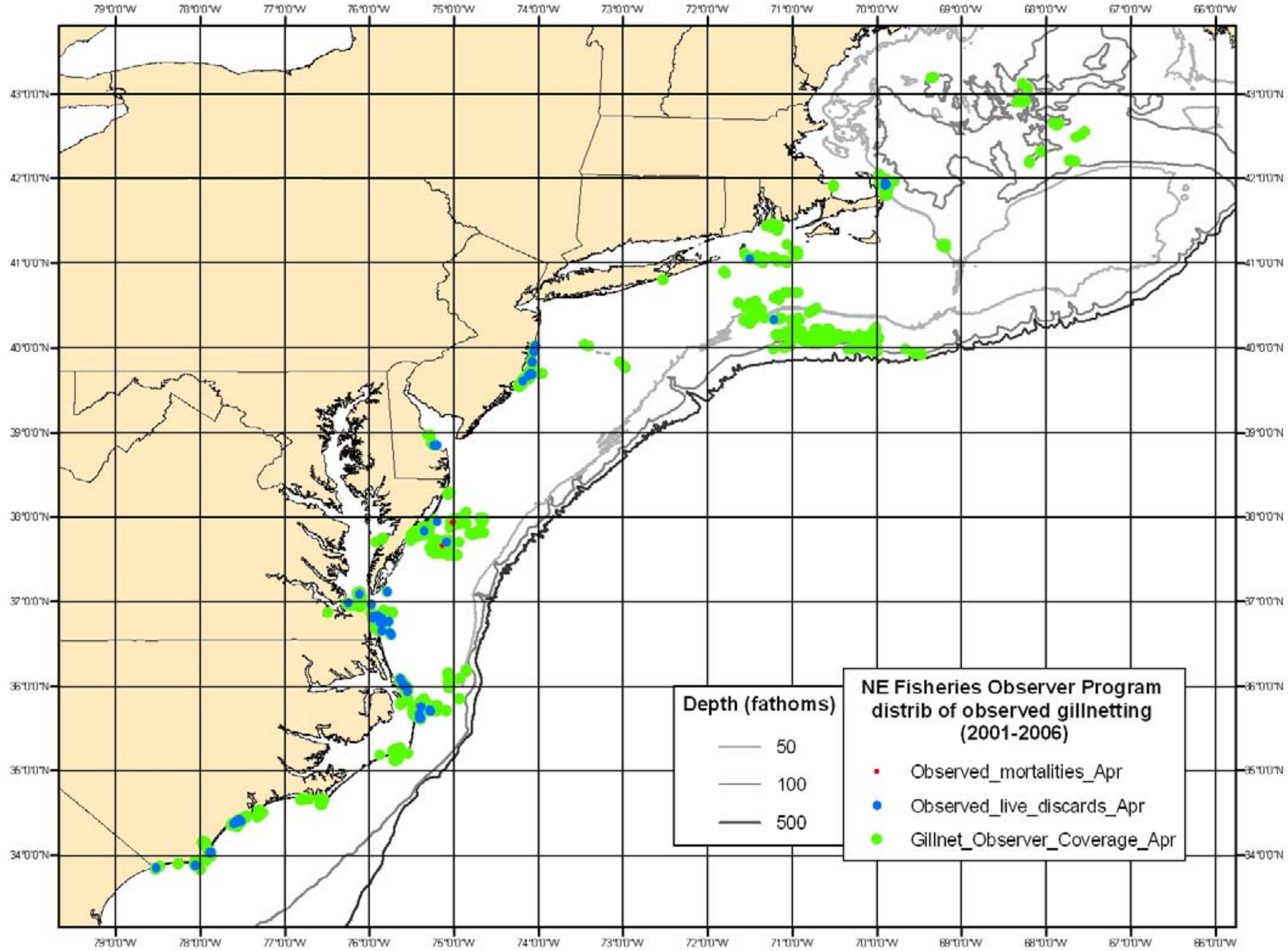

Figure 7. **Observed sturgeon bycatch, April 2001-2006.**

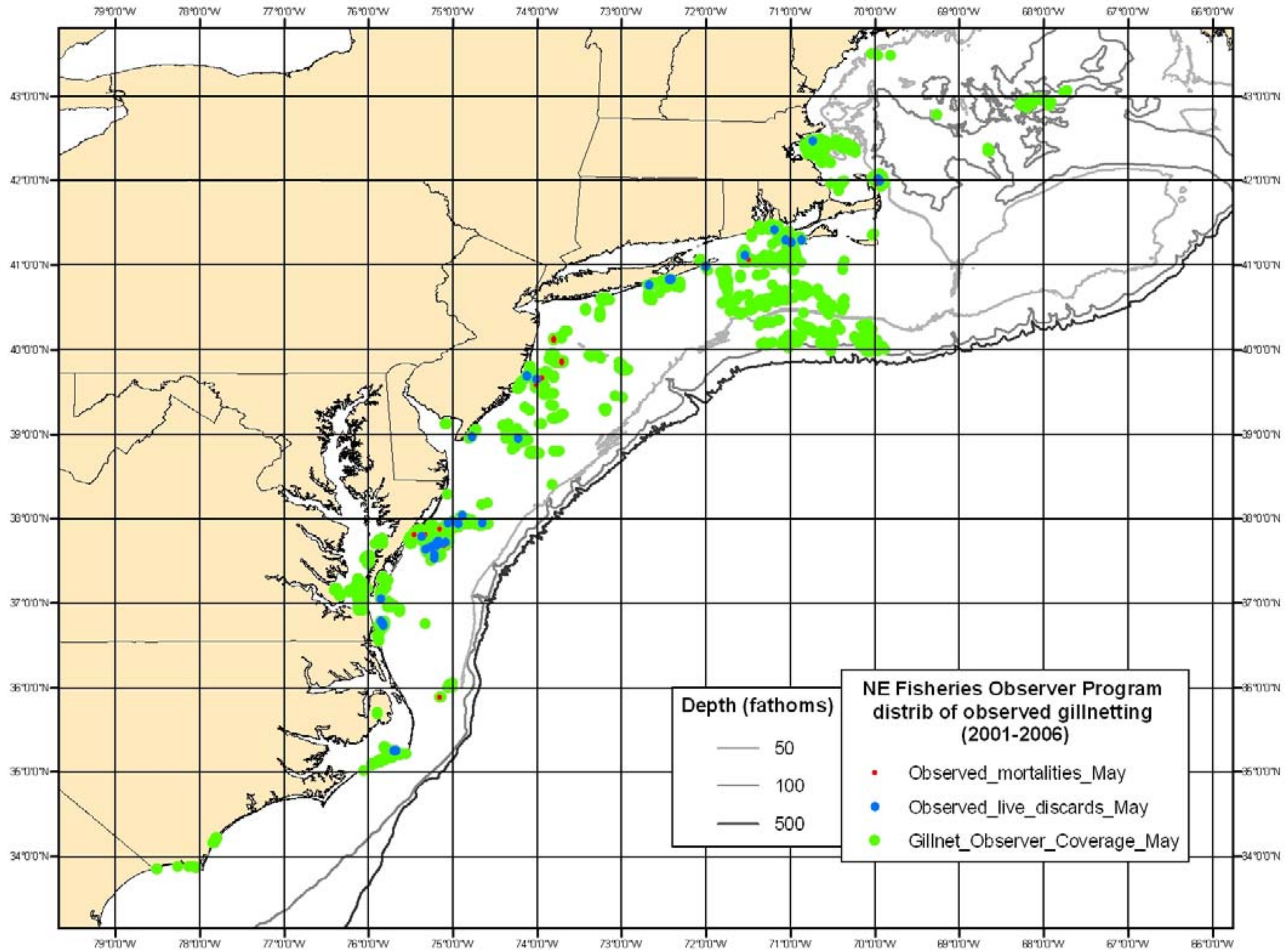

Figure 8. **Observed sturgeon bycatch, May 2001-2006.**

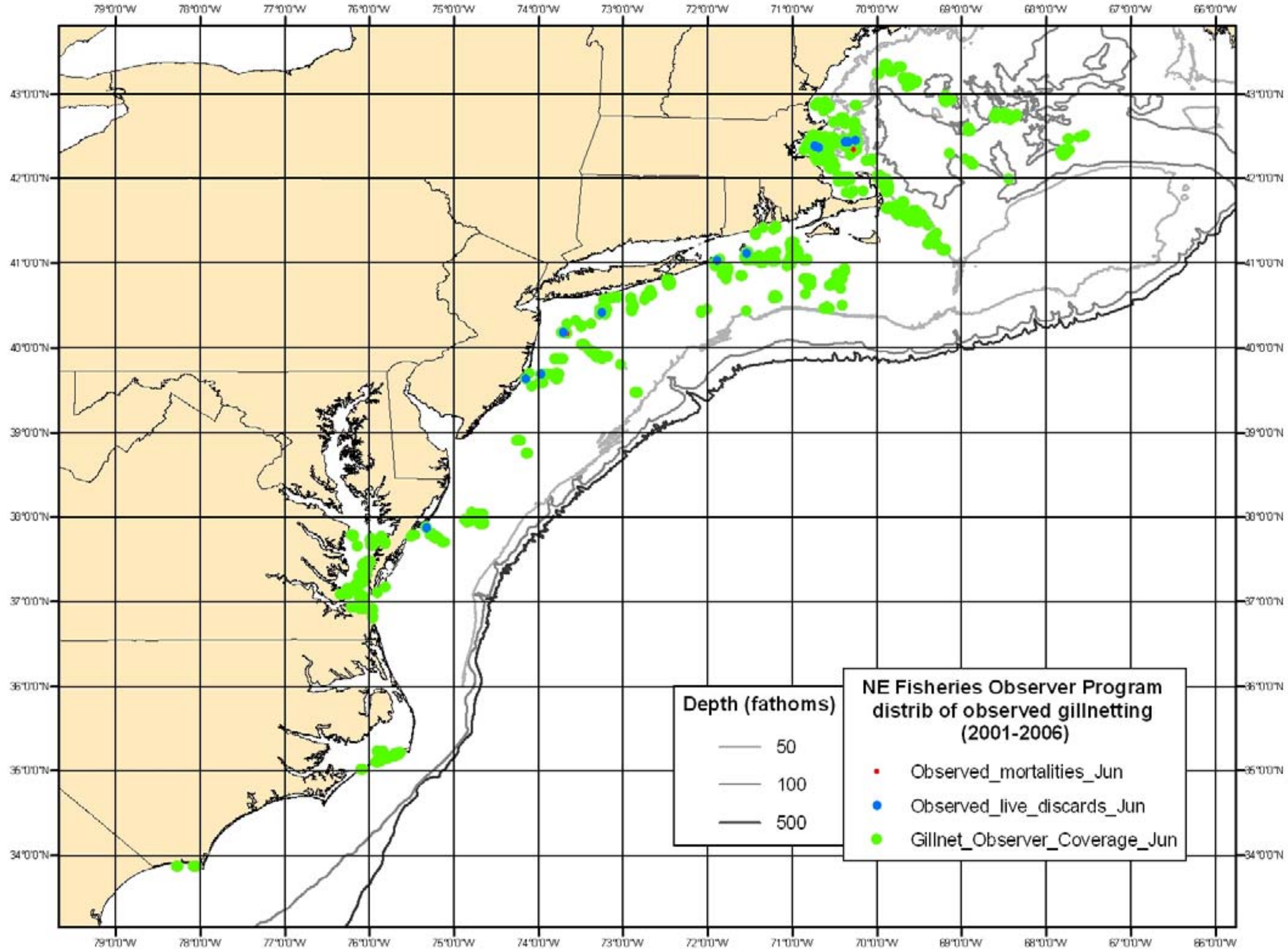

Figure 9. **Observed sturgeon bycatch, June 2001-2006.**

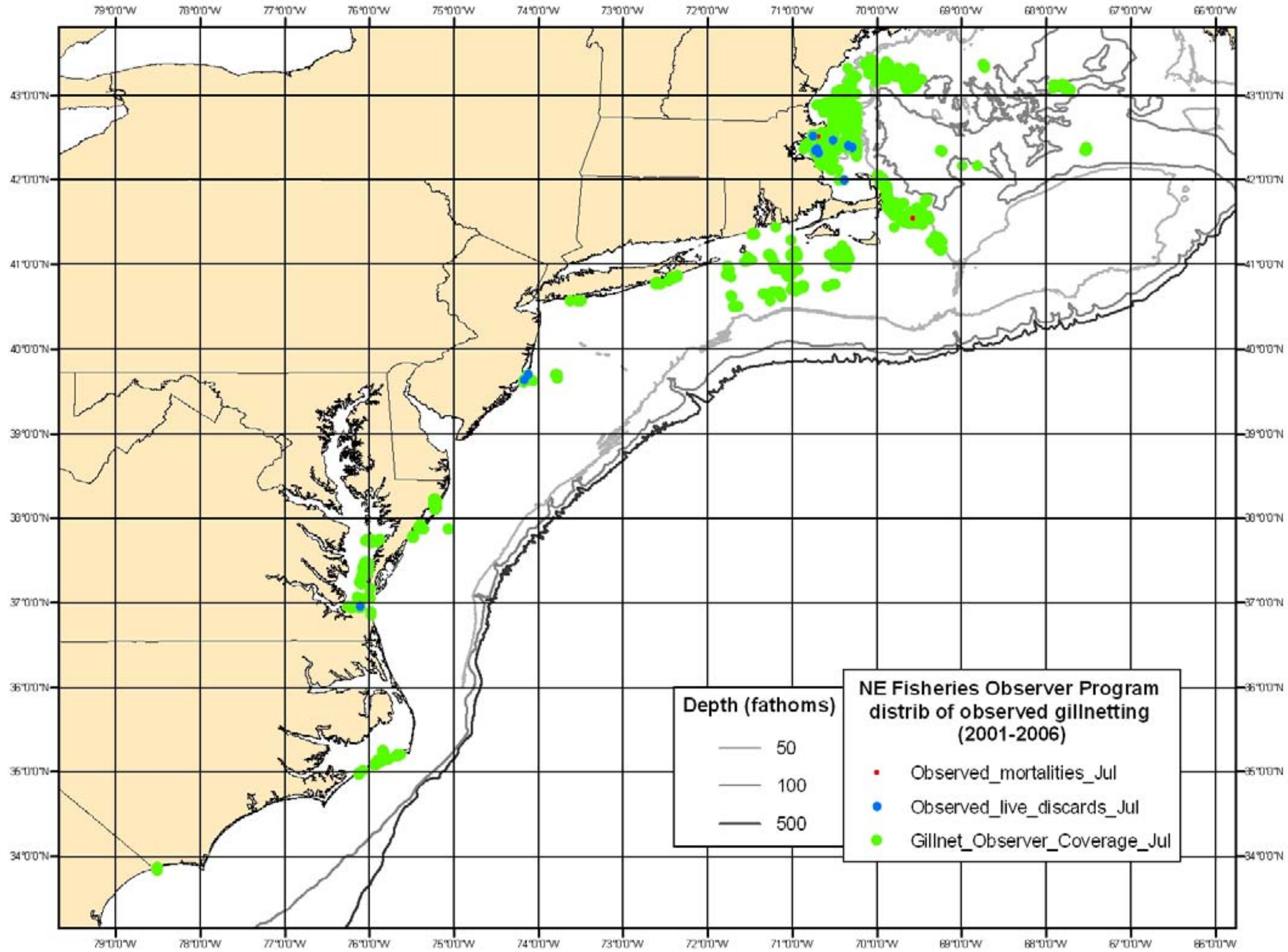

Figure 10. **Observed sturgeon bycatch, July 2001-2006.**

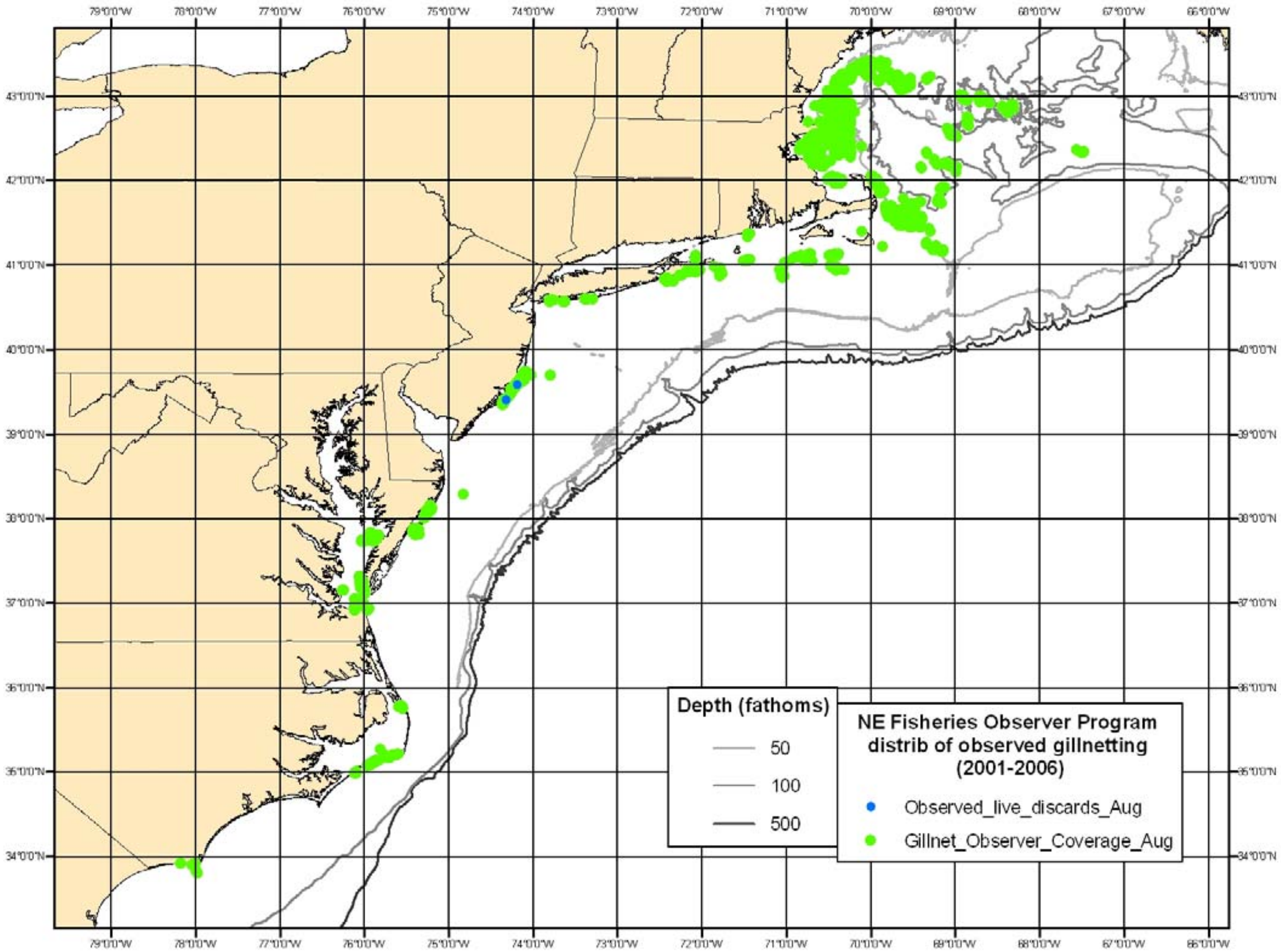

Figure 11. **Observed sturgeon bycatch, August 2001-2006.**

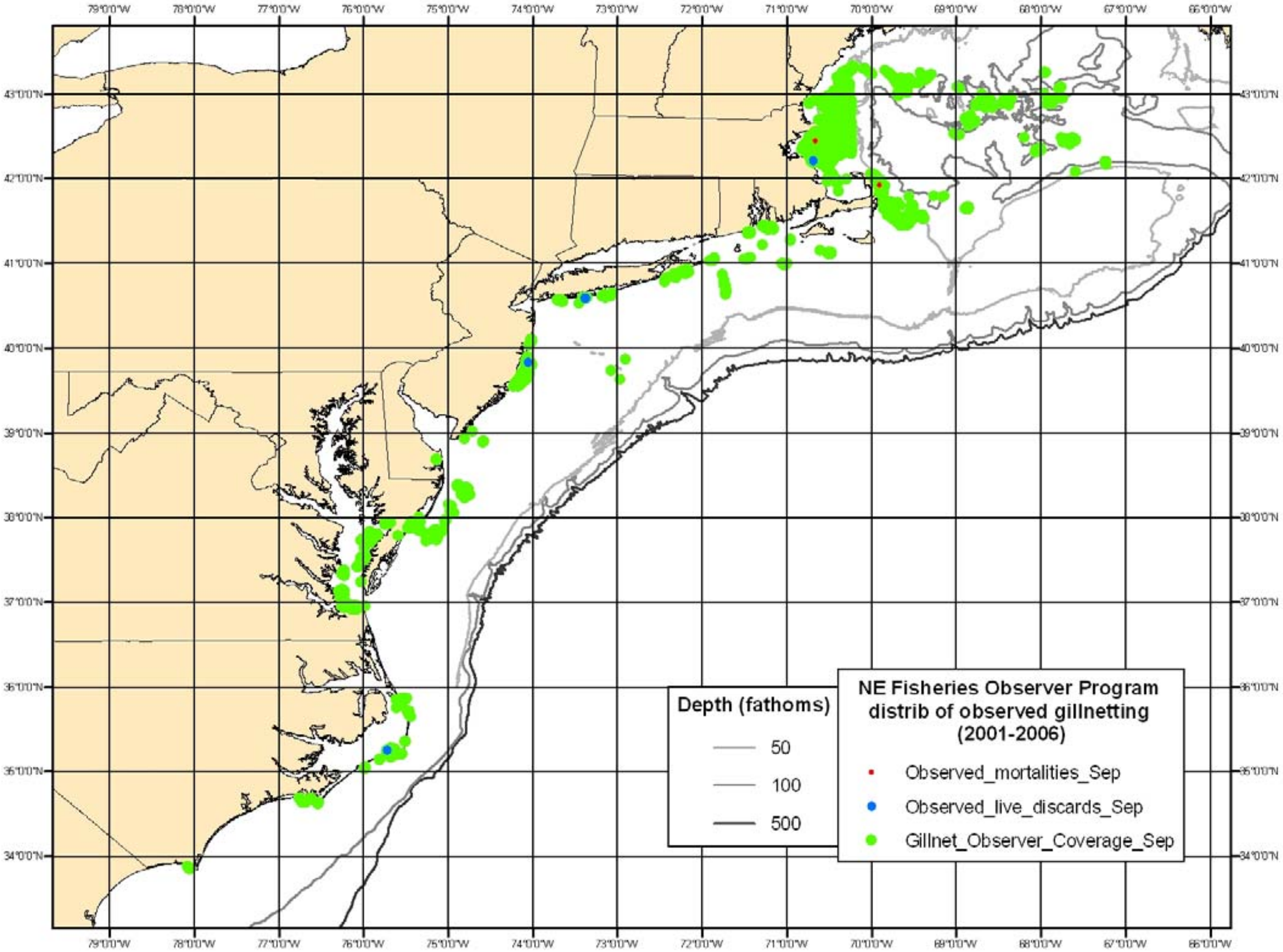

Figure 12. **Observed sturgeon bycatch, September 2001-2006.**

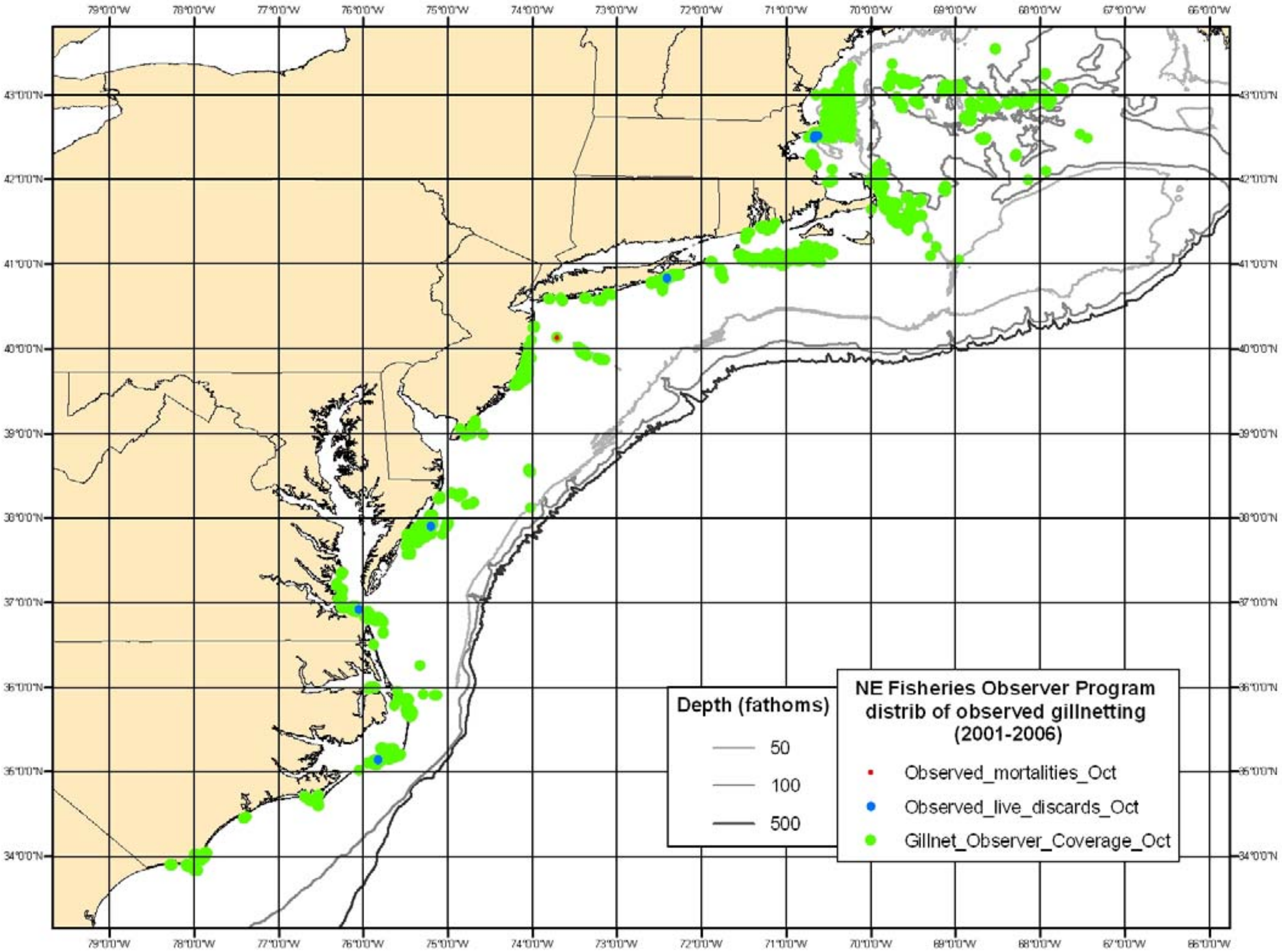

Figure 13. **Observed sturgeon bycatch, October 2001-2006.**

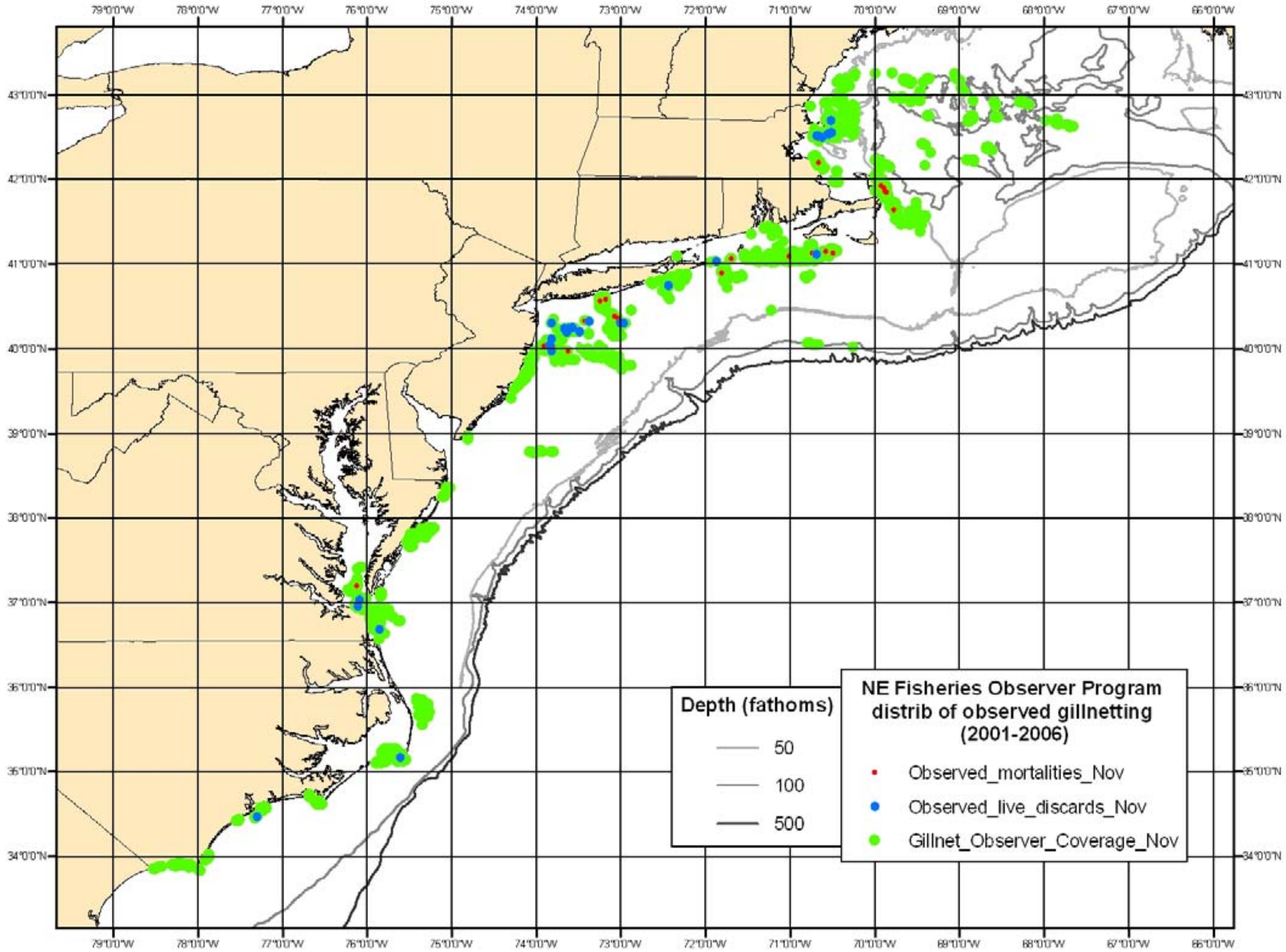

Figure 14. **Observed sturgeon bycatch, November 2001-2006.**

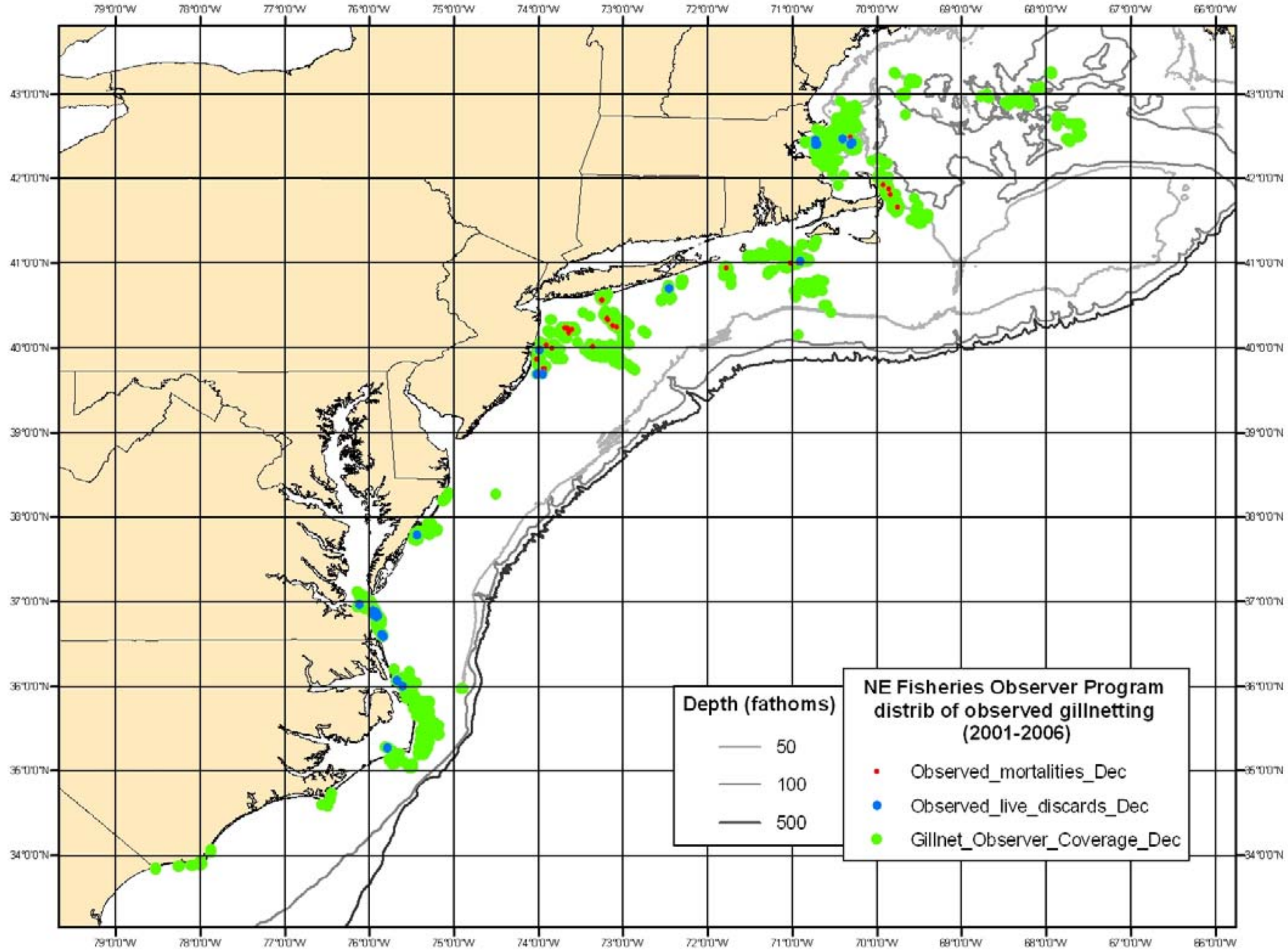

Figure 15. **Observed sturgeon bycatch, December 2001-2006.**

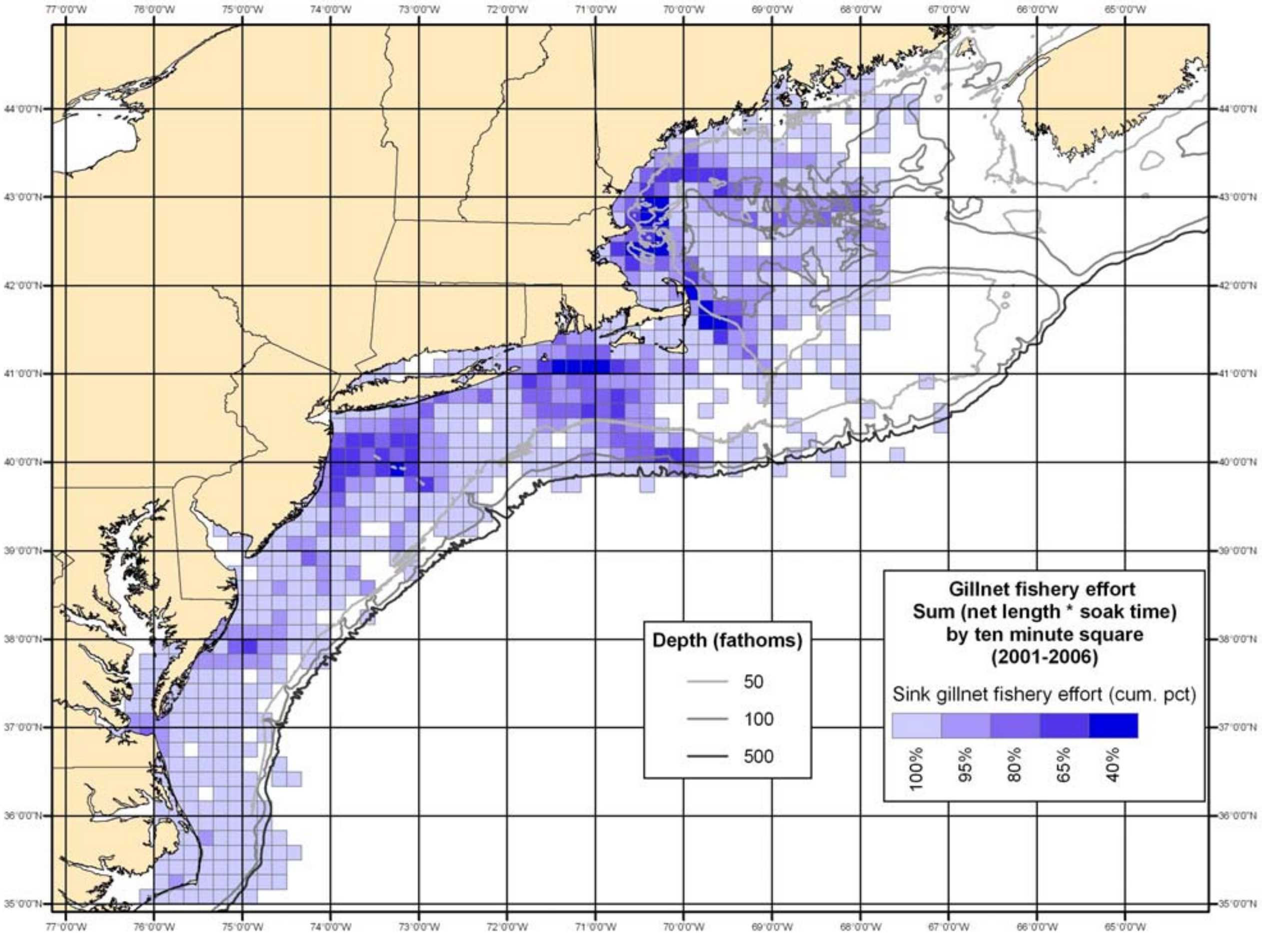

Figure 16. VTR sink gillnet effort for months combined, 2001-2006. See approach for methods used to determine effort.

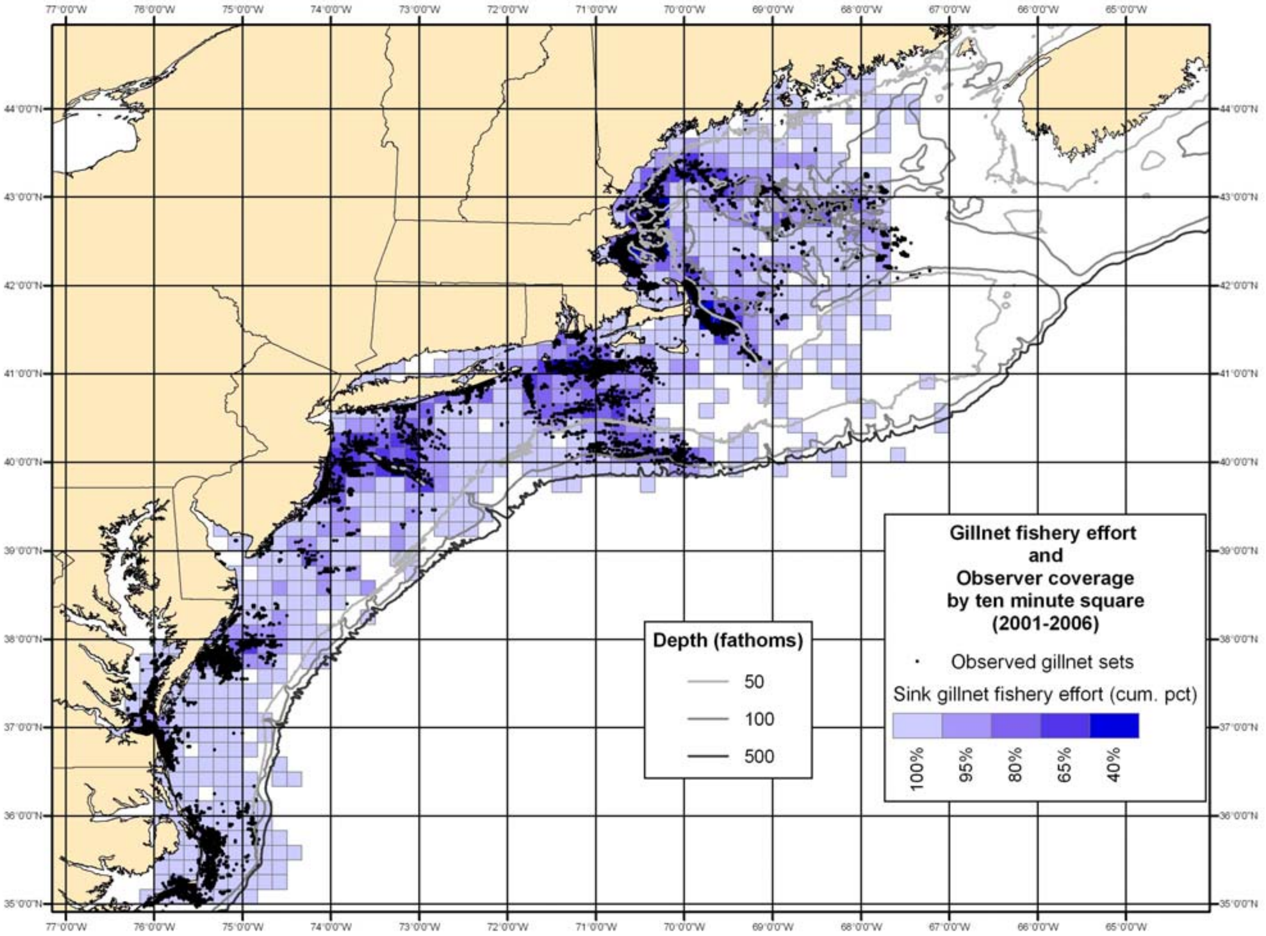

Figure 17. Overlay of Observer Program coverage onto VTR sink gillnet effort for months combined, 2001-2006.

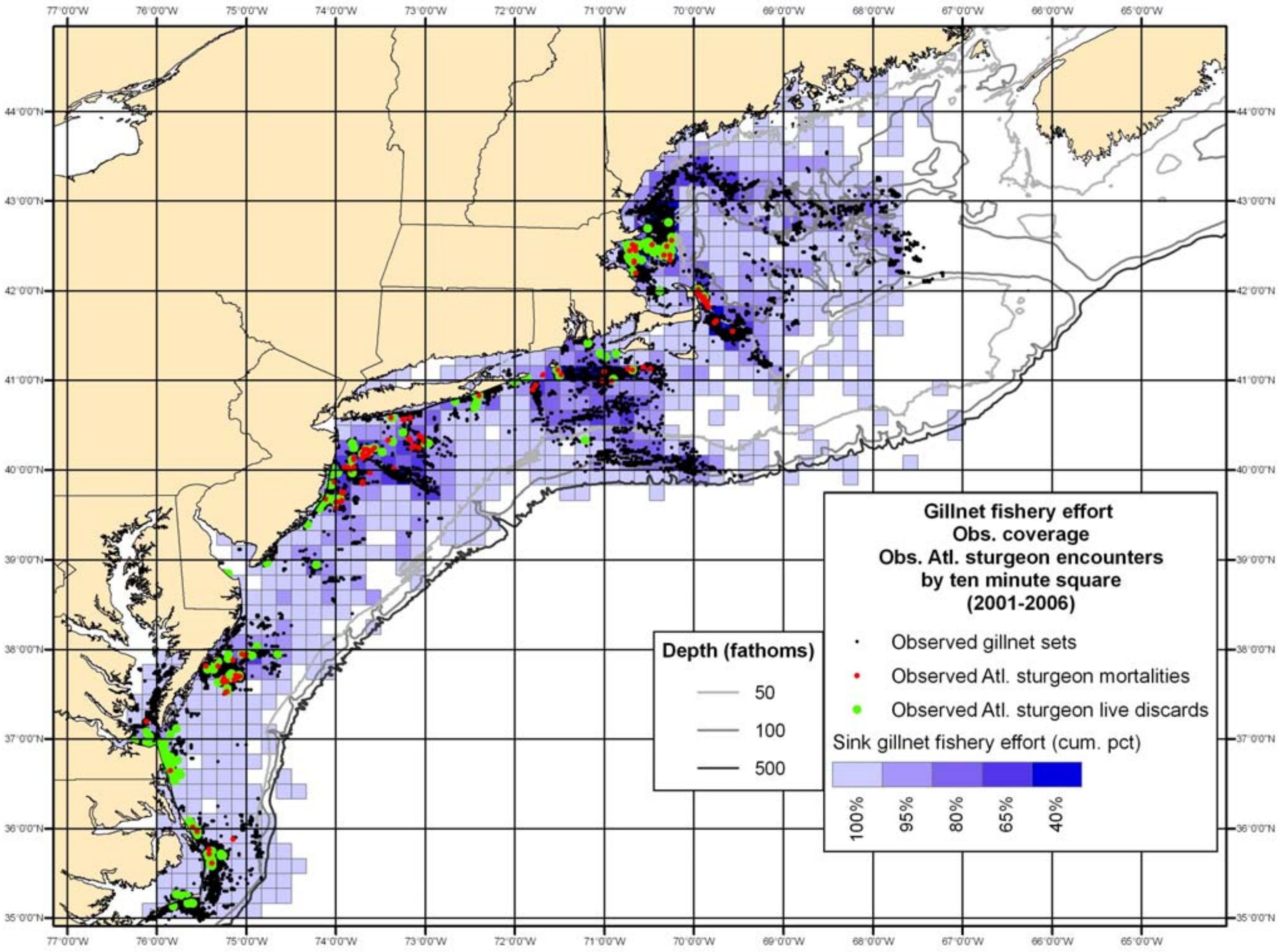

Figure 18. Overlay of sturgeon bycatch (live and dead) onto Observer Program coverage and VTR sink gillnet effort for months combined, 2001-2006.

SECTION 4

FACTORS ASSOCIATED WITH MORTALITY OF INCIDENTALLY CAUGHT STURGEON IN THE NORTHWEST ATLANTIC OCEAN

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Summary

We preformed statistical analyses to assess whether covariates (i.e., targeted species, surface water temperature, sturgeon length, attributes of gear and its application) were correlated with mortality of sturgeon incidentally caught in fisheries using gillnet or trawl gear. For each gear type, gillnet and trawl, we fit a suite of nested logistic regression models to data collected by observers in fishing fleets off of the northeastern United States between 2001 and 2006 and compared them using likelihood ratio tests, to determine whether the various covariates were significantly correlated with sturgeon mortality. For gillnet gear, the probability of mortality was significantly different by targeted species and whether or not tie-downs were used. For trawl gear, no covariates were significantly correlated with sturgeon mortality. As only 43 sturgeon bycatch observations (3 mortalities) were available for trawl gear where the status of the fish was known and all covariate data were available, inability to detect associations of any covariates with mortality could be due to low statistical power.

Introduction

Previous work (Stein *et al*. 2004) and other sections of this report have analyzed the total number of sturgeon incidentally caught by fishing activities in the Northwest Atlantic Ocean along the east coast of the United States. However, it is known that some proportion of the sturgeon that are caught survive the event. Certain attributes of the fishing process were hypothesized by the Sturgeon Working Group (workshop participants) to affect the probability of mortality, or survival, of a sturgeon that happens to be caught. Data pertaining to some of these fishing attributes are collected by personnel of the NEFSC Sea Sampling (Observer) Program (Observer Program) along with the status of sturgeon bycatch.

Here we use generalized linear models and likelihood ratio tests to analyze evidence of correlation of factors with sturgeon bycatch mortality. Likelihood ratio tests are based on the asymptotic χ^2 distribution of twice the negative log-likelihood maximized as a function of parameters given the data. The likelihood ratio tests provide results analogous to classical linear regression models, but allow specification of probability models other than Gaussian for the observed data (for further details see McCullagh and Nelder 1989, pp. 469-473, 476-478; Neter *et al*. 1996, pp. 585-601). We emphasize that the estimated relationships of the covariates to bycatch mortality should be viewed as correlative rather than causal because the data we used in the analysis were collected through observational studies. Controlled experiments where individuals are randomized among treatment levels of factors of interest provide much stronger evidence of causal relationships (e.g., Cochran 1965; Box 1966).

Data and Analytical Methods

Observer Data

The Observer Program collects at-sea information from various fisheries conducted in U.S. waters between Maine and North Carolina. Observers participate in trips to record data on species composition and fate (landed or discarded), gear information, effort, biological data from landed and discarded species (length, weight, condition if discarded, etc.), and economic information. Among some gillnet trips, observers may limit the collection of fish information in order to focus attention on encounters with protected species. Although fish discards are not recorded on these limited trips, sturgeon presence is noted and sizes recorded, as well as total weight of landings. The gears used in this analysis were restricted to sink and anchor gillnets and otter trawls for years 2001 through 2006 and hauls with Atlantic sturgeon or unknown sturgeon. Effort for trawls was recorded as tow duration in hours and gillnet effort was soak time in hours. Fish length in inches was determined either by measurement or estimation, and, when possible, sturgeon weights were recorded to the nearest pound. The fate of sturgeon was recorded as either released alive, returned dead, or fate unknown.

Statistical Analyses

Conditional on a sturgeon being caught, we assumed that the binary response of whether the fish is dead or alive is a Bernoulli random variable and that the outcome of each caught sturgeon was independent of the others. A generalized linear model with a logit link (i.e., logistic regression) is a natural approach for estimating the effects of covariates on the probability or odds of mortality for a caught fish. The Sturgeon Working Group determined an appropriate set of potential covariates to consider as predictors of sturgeon mortality. For trawl fisheries, we assessed whether tow duration, surface water temperature, targeted species (monkfish, groundfish, striped bass, or other), cod end mesh size, and length of the captured sturgeon were correlated with probability of mortality. For each gear type, we estimated covariate effects for a suite of nested models and compared them using likelihood ratio tests to determine whether covariates were significantly correlated with probability of mortality.

We determined a best model from a nested suite of models by removing terms sequentially from a saturated or full model that do not significantly ($\alpha = 0.05$) reduce the residual deviance (∞ 2 maximized log-likelihood). To interpret the model ultimately determined to be best, we estimate the change in odds of sturgeon mortality under appropriate predictor specifications. The generalized linear model considers the expected or average value of a random variable as a function of the covariates (or predictors). In particular, the link function of the expected value is linear in the covariates. For a Bernoulli random variable (Y) with expected value $E(Y) = p$, a common link function is the log-odds or logit of the probability,

$$f(p) = \log\left(\frac{p}{1-p}\right) = \mathbf{X}\boldsymbol{\beta},$$

where $\boldsymbol{\beta} = (\beta_0, \beta_1, \ldots, \beta_{m-1})^T$ is the m x 1 column vector of, $\mathbf{X} = (1, X_1, X_2, \ldots, X_{m-1})$ is the m x 1 row vector of covariates and $\mathbf{X}\boldsymbol{\beta}$ is the matrix multiplication of the vectors yielding.

Conversely, the inverse of the logit link is referred to as the "explicit,"

$$p = \frac{\exp(\mathbf{X}\boldsymbol{\beta})}{1+\exp(\mathbf{X}\boldsymbol{\beta})}.$$

Given estimates of the coefficients ($\hat{\boldsymbol{\beta}}$) for the covariates from a fitted model, we form estimates of the odds and probability of observing, in our case, a mortality of a sturgeon bycatch,

$$\frac{\hat{p}}{1-\hat{p}} = \exp\left(\mathbf{X}\hat{\boldsymbol{\beta}}\right)$$

and

$$\hat{p} = \frac{\exp\left(\mathbf{X}\hat{\boldsymbol{\beta}}\right)}{1+\exp\left(\mathbf{X}\hat{\boldsymbol{\beta}}\right)},$$

respectively.

For continuous predictors, quantifying the reduction or increase in the odds with a unit change in the covariate is a simple way to describe the effects of predictors on sturgeon mortality. For example, suppose that $\hat{\beta}_1$ is the estimated coefficient for soak time. Then the estimated scalar change in the odds for a unit change in soak time is

$$\frac{\exp\left(X\hat{\beta}_1\right)}{\exp\left[(X-1)\hat{\beta}_1\right]} = \exp\left(\hat{\beta}_1\right)$$

and the estimated percent change in the odds is

$$\%\Delta odds = \left\lfloor\exp\left(\hat{\beta}_1\right)-1\right\rfloor\times 100 .$$

To elaborate further, now suppose that the relationship of soak time to mortality depends on whether tie-downs are used. Let the intercept β_0 represent the log-odds of mortality when no tie-downs are used and soak time is zero (intercept for non-tie-down gillnet fishing), β_1 represent the rate of change in the log-odds of sturgeon mortality with soak time when tie-downs are absent. Also, β_2 represents the difference between the log-odds of mortality when tie-downs are present and soak time is zero, and β_3 represents the difference between the rate of change of the log-odds of mortality with soak time when tie-downs are present. Thus, the estimated change in the odds with a unit change in soak time when tie-downs are absent is the same as above and the estimated change when tie-downs are present is

$$\frac{\exp\left[\hat{\beta}_0+\hat{\beta}_2+X\left(\hat{\beta}_1+\hat{\beta}_3\right)\right]}{\exp\left[\hat{\beta}_0+\hat{\beta}_2+(X-1)\left(\hat{\beta}_1+\hat{\beta}_3\right)\right]} = \exp\left(\hat{\beta}_1+\hat{\beta}_3\right),$$

so that exp($\hat{\beta}_1+\hat{\beta}_3$) represents the estimated scalar change in the odds with a unit change in soak time when tie-downs are present. Likewise,

$$\left\lfloor\exp\left(\hat{\beta}_1+\hat{\beta}_3\right)-1\right\rfloor\times 100$$

is the percent difference between the rate of change in the odds of sturgeon mortality with soak time when tie-downs are absent and the rate of change in the odds of sturgeon mortality with soak time when tie-downs are present. For the final model, we make estimates of variance (and standard error) for the percent changes in odds using Taylor series approximation (i.e., the delta method; Casella and Berger 2002) and calculate asymmetric (approximately) 95% confidence intervals for the percent change in odds with covariates and probability of mortality as

$$CI(\%\Delta odds) = \left\{\exp\left[\sum \hat{\beta}_i \pm z_{0.975} SE\left(\sum \hat{\beta}_i\right)\right] - 1\right\} \times 100$$

and

$$CI_{95\%}(\hat{p}) = \frac{\exp\left[\mathbf{X}\hat{\boldsymbol{\beta}} \pm z_{0.975} SE\left(\mathbf{X}\hat{\boldsymbol{\beta}}\right)\right]}{1 + \exp\left[\mathbf{X}\hat{\boldsymbol{\beta}} \pm z_{0.975} SE\left(\mathbf{X}\hat{\boldsymbol{\beta}}\right)\right]},$$

where $\sum \hat{\beta}_i$ is the sum of the estimated coefficients appropriate to the given change in odds and $z_{0.975}$ is the quantile of the standard normal random variable corresponding to probability, $0.975 = 1 - \alpha/2$.

Table 1. Definition of covariates assessed as predictors of sturgeon mortality in gillnet and trawl fisheries.

Terms	Gillnet	Trawl	Covariate
A	•	•	Target species (factor)
B	•		Indicator of whether tie-down was used (factor)
C	•		Soak time (continuous)
D	•	•	Surface water temperature (continuous)
E	•	•	Length of caught sturgeon (continuous)
F	•	•	Size of mesh on the gillnet or cod end (continuous)
G		•	Duration of tow (continuous)

Results

Gillnet Fishing Gear

The saturated (full) model with target fishery and tie-down-specific (A and B) effects of soak time (C), surface water temperature (D), length of caught sturgeon (E), and mesh size (F) was over-parameterized in that mesh size was the same for the two sturgeon bycatch observations when dogfish was targeted and tie-downs were present and the same for the five sturgeon bycatch observations when monkfish was targeted and tie-downs were absent. (See Table A1 in Appendix 2 for numbers of observations by target-species and tie-down presence or absence.) As such, the most saturated model feasible with the gillnet sturgeon bycatch observations is the saturated model without target species and tie-down-specific mesh size effects on sturgeon mortality (Model GNF in top row, Table 2). There was negligible change in deviance for the feasible saturated model (GNF) and a model excluding target species and tie-down-specific surface water temperature effects on sturgeon mortality (Model GN1, Table 2). Changes in deviance by further excluding target species and tie-down-specific sturgeon length effects (Model GN2), then target species-specific mesh size effects (Model GN3), and then target species-specific surface water temperature effects (Model GNB) showed that using these terms did not significantly reduce the residual deviance for mortality of sturgeon bycatch (Table 2). Thus the best or most parsimonious model (Model

GNB) implies that target species, tie-down presence, soak time, water surface temperature, length of the caught sturgeon, and mesh size are all important predictors of mortality for sturgeon bycatch in gillnet fisheries. However, the significant interactions of predictors imply that the effects of continuous predictors (soak time, surface water temperature, length of the sturgeon, and mesh size) can depend on the target species and tie-down presence.

Table 2. **Model reduction from full model (top row) to best model (bottom row) based on likelihood ratio tests for sturgeon mortality in gillnet fisheries. Changes in deviance (Δ Dev.) are between the respective model and the next more general model (row directly above) and p-values are based on χ^2 test of the change in deviance with change in number of parameters (n_p) as the degrees of freedom. See Table 1 for definitions of model terms.**

Model	Terms	Res. Dev.	n_p	Δ Dev.	P	AIC	Term Removed
GFN	A + B + C + D + E + F + (A + B) : (C + D + E + F) + A : B : (C + D + E)	406.81	42	~0	~1.0	490.81	
GN1	A + B + C + D + E + F + (A + B) : (C + D + E + F) + A : B : (C + E)	406.81	41	0.20	0.90	488.81	A:B:D
GN2	A + B + C + D + E + F + (A + B) : (C + D + E + F) + A : B : C	407.01	39	8.20	0.15	485.01	A:B:E
GN3	A + B + C + D + E + F + (A + B) : (C + D + E) + B : F + A : B : C	415.21	34	9.25	0.10	483.21	A:F
GNB	A + B + C + D + E + F + (A + B) : (C + E) + B : (D + F) + A : B : C	424.46	29			482.46	A:D

Table 3. **Comparisons of best model (top row) with those where one term is removed for sturgeon mortality in gillnet fisheries. Changes in deviance (Δ Dev.) are between the respective model and the best model and p-values are based on χ^2 test of the change in deviance with change in number of parameters (n_p) as the degrees of freedom. See Table 1 for definitions of model terms.**

Terms	Res. Dev.	n_p	Δ Dev.	P	AIC	Term Removed
A + D + E + F + A (D + E + F)	424.46	29			482.46	
A + B + C + D + E + F + (A + B) : (C + E) + B : (D + F)	433.63	28	9.17	0.002	489.63	A:B:C
A + B + C + D + E + F + (A + B) : (C + E) + B : F + A : B : C	432.15	28	7.69	0.006	488.15	B:D
A + B + C + D + E + F + A : (C + E) + B : (C + D + F) A : B : C	434.91	28	10.45	0.001	490.91	B:E
A + B + C + D + E + F + A : C + B : (C + D + E + F) + A : B : C	439.08	24	14.62	0.012	487.08	A:E
A + B + C + D + E + F + (A + B) : (C + E) + B : D + A : B : C	436.10	28	11.64	0.001	492.10	B:F

When tie-downs were absent, the estimated percent change in the odds of sturgeon mortality with a unit increase in sturgeon length (holding other covariates constant) is largest and significantly positive (by inspection of the confidence interval) when striped bass are targeted (Table 4). The model indicates that the odds of mortality for a caught sturgeon increase by approximately 5-11% for every centimeter in length of the sturgeon holding other covariates constant. For other targets—dogfish, kingfish, groundfish, and other species—where more than a few sturgeon were caught without using tie-downs, the percent change in the odds with sturgeon length could not be shown to be significantly different from zero. In fact, no mortalities were observed when kingfish were targeted, which provided a non-informative confidence interval.

Table 4. Estimated percent change in odds of sturgeon mortality for various predictor specifications holding other predictors constant. Parameter estimates and corresponding estimated standard errors are based on Model GNB in Table 2.

Predictor Specification	Estimate	SE	*CI*
Tie-downs Absent			
Unit change in length for dogfish target	2.44	2.89	(-0.42 – 5.37)
Unit change in length for kingfish target	-0.19	12,532.52	(-100.00 – ∞)
Unit change in length for striped bass target	8.07	3.03	(5.08 – 11.14)
Unit change in length for other target	1.76	1.81	(-0.04 – 3.59)
Unit change in length for groundfish target	0.74	0.92	(-0.18 – 1.66)
Unit change in soak time for dogfish target	0.35	2.85	(-2.46 – 3.24)
Unit change in soak time for kingfish target	-0.49	30,217.27	(-100.00 – ∞)
Unit change in soak time for striped bass target	4.15	3.49	(0.72 – 7.71)
Unit change in soak time for other target	4.28	6.13	(-1.68 – 10.60)
Unit change in soak time for groundfish target	1.88	1.27	(0.62 – 3.16)
Unit change in mesh size (all targets)	-14.99	18.13	(-31.31 – 5.21)
Unit change in water temperature (all targets)	-1.79	2.83	(-4.58 – 1.08)
Tie-downs Present			
Unit change in length for groundfish	-7.53	2.96	(-10.44 – -4.53)
Unit change in length for monkfish	-0.44	0.51	(-0.95 – 0.07)
Unit change in soak time for other target	1.04	1.70	(-0.65 – 2.75)
Unit change in soak time for groundfish	1.87	0.43	(1.44 – 2.30)
Unit change in mesh size (all targets)	179.50	91.36	(101.57 – 287.55)
Unit change in water temperature (all targets)	10.95	3.85	(7.17 – 14.86)

The estimated percent change in the odds of sturgeon mortality with a unit increase in soak time and tie-downs absent was significantly positive when striped bass and groundfish species were targeted. The odds of mortality increased by approximately 1-8% and 1-3% with every centimeter of sturgeon length for striped bass and groundfish targets, respectively. For other targeted species, the changes in odds with soak time were not significantly different from zero and the same non-informative results when kingfish, in particular, was targeted.

The changes in odds with mesh size and water temperature when tie-downs were absent were not target-specific and not significantly different from zero.

When tie-downs were present, there was a significant decrease in odds of mortality (approximately 4-10%) with sturgeon length when groundfish were targeted, but not when monkfish were targeted (Table

4). There was also a significant increase in the odds of mortality with soak time (approximately 1-2%) when tie-downs were present and groundfish were targeted. In contrast to gillnet fishing without tie-downs, there is a significant increase in the odds of mortality with mesh size (approximately 102-288%) and water temperature (approximately 7-15%) when tie-downs are present.

For further illustration of the results of this analysis, we provide plots of the change in estimated probability of mortality with each of the continuous covariates univariately (Figures 1-6) and bivariately (Figures 7-12) holding other covariates constant for a given target category and indication of whether tie-downs were present or not. For both the univariate and bivariate plots, the actual covariate values for the observed data are provided to display where the data provide information along the axes, but there is also indication (by color) whether a mortality or survival was associated with that observation.

Nearly all bycatch observations when monkfish were targeted also had tie-downs present. Thus, meaningful inference on the difference in the association of the continuous covariates and mortality between presence and absence of tie-downs was not possible. Furthermore, most mortalities were observed associated with large (12-inch) mesh size when monkfish were targeted (Figures 1 and 7). Observations were well distributed across temperature, soak time, and sturgeon length, and modeled relationships between probability of mortality and temperature and soak time were well supported with relatively tight confidence limits (Figure 1). The additivity of soak time and water temperature in the model combined with the estimated positive relationships of both covariates with mortality when monkfish was targeted was also well supported by the data (Table 4; Figure 7), suggesting that higher mortality associated with temperature could be offset by shorter soak times.

The statistically significant increase of odds of mortality with smaller sturgeon size and larger mesh size in the groundfish fishery with tie-downs is reflected in respective changes in probability of mortality (Figure 2), although the significant positive relationship of mortality with mesh size was not specific to target category (groundfish or monkfish) when tie-downs were present (Table 4). The lack of significant association between soak time and mortality is also reflected by the plots (Figures 2 and 8). Bivariate plots reflect positive relationships of mortality to both temperature and mesh size and a negative relationship to temperature (Figure 8).

For target categories of groundfish, dogfish, and other, the gillnet fisheries not using tie-downs did not support strong associations between probability of mortality and application variables (Figures 3, 4, 6, 10, and 12).

The small but significantly positive associations of sturgeon length and soak time with mortality when striped bass were targeted and tie-downs were absent were also reflected in the plots (Figures 5 and 11). For most soak times (usually <24 hours) the estimated probability of mortality was less than approximately 0.1 when other covariates were held at the average values for all observed bycatch where striped bass was the target.

A lack of coherence between the trend in mortalities of the observed data and the estimated probability of mortality in the plots does not imply a poor fit of the model in such cases because the values of the remaining continuous covariates are different from the assumed values for the probability curve (provided that the top of each plot). However, the existence of coherence between the observed mortalities and the probability curve may imply an association of mortality to the given covariate that may be strong relative to other covariates.

Comparisons of the estimated relationships between probability of mortality and each of the continuous covariates holding others constant for groundfish and monkfish targets shows little evidence for statistical differences between these target categories when tie-downs are present and the same mesh size, water temperature, soak time, and length of sturgeon occur (Figure 13). The one exception is a possibly higher probability of mortality for small sturgeon when groundfish are targeted (Figure 13). Similarly, there is little evidence of significant differences in the probability of mortality at a given sturgeon size, mesh size, water temperature, or soak time holding remaining covariates at specified values (Figure 14). There may be a higher probability of mortality when not using tie-downs with small mesh sizes (approximately 4-inch).

Trawl Fishing Gear

Because of complete co-linearity of some covariates and few sturgeon mortalities, the saturated model was over-parameterized in that mortalities could be predicted perfectly by the model (top row, Table 5). The most saturated model that was not over-parameterized included target species and either duration of the tow or length of the caught sturgeon additively. The better of these two saturated models in terms of residual deviance included the latter of the two continuous covariates (Row 5, Table 5). However, this saturated model was not significantly better than the null model (no covariates) for predicting mortality of caught sturgeon (bottom row, Table 5). The probability of mortality in trawl gear is estimated to be between 0.020 and 0.176 with 95% confidence ($\hat{p}$ = 0.0625, *SE*($\hat{p}$) = 0.0349).

Table 5. Model reduction from full model (top row) to best model (bottom row) based on likelihood ratio tests for sturgeon mortality in trawl fisheries. Changes in deviance (Δ Dev.) are between the respective model and the next more general model (row above) and p-values are based on χ^2 test of the change in deviance with change in number of parameters (n_p) as the degrees of freedom. See Table 1 for definitions of model terms.

Model	Terms	Res. Dev.	Δ Dev.	n_p	P	AIC	Term Removed
TRF	A + D + E + F + G + A : (D + E + F + G)	~0		14		28.00	
TR1	A + D + E + F + G	~0	~0	8	~1.0	16.00	A : (D + E + F + G)
TR2	A + E + F + G	~0	~0	7	~1.0	14.00	D
TR3	A + E + G	~0	~0	6	~1.0	12.00	F
TR4	A + E	14.57	14.57	5	0.0001	24.57	G
TRB	Null	22.44	7.88	1	0.0961	24.44	A + E

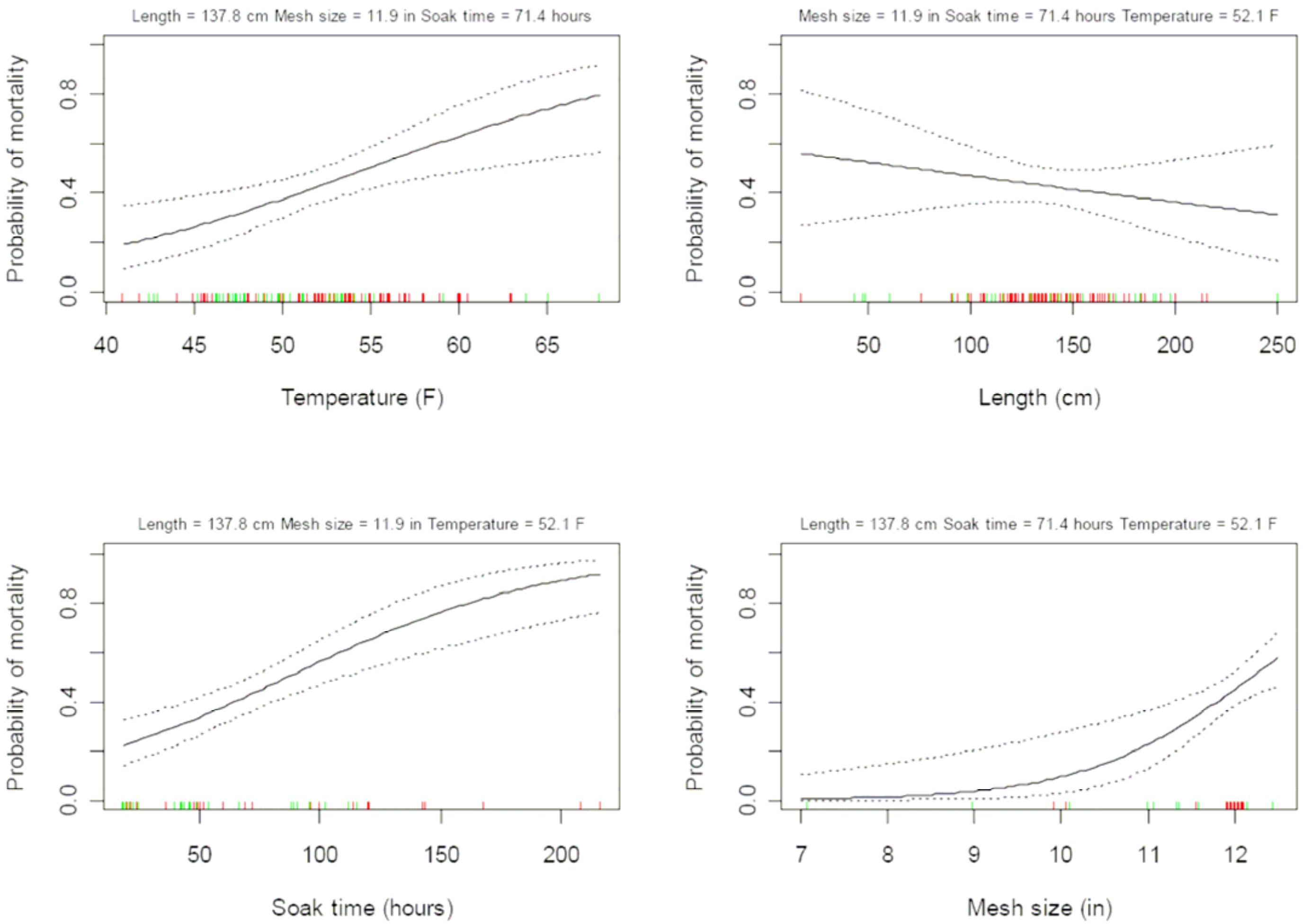

Figure 1. **Changes in estimated probability of mortality and 95% confidence intervals with temperature, soak time, length of caught sturgeon, and mesh size for sturgeon incidentally caught in gillnets when fishers are using tie-downs and targeting monkfish. Each plot shows how estimated mortality changes with a continuous covariate holding the other three constant. Red and green ticks correspond to individuals that died and that survived the fishing interaction, respectively.**

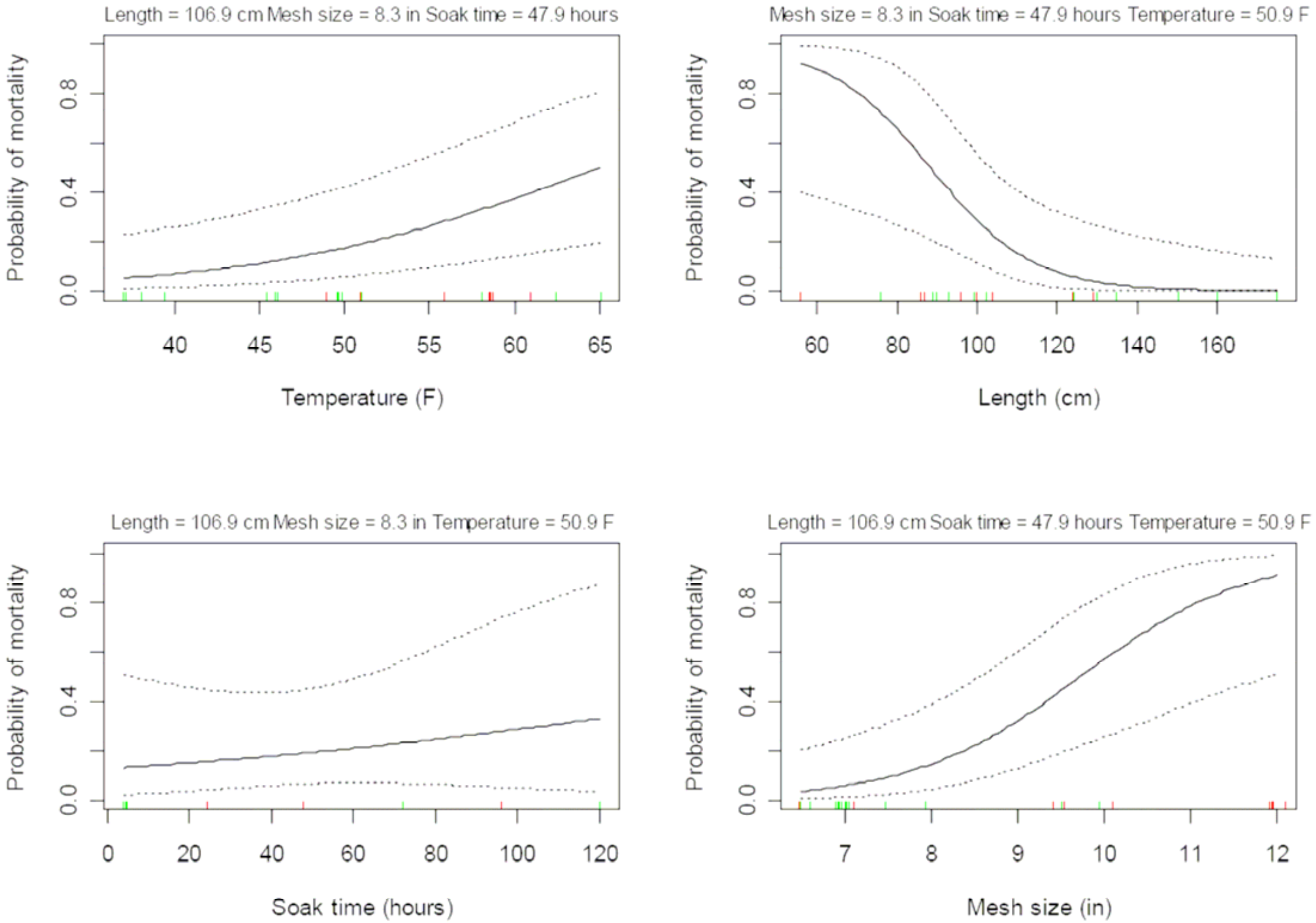

Figure 2. **Changes in estimated probability of mortality and 95% confidence intervals with temperature, soak time, length of caught sturgeon, and mesh size for sturgeon incidentally caught in gillnets when fishers are using tie-downs and targeting groundfish. Each plot shows how estimated mortality changes with a continuous covariate holding the other three constant. Red and green ticks correspond to individuals that died and that survived the fishing interaction, respectively.**

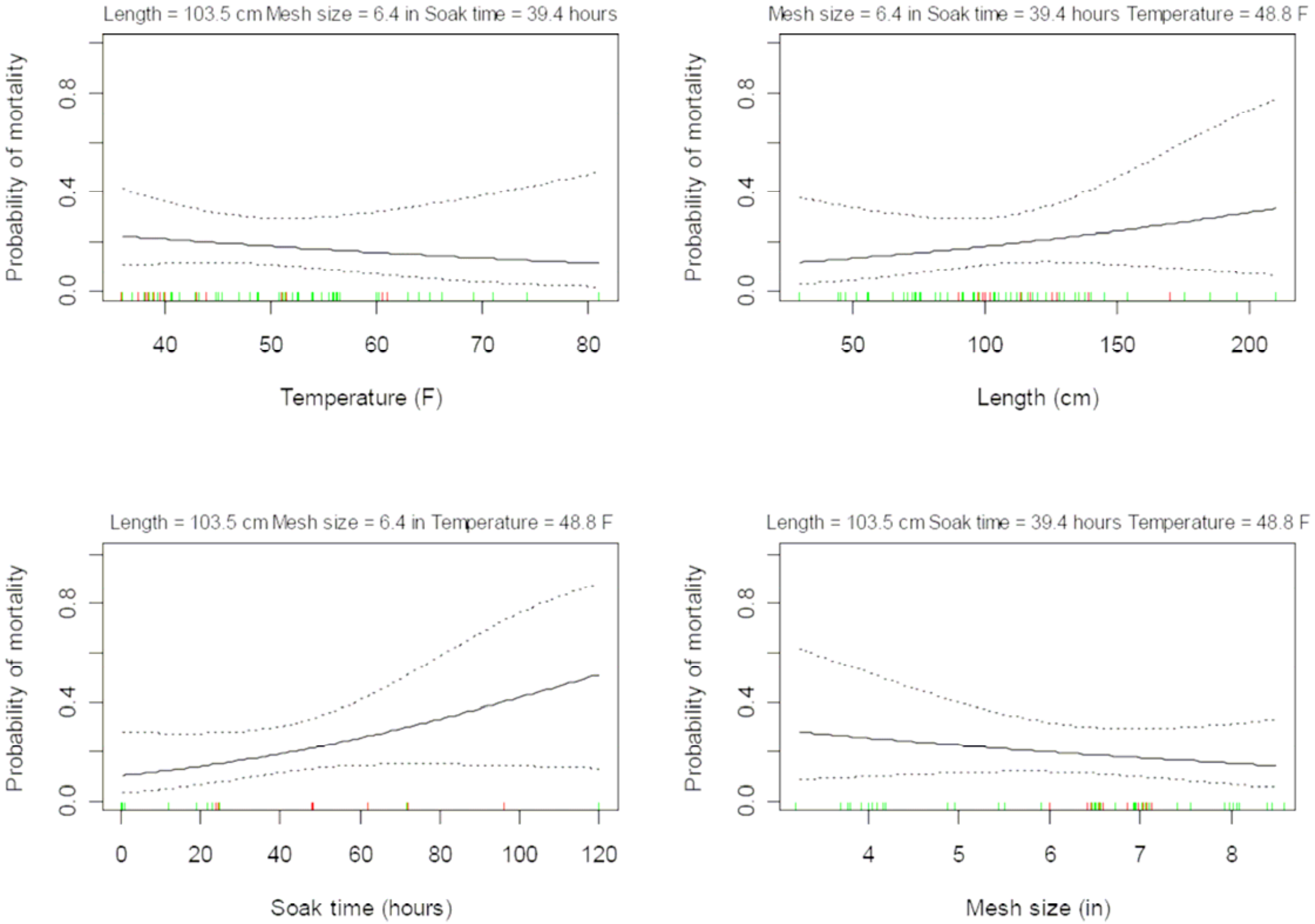

Figure 3. **Changes in estimated probability of mortality and 95% confidence intervals with temperature, soak time, length of caught sturgeon, and mesh size for sturgeon incidentally caught in gillnets when fishers are not using tie-downs and targeting groundfish. Each plot shows how estimated mortality changes with a continuous covariate holding the other three constant. Red and green ticks correspond to individuals that died and that survived the fishing interaction, respectively.**

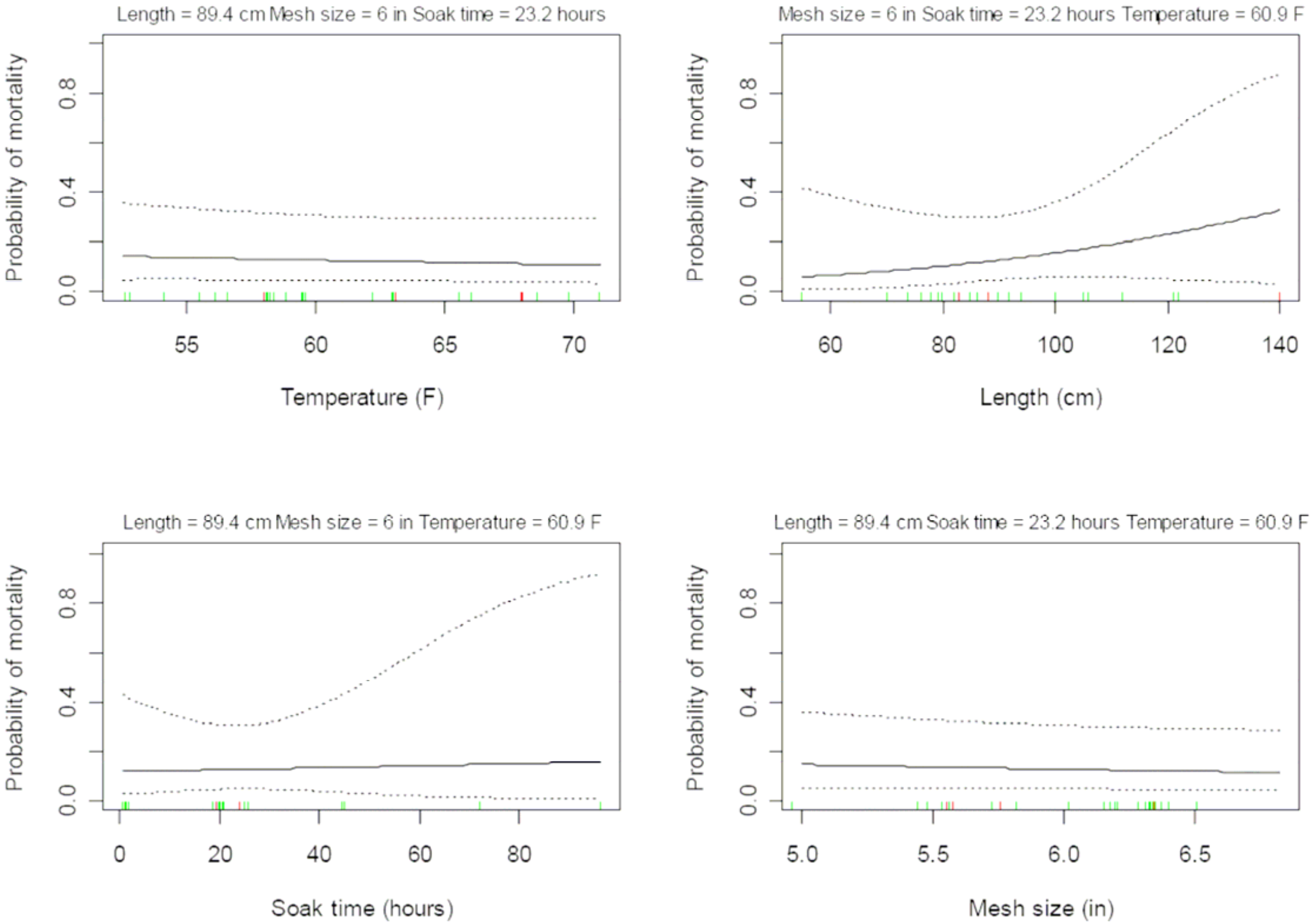

Figure 4. Changes in estimated probability of mortality and 95% confidence intervals with temperature, soak time, length of caught sturgeon, and mesh size for sturgeon incidentally caught in gillnets when fishers are not using tie-downs and targeting dogfish. Each plot shows how estimated mortality changes with a continuous covariate holding the other three constant. Red and green ticks correspond to individuals that died and that survived the fishing interaction, respectively.

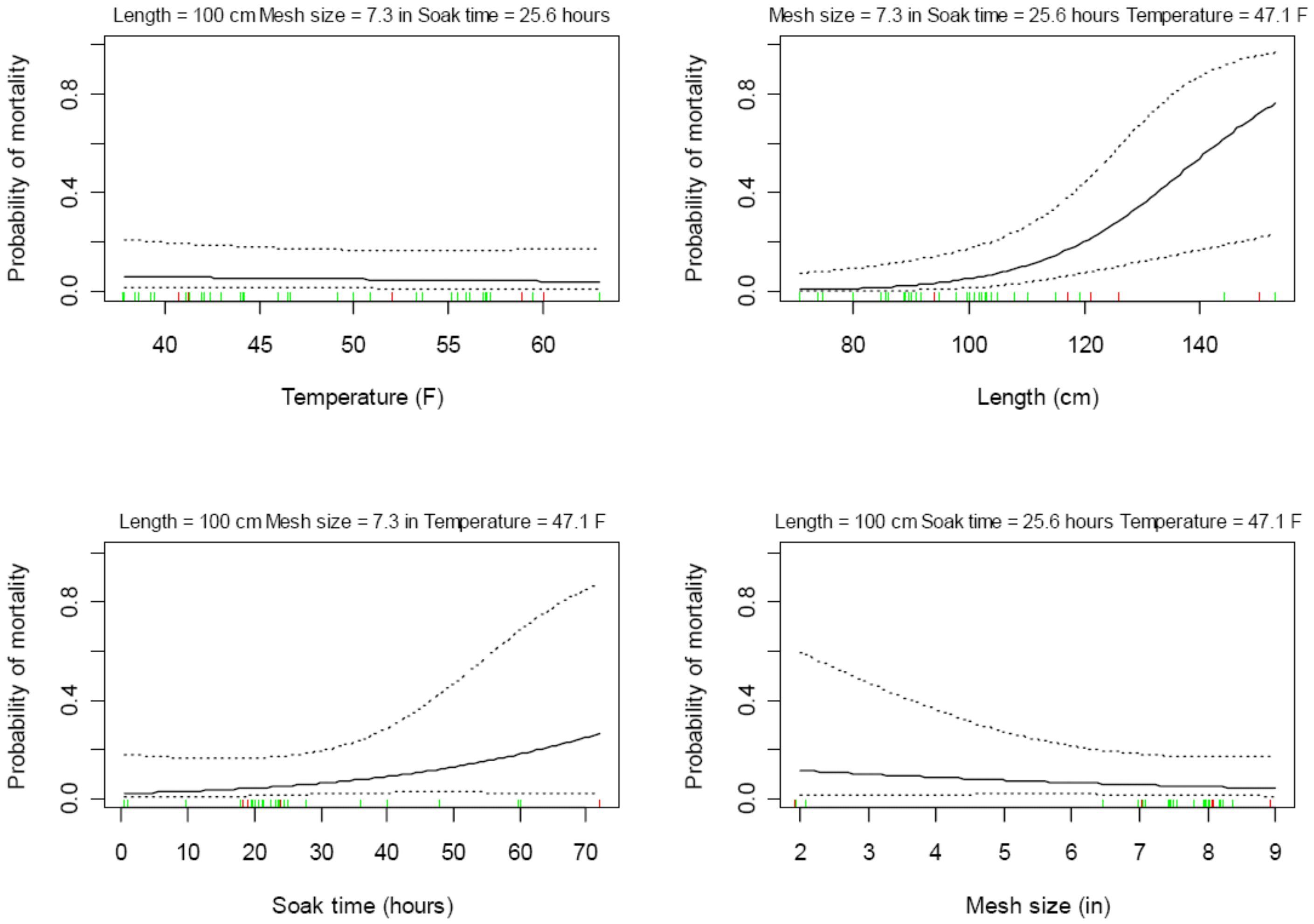

Figure 5. Changes in estimated probability of mortality and 95% confidence intervals with temperature, soak time, length of caught sturgeon, and mesh size for sturgeon incidentally caught in gillnets when fishers are not using tie-downs and targeting striped bass. Each plot shows how estimated mortality changes with a continuous covariate holding the other three constant. Red and green ticks correspond to individuals that died and that survived the fishing interaction, respectively.

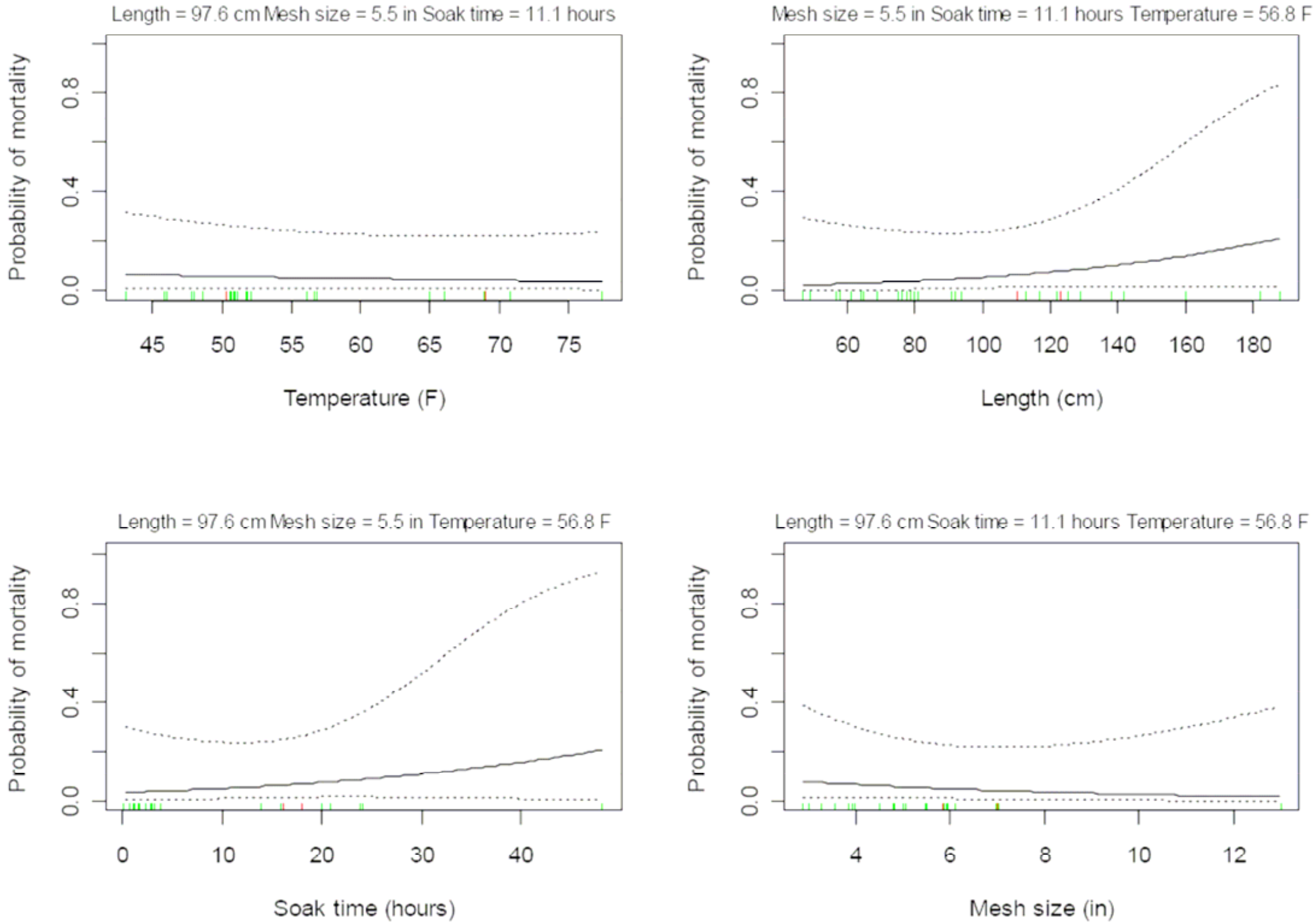

Figure 6. **Changes in estimated probability of mortality and 95% confidence intervals with temperature, soak time, length of caught sturgeon, and mesh size for sturgeon incidentally caught in gillnets when fishers are not using tie-downs and targeting species other than monkfish, groundfish, dogfish, kingfish, or striped bass. Each plot shows how estimated mortality changes with a continuous covariate holding the other three constant. Red and green ticks correspond to individuals that died and that survived the fishing interaction, respectively.**

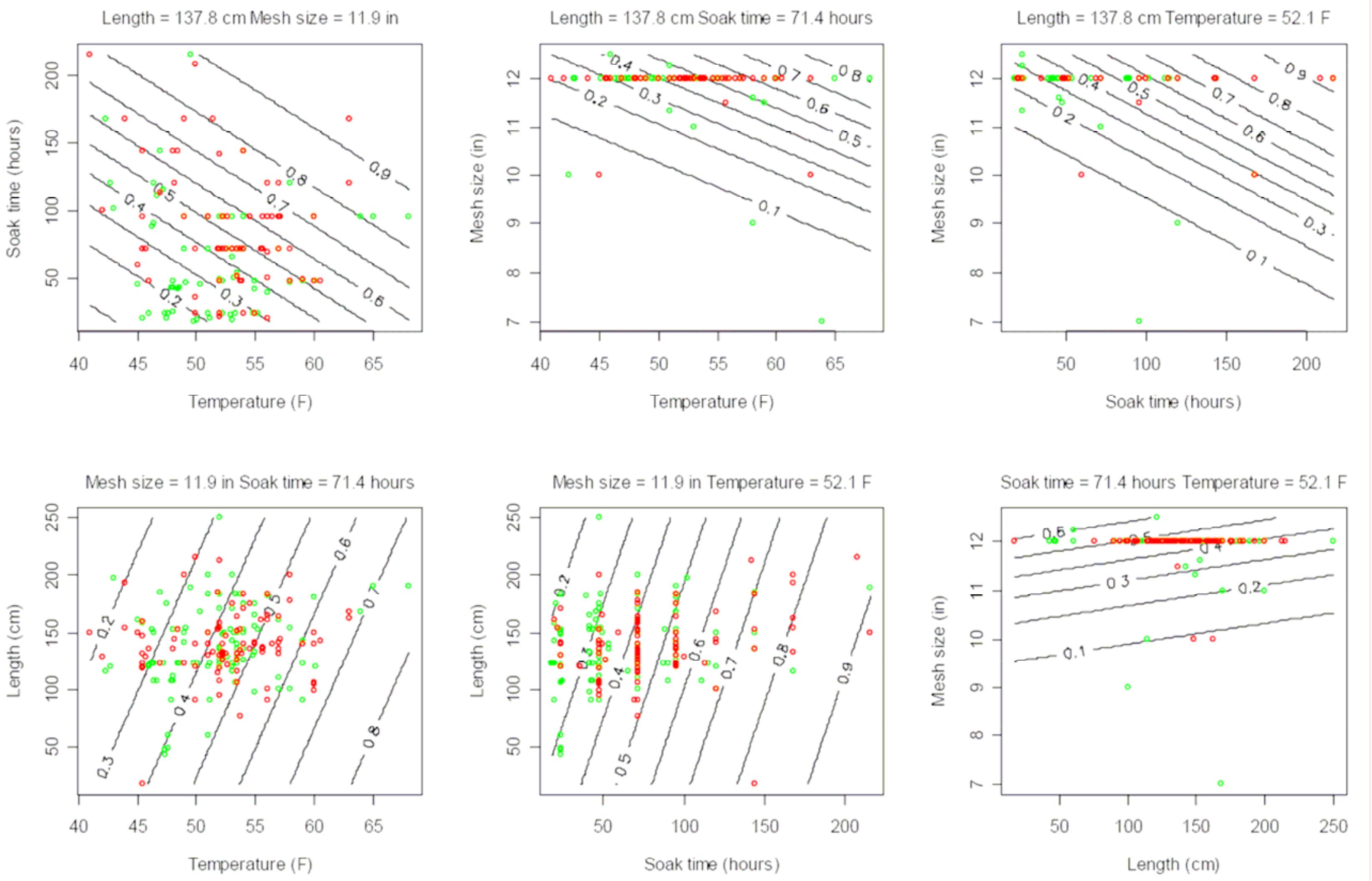

Figure 7. Changes in estimated probability of mortality with temperature, soak time, length of caught sturgeon, and mesh size for sturgeon incidentally caught in gillnets when fishers are using tie-downs and targeting monkfish. Each plot shows how estimated mortality changes with two continuous covariates holding the other two constant. Red and green points correspond to individuals that died and survived the fishing interaction, respectively.

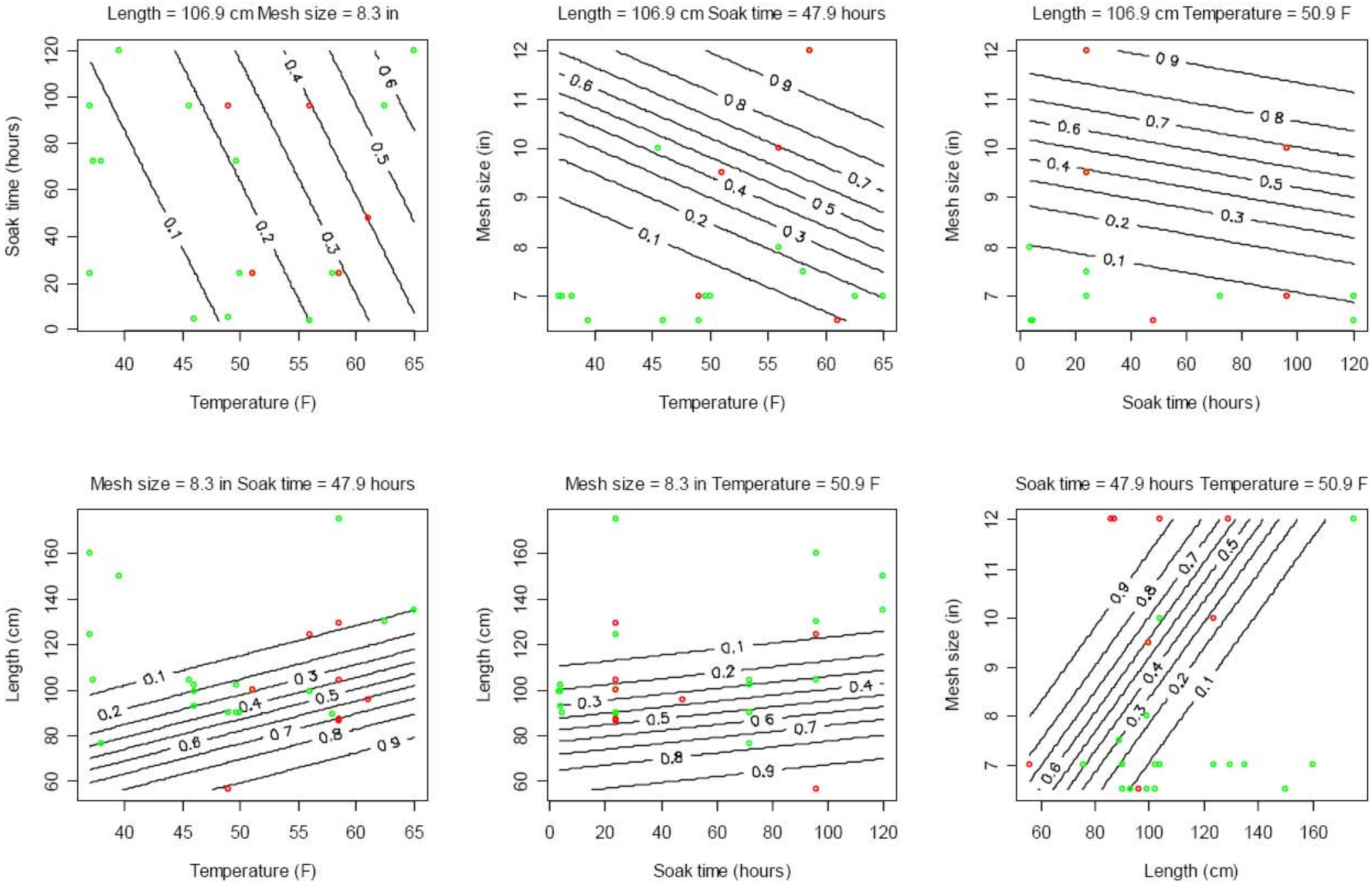

Figure 8. **Changes in estimated probability of mortality with temperature, soak time, length of caught sturgeon, and mesh size for sturgeon incidentally caught in gillnets when fishers are using tie-downs and targeting groundfish. Each plot shows how estimated mortality changes with two continuous covariates holding the other two constant. Red and green points correspond to individuals that died and survived the fishing interaction, respectively.**

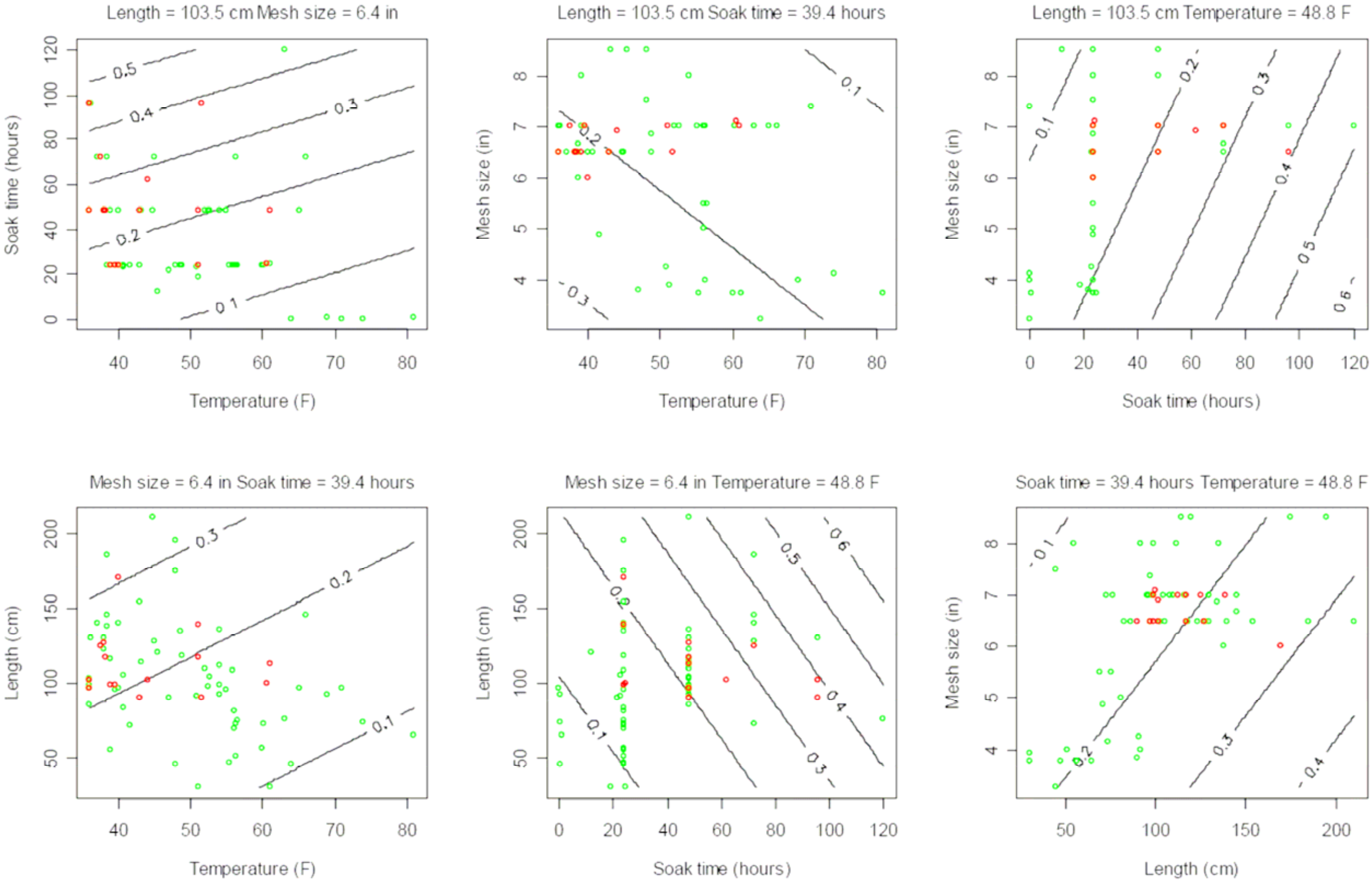

Figure 9. Changes in estimated probability of mortality with temperature, soak time, length of caught sturgeon, and mesh size for sturgeon incidentally caught in gillnets when fishers are not using tie-downs and targeting groundfish. Each plot shows how estimated mortality changes with two continuous covariates holding the other two constant. Red and green points correspond to individuals that died and survived the fishing interaction, respectively.

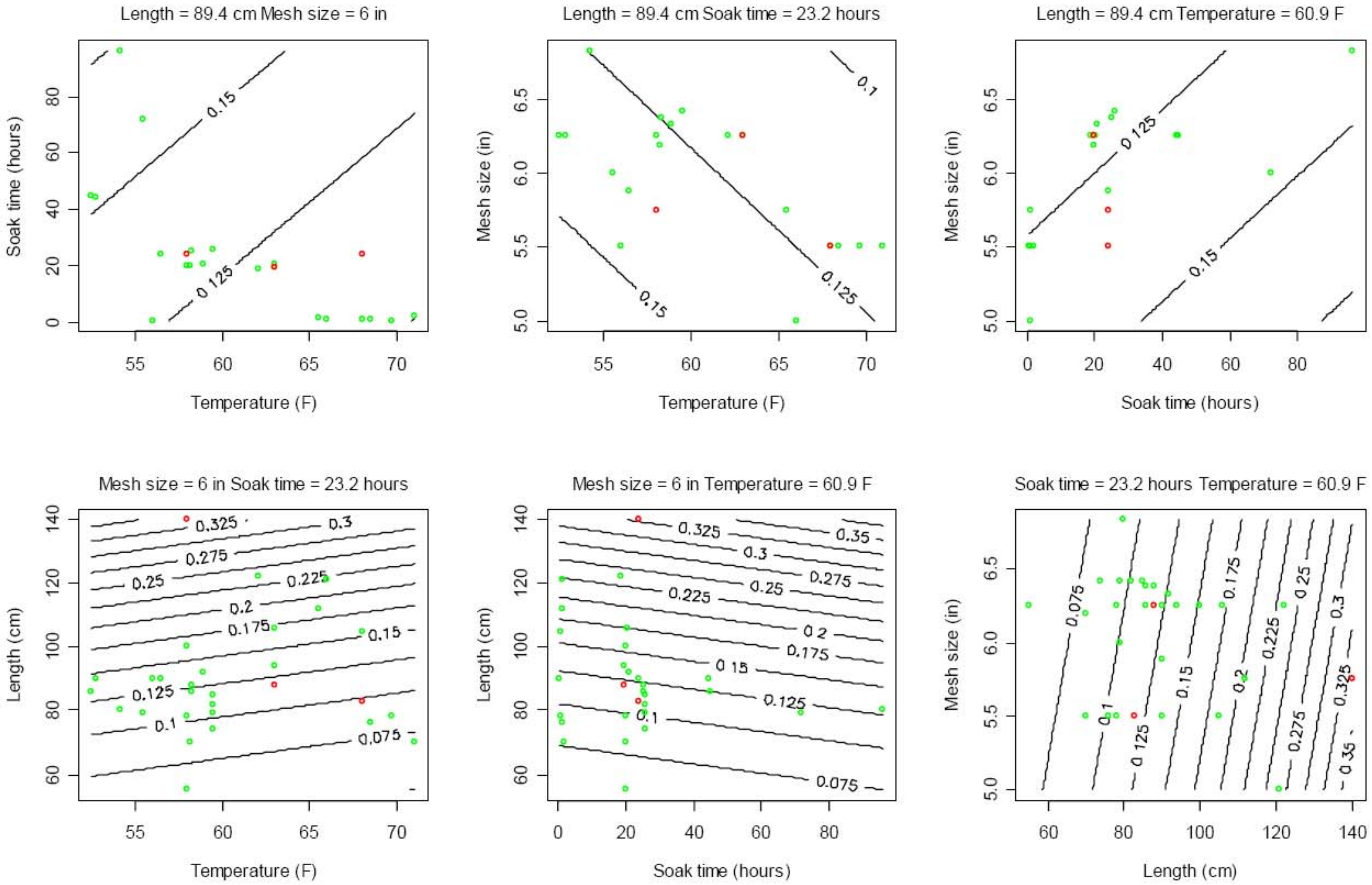

Figure 10. Changes in estimated probability of mortality with temperature, soak time, length of caught sturgeon, and mesh size for sturgeon incidentally caught in gillnets when fishers are not using tie-downs and targeting dogfish. Each plot shows how estimated mortality changes with two continuous covariates holding the other two constant. Red and green points correspond to individuals that died and survived the fishing interaction, respectively.

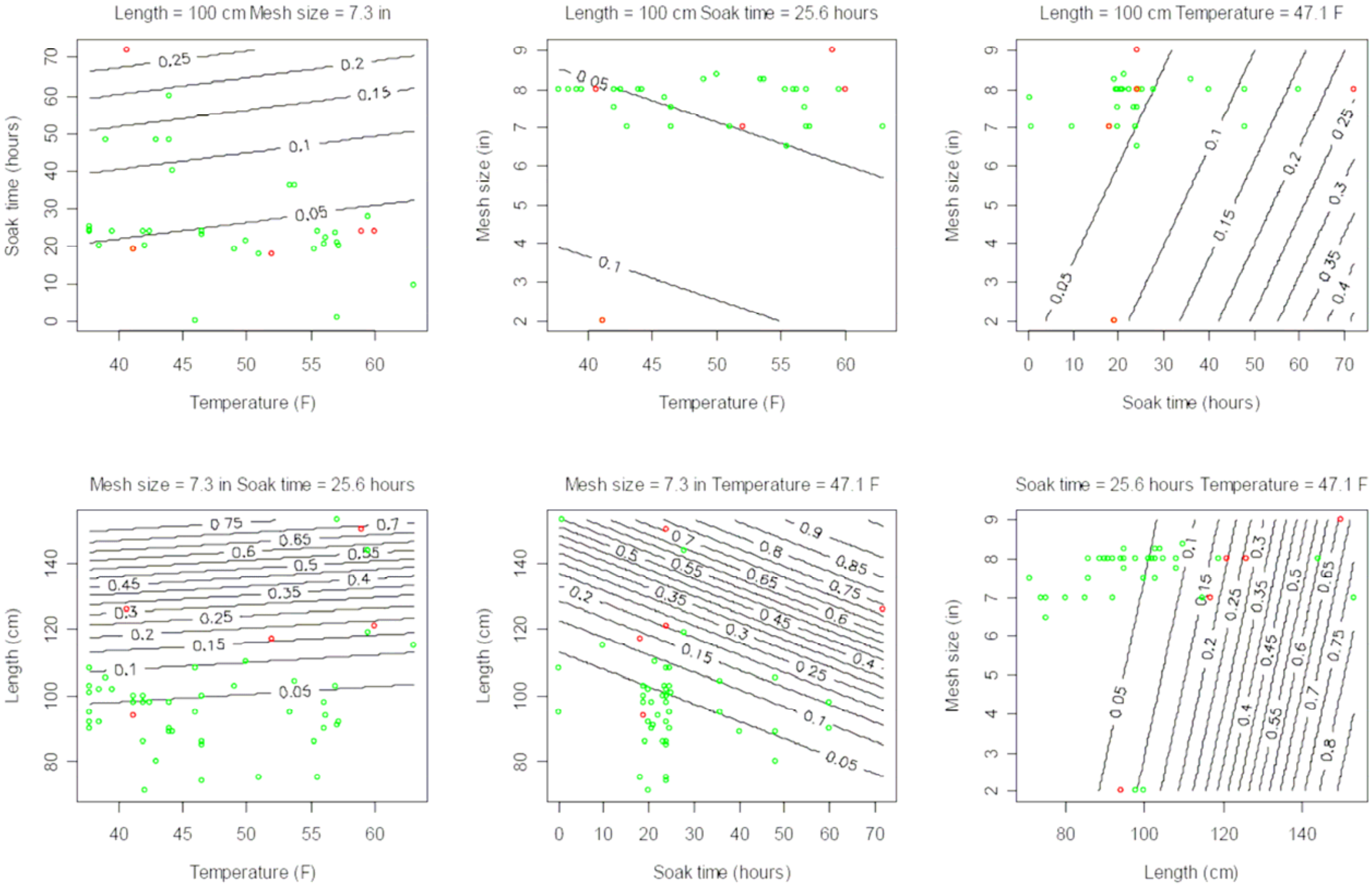

Figure 11. Changes in estimated probability of mortality with temperature, soak time, length of caught sturgeon, and mesh size for sturgeon incidentally caught in gillnets when fishers are not using tie-downs and targeting striped bass. Each plot shows how estimated mortality changes with two continuous covariates holding the other two constant. Red and green points correspond to individuals that died and survived the fishing interaction, respectively.

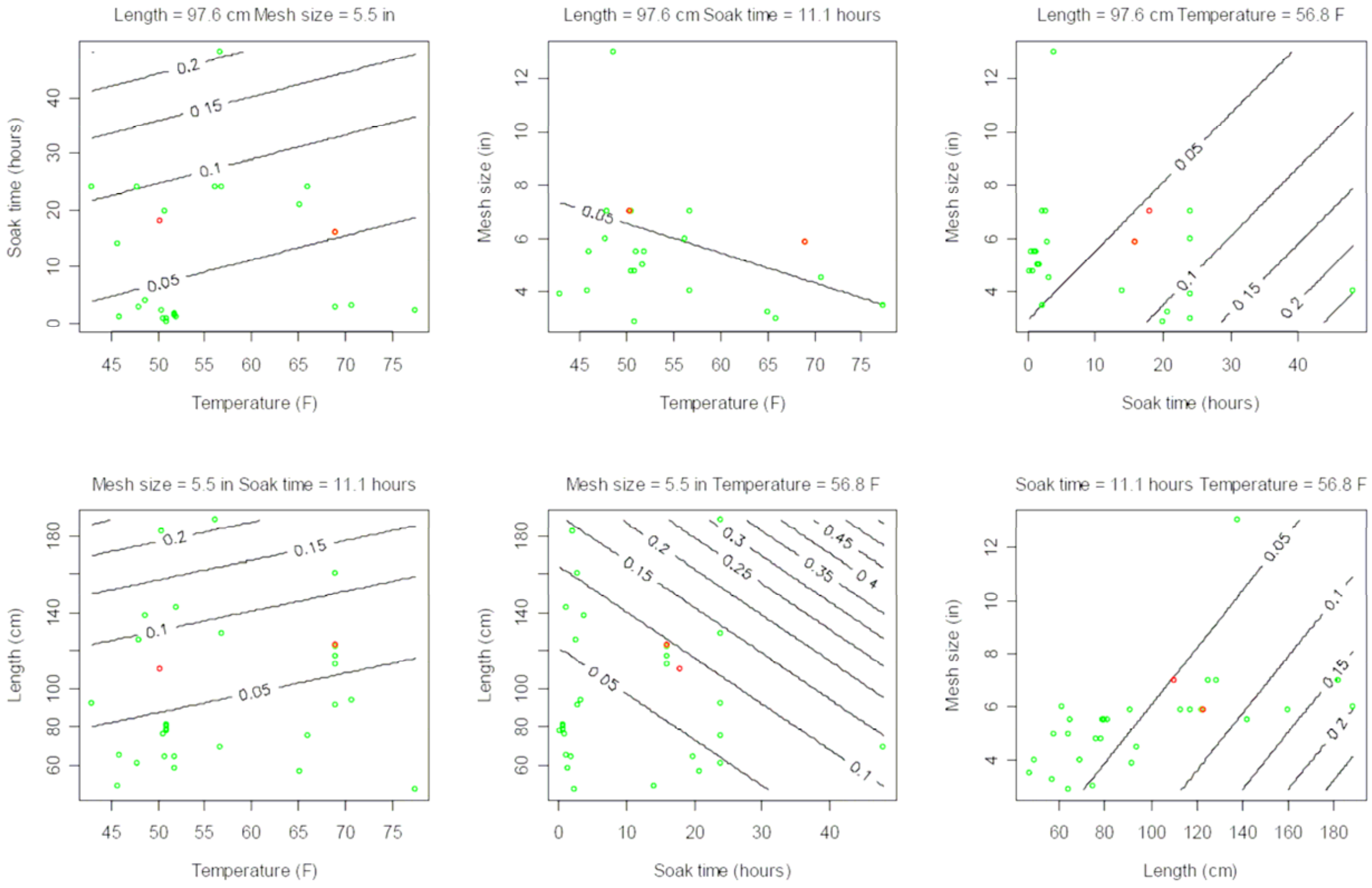

Figure 12. **Changes in estimated probability of mortality with temperature, soak time, length of caught sturgeon, and mesh size for sturgeon incidentally caught in gillnets when fishers are not using tie-downs and targeting species other than monkfish, groundfish, dogfish, kingfish, or striped bass. Each plot shows how estimated mortality changes with two continuous covariates holding the other two constant. Red and green points correspond to individuals that died and survived the fishing interaction, respectively.**

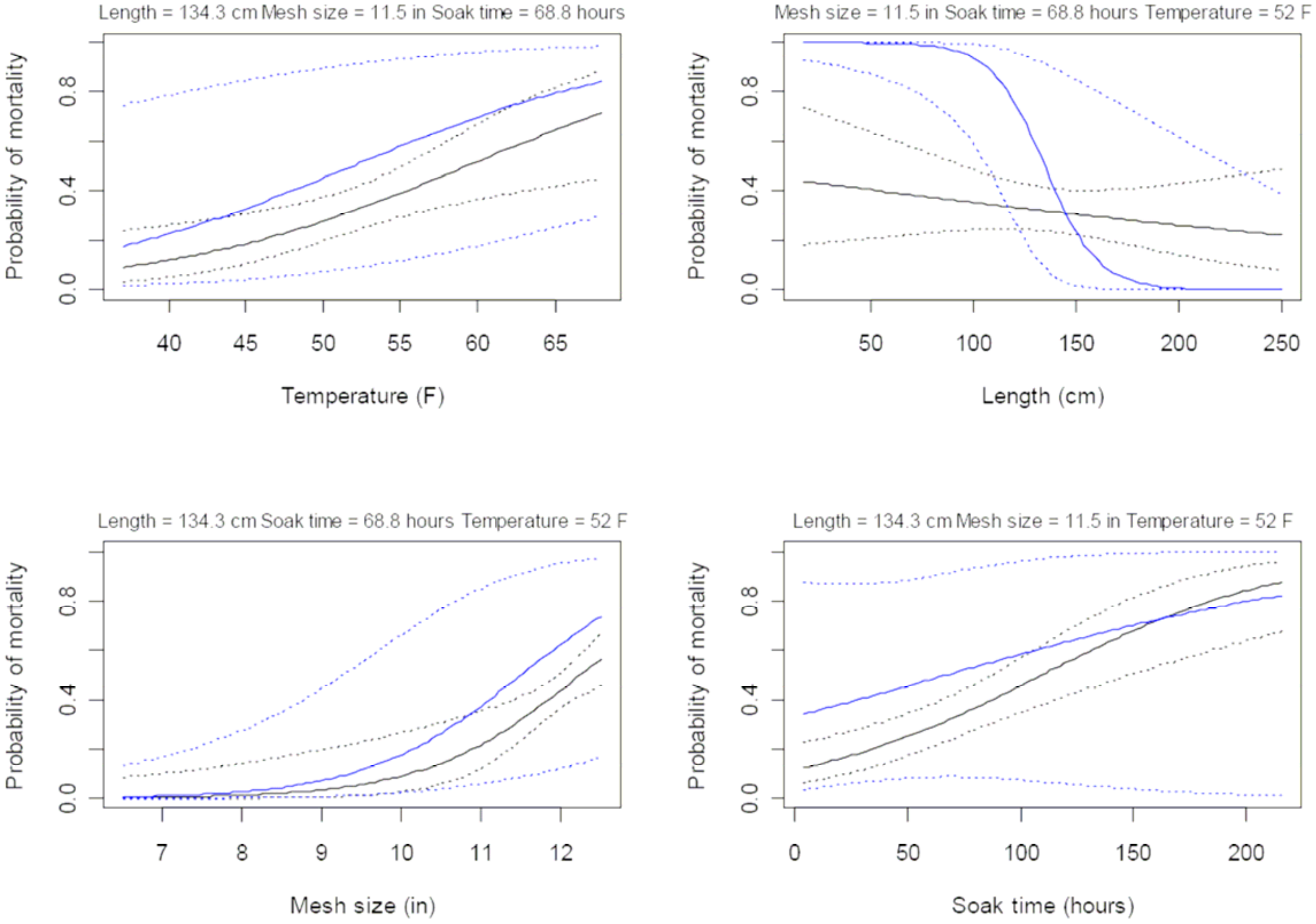

Figure 13. **Comparison of changes in estimated probability of mortality and 95% confidence intervals with temperature, soak time, length of caught sturgeon, and mesh size for sturgeon incidentally caught in gillnets when fishers are using tie-downs and targeting monkfish (black) or groundfish (blue). Each plot shows how estimated mortality changes with a covariate, holding the remaining three continuous covariates constant.**

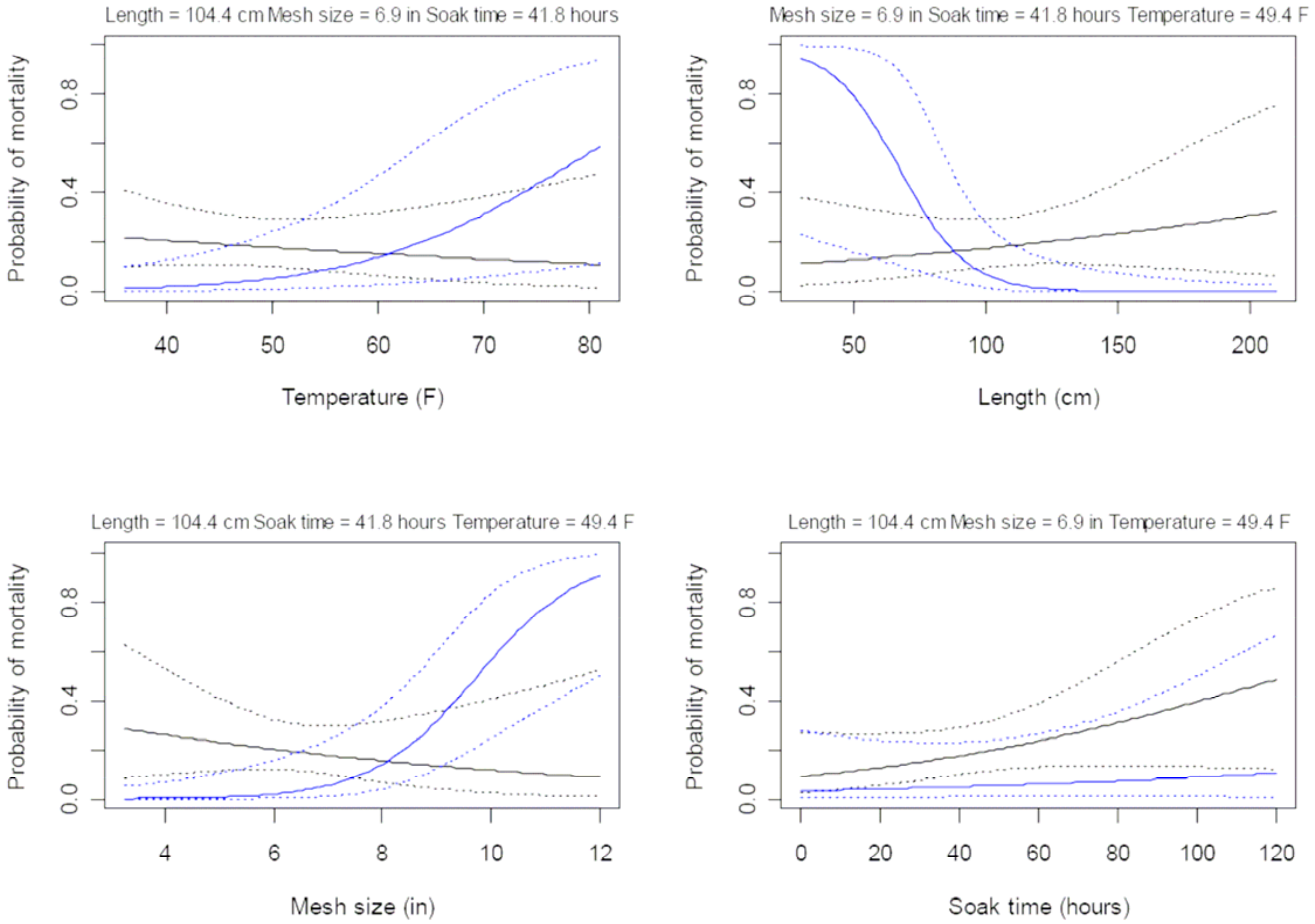

Figure 14. **Comparison of changes in estimated probability of mortality and 95% confidence intervals with temperature, soak time, length of caught sturgeon, and mesh size for sturgeon incidentally caught in gillnets when fishers targeting groundfish and are not using tie-downs (black) or are using tie-downs (blue). Each plot shows how estimated mortality changes with a covariate, holding the remaining three continuous covariates constant.**

SECTION 5

PRESENCE:ABSENCE ANALYSIS OF FACTORS ASSOCIATED WITH ATLANTIC STURGEON BYCATCH

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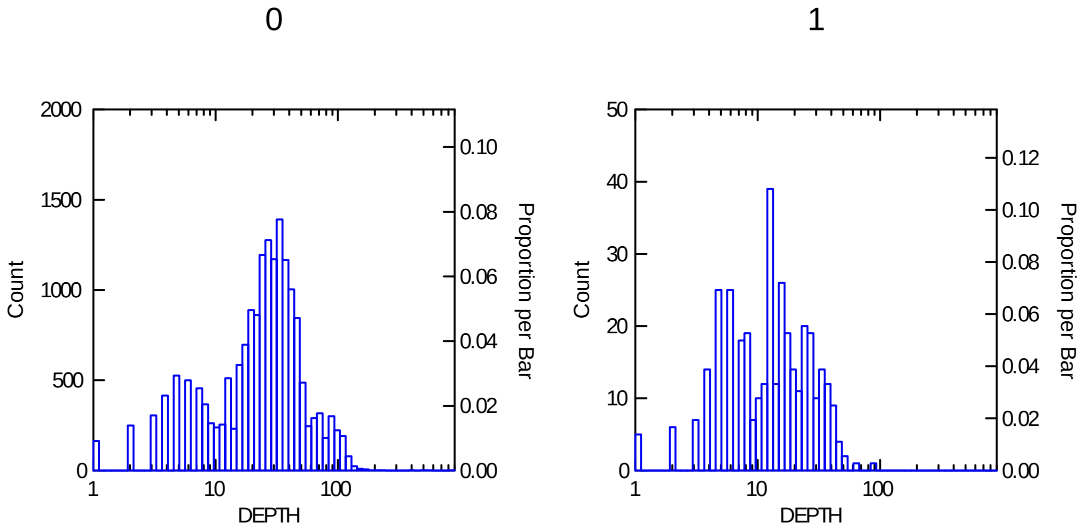
Introduction and Approach

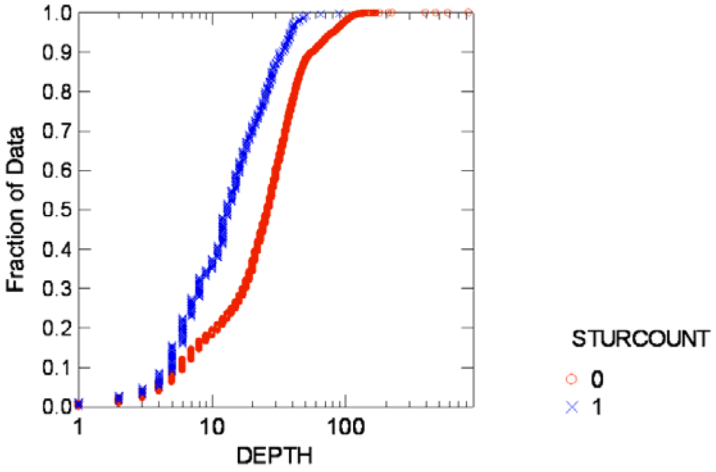
Analysis of incidence data (presence:absence) can be useful to evaluate associations of abundance with factors of interest for rare species. To help visualize and further evaluate the amplitude and pattern of relationships between Atlantic sturgeon bycatch, presence:absence analysis was conducted for the NEFSC Sea Sampling (Observer) Program Database for sink gillnet and trawl fishing gears. Distributions of data across factors were compared for gear sets with and without bycatch of sturgeon. Chi-squared tests were conducted for presence of sturgeon across factors binned into two or more classes. It should be noted that in estimation of Atlantic sturgeon bycatch (Section 1) and factors associated with Atlantic sturgeon mortality (Sections 3-4), the Sturgeon Working Group used total numbers of sturgeons rather than a presence:absence response because this was a more sensitive response to factors associated with bycatch. In plots below, STURCOUNT 0=no observed sturgeon; STURCOUNT 1=observed sturgeon (n>0).

Results

Sink Gillnet Depth

Distributions differed for positive sturgeon bycatch observations, which tended to be shifted towards waters <30 m in depth (Figure 1). Note difference in distributions; observed effort showed a bimodal distribution in depth, but positive bycatch observations were skewed towards depths <10 m. Quartile plots indicated that sturgeons were observed as by-catch up to approximately 40 meters, whereas observer database depths extend beyond 100 meters. Chi-square table showed a significant depth class effect on positive observations between depths <10 m and those ≥10 m.





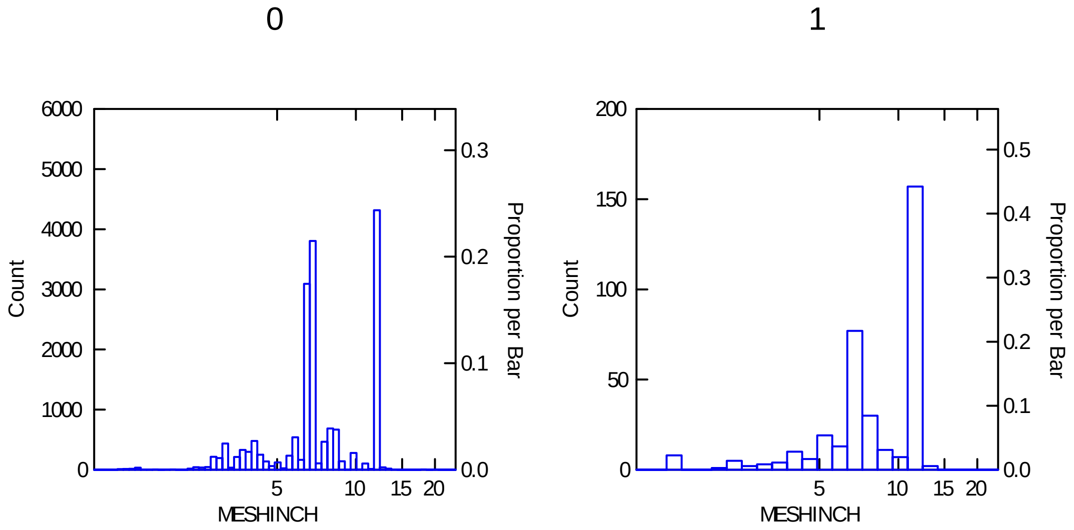
Row Percents
STURCOUNT (rows) by DEPTHCLASS (columns)

	<10	≥10	Total	N
0	18.117	81.883	100	17,922
1	34.903	65.097	100	361
Total	18.449	81.551	100	
N	3,373	14,910		18,283

Test Statistic	Value	d.f.	Prob.
Pearson Chi-square	66.2	1	0

Sink Gillnet Mesh Size

Mesh size was centered on three modes <5” (class 1), 5-9.9” (class 2), and ≥10” (class 3). A chi-squared test indicated significant differences in sturgeon incidence between mesh classes, with a higher fraction of observed by-catch associated with the largest mesh class. Indeed the quantile plot shows that approximately 50% of by-catch is associated with meshes >10”.



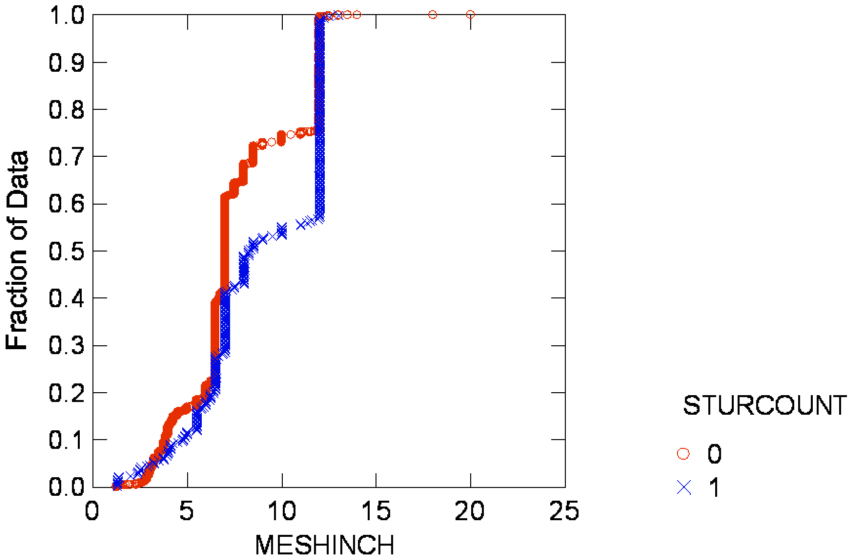
Row percents
STURCOUNT (rows) by MESH-CLASS (columns)

	1	2	3	Total	N
0	16.864	56,101	27.035	100	17,718
1	11.831	41.408	46.761	100	355
Total	16.765	55.813	27.422	100	
N	3,030	10,087	4,956		18,073

Test Statistic	Value	d.f.	Prob.
Pearson Chi-square	68.1	2	0

Sink Gillnet Year and Month

Here, temporal data were treated as categorical variables. Chi-squared statistics showed significant year effects with 2001, 2004 and 2006 showing highest relative incidence of bycatch (>2% of observations by year). Interestingly, these years did not show a pattern of particularly high observer coverage. The month also had significant effect on sturgeon presence, with bycatch incidence highest during April and May and lowest from Aug to Oct. Again there was no obvious pattern attributable to coverage.



Frequencies
YEAR (rows) by STURCOUNT (columns)

Year	0	1	Total
2001	2,562	68	2,630
2002	1,917	36	1,953
2003	2,288	43	2,331
2004	4,572	103	4,675
2005	4,222	49	4,271
2006	2,485	70	2,555
Total	**18,046**	**369**	**18,415**

Row percents
YEAR (rows) by STURCOUNT (columns)

Year	0	1	Total	N
2001	97.414	2.586	100	2,630
2002	98.157	1.834	100	1,953
2003	98.155	1.845	100	2,331
2004	97.797	2.203	100	4,675
2005	98.835	1.147	100	4,271
2006	97.260	2.740	100	2,555
Total	**97.996**	**2.004**	**100**	
N	**18,046**	**369**		**18,415**

Test Statistic	Value	d.f.	Prob.
Pearson Chi-square	29.0	5	0

Frequencies
MONTH (rows) by STURCOUNT (columns)

	0	1	Total
1	1,196	11	1,207
2	1,053	37	1,090
3	1,018	25	1,043
4	1,031	78	1,109
5	1,546	68	1,614
6	1,358	15	1,373
7	1,574	16	1,590
8	1,860	2	1,862
9	2,111	6	2,117
10	1,964	12	1,976
11	1,787	51	1,838
12	1,548	48	1,596
Total	**18,046**	**369**	**18,415**

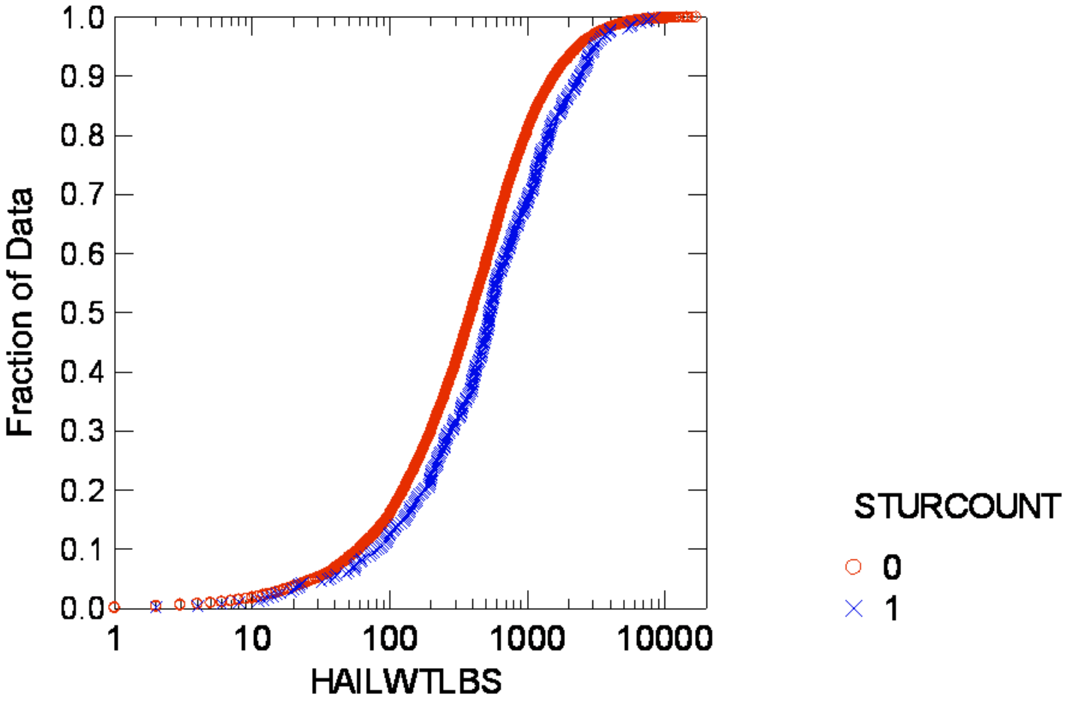
Row percents
MONTH (rows) by STURCOUNT (columns)

	0	**1**	**Total**	**N**
1	99.089	0.911	100	1,207
2	96.606	3.394	100	1,090
3	97.603	2.397	100	1,043
4	92.967	7.033	100	1,109
5	95.787	4.213	100	1,614
6	98.908	1.092	100	1,373
7	98.994	1.006	100	1,590
8	99.893	0.107	100	1,862
9	99.717	0.283	100	2,117
10	99.393	0.607	100	1,976
11	97.225	2.775	100	1,838
12	96.992	3.008	100	1,596
Total	**97.996**	2.004	100	
N	**18046**	**369**		**18415**

Test Statistic	**Value**	**d.f.**	**Prob.**
Pearson Chi-square	315.12	11	0.0008

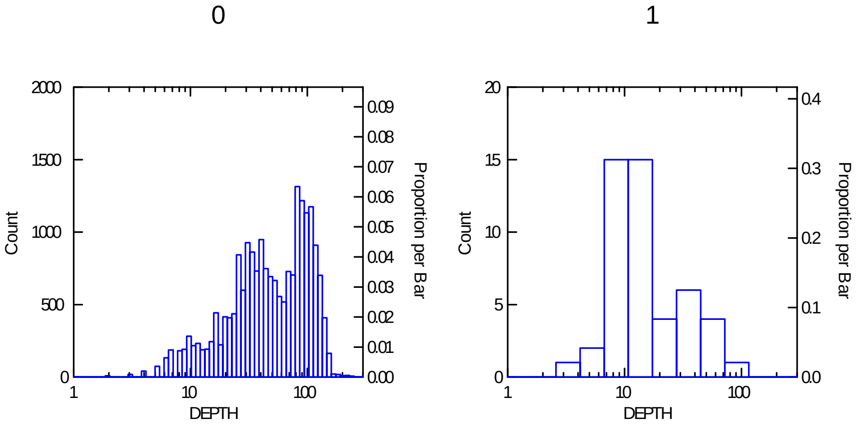
Sink Gillnet Hail wt

Sink gillnet Hail wt (hailwt) is clearly a continuous variable without evidence of modality. Cumulative frequencies indicated that larger hauls tend to be associated with higher bycatch. ANOVA on log-10 hailwt indicated a significant difference between hauls with sturgeon and those with none.



Otter Trawl Depth

A multinomial pattern was observed with effort centered at approximately 10, 30 and 90 m depths. Distributions and Chi-square analysis showed that a significant majority (84%) of bycatch occurred at depths <20 m. The quantile plot shows that about 90% of bycatch was observed at depths <30 m.



Data for the following results were selected according to: (DEPTH < 250)

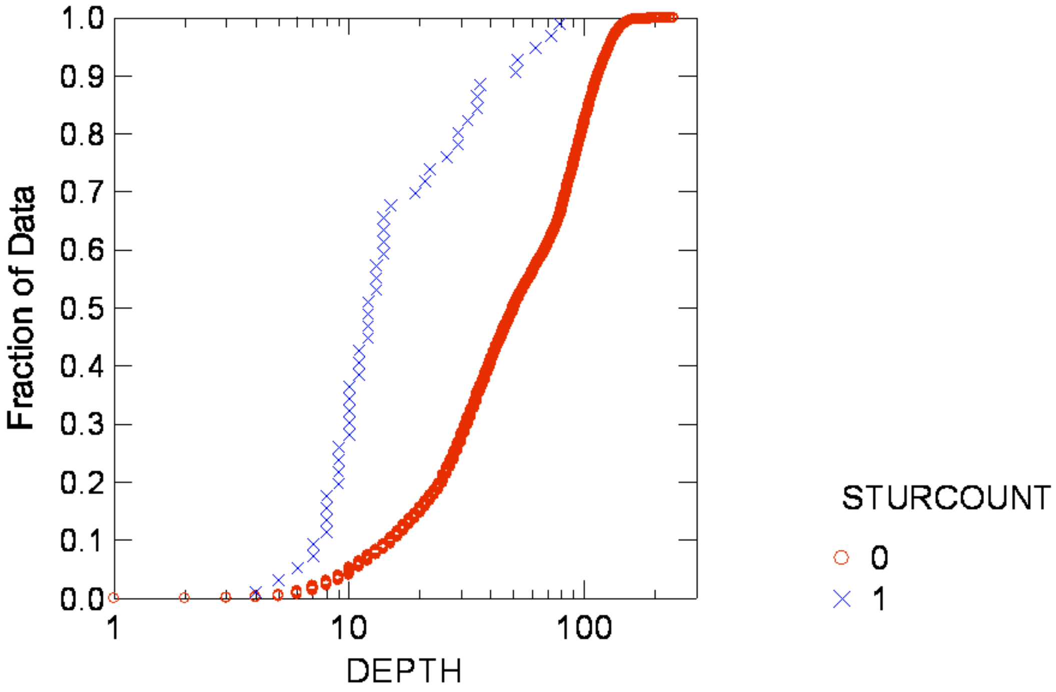
Frequencies
STURCOUNT (rows) by DEPTHCLASS (columns)

	<20 m	>19m	Total
0	3,265	17,456	20,721
1	34	14	48
Total	3,299	17,470	20,769

Row percents
STURCOUNT (rows) by DEPTHCLASS (columns)

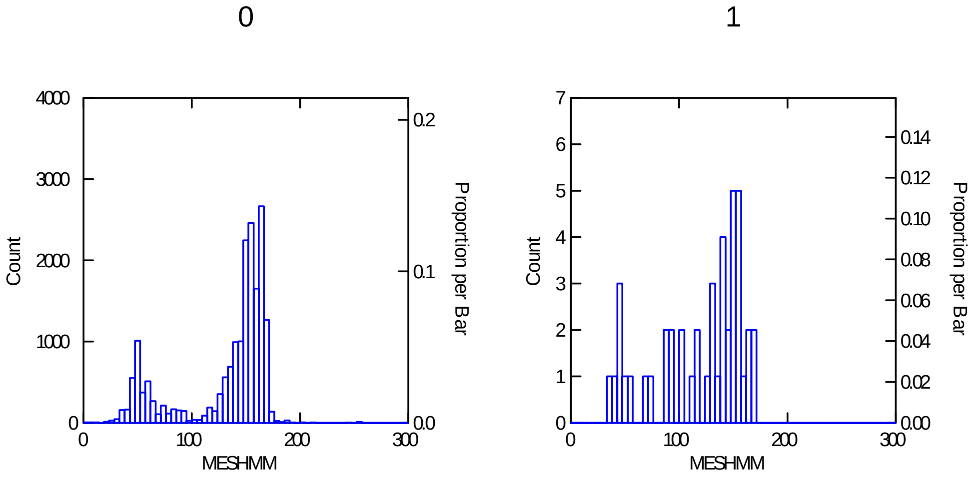
	<20 m	>19m	Total	N
0	15.757	84.243	100	20,721
1	70.833	29.167	100	48
Total	15.884	84.116	100	
N	3,299	17,470		20,769

Data for the following results were selected according to: (DEPTH < 250)



Otter Trawl Mesh

A bimodal pattern in effort was observed across meshes with broad modes centered at 50 and 150 mm and a clear nadir at 100 mm mesh. Meshes less than and greater than 50 mm were used in cross tabulation analysis. Chi-squared test did not show significant differences between these mesh size classes, although a quartile plot indicated that meshes 100-150 mm may be moderately more likely to be associated with sturgeon by-catch.



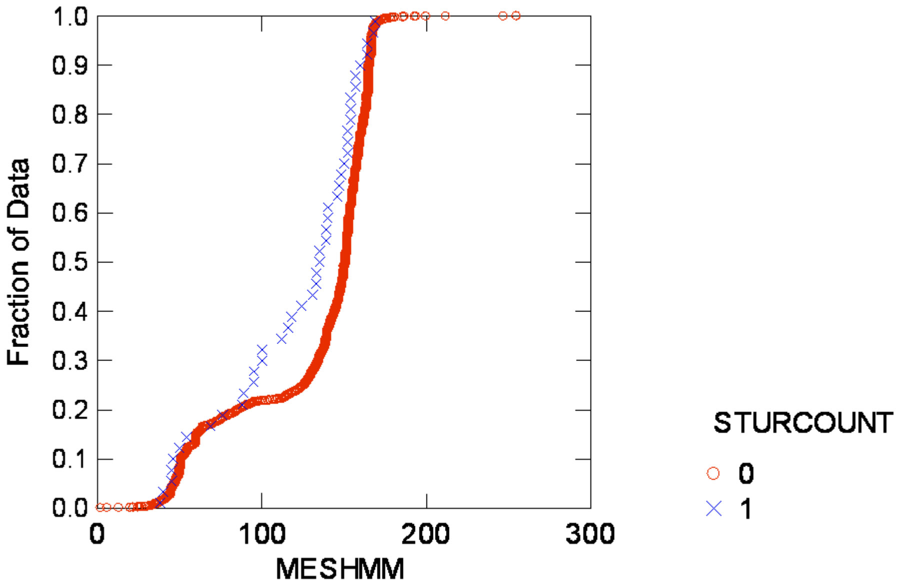
Frequencies
STURCOUNT (rows) by MESHCLASS (columns)

	<50 mm	≥50 mm	Total
0	4,073	14,675	18,748
1	13	32	45
Total	4,086	14,707	18,793

Row percents
STURCOUNT (rows) by MESHCLASS (columns)

	<50 mm	>50 mm	Total	N
0	21.725	78.275	100	18,748
1	28.889	71.111	100	45
Total	21.742	78.258	100	
N	4,086	14,707		18,793

Test Statistic	Value	d.f.	Prob.
Pearson Chi-square	1.354	1	0.245



Otter Trawl Month and Year

Chi-square tests showed moderately significant year effects, with highest bycatch observed in 2006 (0.5%) and lowest in 2002 (0.1%). Stronger month effects occurred with highest bycatch observed in June (0.6%) and no bycatch observed in February.

Frequencies
YEAR (rows) by STURCOUNT (columns)

	0	**1**	**Total**
2001	1,518	4	1,522
2002	2,806	2	2,808
2003	4,604	6	4,610
2004	4,867	12	4,879
2005	4,158	11	4,169
2006	2,887	14	2,901
Total	**20,840**	**49**	**20,889**

Row percents
YEAR (rows) by STURCOUNT (columns)

	0	**1**	**Total**	**N**
2001	99.737	0.263	100	1,522
2002	99.929	0.071	100	2,808
2003	99.870	0.130	100	4,610
2004	99.754	0.246	100	4,879
2005	99.736	0.264	100	4,169
2006	99.517	0.483	100	2,901
Total	**99.756**	**0.244**	**100**	
N	**20,840**	**49**		**20,889**

Test Statistic	**Value**	**d.f.**	**Prob.**
Pearson Chi-square	13.2	5	0.02

MONTH (rows) by STURCOUNT (columns)

	0	1	Total
1	2,319	9	2,328
2	1,756	0	1,756
3	1,635	3	1,638
4	1,331	5	1,336
5	884	4	888
6	1,189	7	1,196
7	1,899	5	1,904
8	1,809	2	1,811
9	1,715	0	1,715
10	1,835	5	1,840
11	2,216	8	2,224
12	2,252	1	2,253
Total	20,840	49	20,889

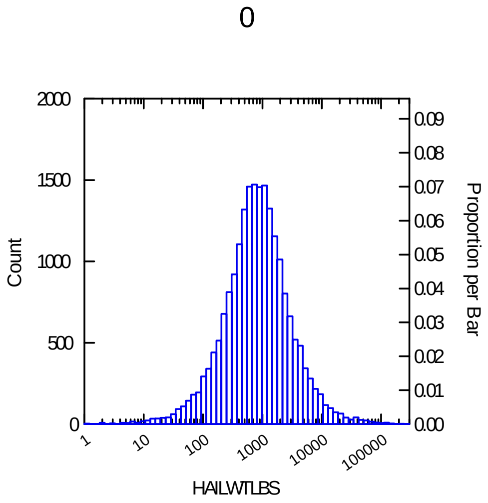
Row percents
MONTH (rows) by STURCOUNT (columns)

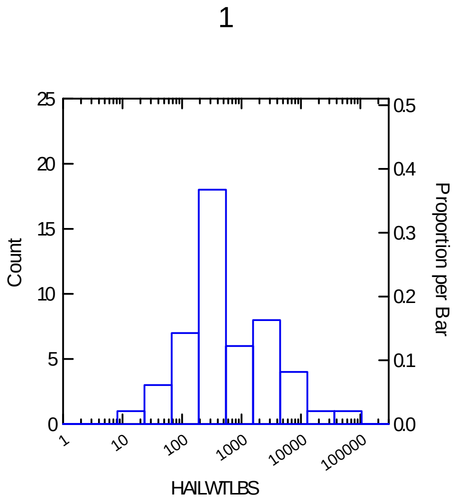
	0	1	Total	N
1	99.613	0.387	100	2,328
2	100.000	0.000	100	1,756
3	99.817	0.183	100	1,638
4	99.626	0.374	100	1,336
5	99.550	0.450	100	888
6	99.415	0.585	100	1,196
7	99.737	0.263	100	1,904
8	99.890	0.110	100	1,811
9	100.000	0.000	100	1,715
10	99.728	0.272	100	1,840
11	99.640	0.360	100	2,224
12	99.956	0.044	100	2,253
Total	**99.765**	**0.235**	**100**	
N	**20,840**	**49**		**20,889**

Test Statistic	Value	d.f.	Prob.
Pearson Chi-square	26.14	11	0.006

Otter Trawl Hailwt

There was no significant difference in hailwt observed between bycatch and absent trawls (P=0.07). No trend was observed for increased sturgeon bycatch or total sturgeon weight with larger hailwt.





SECTION 6

SINK GILLNET FISHERIES AND DESCRIPTIONS OF FACTORS THAT CAN CONTRIBUTE TO HIGHER OR LOWER INTERATION AND RETENTION RATES

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Introduction

Data from the NEFSC Sea Sampling (Observer) Program Database and the U.S. Fish and Wildlife Service (USFWS0 tag reports (Eyler *et al*. 2004) identify sink gillnets as the principal source of Atlantic sturgeon bycatch and bycatch mortality. Sink gillnet fisheries are numerous along the Atlantic coast, targeting both large and small species in inshore and offshore waters. As we examine sturgeon catch records based on Observer data more closely, data availability becomes an obvious limitation to analysis. Caution should be exercised whenever NEFSC Observer data is examined alone to investigate any species' interaction or retention. Coverage is sometimes sparse and sometimes inaccurately reported with regard to variables. Further, a large portion of the sturgeon take records was attained as a result of studies in specific regions (often inshore waters) on certain fisheries in order to investigate particular bycatch problems suspected to be occurring with protected species like turtles and marine mammals. Subsequently, Observer data on sturgeon bycatch is not homogenous across or within fisheries, effort, target species, state, or areas of operation. This implies that because a target species or regional fishery is not represented, it does not mean that sturgeon bycatch or mortality is not occurring. Similarly, the appearance of bycatch in a given fishery does not necessarily imply that sturgeon bycatch is proportionally similar to the incidence of occurrence in the Observer Database. Here it is critical to bring in considerations of how the Observer Database represents effort in the fishery (Sections 1 and 4), and ancillary models and understanding of fishery interactions (this section and Section 4). The Observer data is simply a record of sturgeon catches in fisheries that have been observed and is not adjusted for effort.

Limitations aside, the Observer data provides one of the most comprehensive records of sturgeon bycatch for the U.S. northeast Atlantic coast. Unlike the USFWS tag return database (the other federal data base with significant data on sturgeon gillnet interactions), reports in the Observer Program do not depend upon volunteer reporting and thus are not biased in this regard. Meaningful descriptions of the biotic and abiotic factors that likely contribute to alterations in interaction and retention rates can be made between identified categories within which gear and application variables remain relatively constant and between factors that are adequately reported.

Target-Species and Gear Application

To simplify Observer Database sturgeon bycatch data, the ASMFC Sturgeon Working Group separated the gillnet fisheries, in which catch records were reported, into six categories. Two of the six categories are species specific: monkfish and striped bass. The remaining four categories—dogfish, kingfish, groundfish and other—all contain numerous fisheries with their own associated gear and application variability. When SGN are used to target a specific species, gear and techniques generally become relatively standardized, allowing these variables to be accurately described by fishery or category. When categories contain multiple target species, grouping them together often prevents such characterization due to custom alterations in such factors based on target. The dogfish category contains trips when smooth or spiny dogfish were listed as the target species. Regardless of which dogfish is targeted, however, gear and application vary little (D. Grubbs, VIMS, pers. comm.). Target species of dogfish generally varies with water temperature. The kingfish category contains both northern and southern kingfish are fishes of relatively the same size and shape and are difficult to distinguish. In the region where Observer data were collected, these two species often school together; therefore, gear and application vary little in this category as well.

Characterizing gear and application in the groundfish fishery and the all other categories is not possible. Both categories contain various fisheries that often target multiple species simultaneously. When the target consists of multiple species like the groundfish fishery of New England or various fisheries in the mid-Atlantic, gear characteristics (e.g., mesh size, tie downs) and application (e.g., soak time) vary considerably in order to maximize likelihood of interactions with whatever target species is temporally available. This variation prevents a homogenous characterization of gear or application and thus limits evaluation of how such variables might affect sturgeon bycatch equally across the various fisheries contained within the groundfish and all other categories. The gear and application variability within these categories, however, is useful when examining general trends attributable to such factors across categories.

Interaction and Retention Rates

Observer data cannot be used alone to evaluate interaction rates (i.e., the rate at which fish encounter the gear), fishery-specific retention rates (i.e., the rate at which fish that encounter gear are retained), or the reasons for variations in these rates. Fortunately, previous sturgeon research and ongoing scientific collection efforts targeting sturgeon with sink gillnet offer biological information and gear comparisons that can help explain why some fisheries experience higher interaction and retention rates.

Sink gillnets are stationary intercept gear that capture moving species. Sturgeon are known to migrate through near shore waters along the coast seasonally (Hoff 1980; Dovel and Berggren 1983; Rulifson and Huish 1982) moving north in the spring and returning along the same routes moving south in the fall. Some but not all adults and non-reproductive individuals return to tributaries each spring (Bain 1997; Sulak and Randall 2002). Two fisheries operate exclusively near shore (within three miles/state waters only) fisheries: the kingfish (North Carolina) and coastal striped bass fishery (Virginia, mouth of Chesapeake Bay). Both are active when and where sturgeon are known to be migrating (Stein *et al*. 2004; see Section 3). Assuming equal retention by very different types of sink gillnet, this would result in proportionately greater sturgeon bycatch in such fisheries. The kingfish fishery is small and localized. It harvests approximately 500 thousand pounds a year from waters primarily from Morehead City to the South Carolina border. (In comparison, North Carolina harvests 10 million pounds of croaker and 3 million pounds of summer flounder.) Kingfish are targeted with small mesh (2.5” minimum) and most harvest is caught by the 2.5”-2.75” mesh size range (J. Schoolfield, NCDMF, pers. comm.). The kingfish fishery’s appearance as a prominent fishery and category likely speaks to the need for greater observer coverage based on effort within North Carolina and along the coast. The coastal striped bass fishery in Virginia, by contrast, is a large mesh fishery with mesh sizes ranging from 7-10 inches that targets striped bass as they migrate north along the coast and into Chesapeake Bay to spawn (Hager 2005). Nets set to intercept striped bass simultaneously intercept sturgeon. Luckily these nets are being run in cool water conditions and consequently have a very low instantaneous mortality rate associated with their bycatch (7%).

Increased regional movement, and hence availability of migrating sturgeons augments the likelihood of retention in sink gillnet of any type operating within migration corridors. In some cases, high concentrations of sturgeon can mask retention differences between gears by “swamping” any type of gear set in regions of concentration. In addition, gear variables known to be important to retention (e.g., twine size, hanging ratio, net height) are not adequately reported in the Observer Database so quantitative evaluations are limited.

Sturgeon Mortality in Sink Gillnets

When examining Observer data alone, common characteristics in gear and application for four of the six categories are helpful in identification of factors that contribute to sturgeon mortality. Mortality rates are independent of interaction rate. Comparisons between rates can, therefore, provide valuable information on how gear and application methods stress captured fish and how such factors can be altered to minimize mortality (see also Section 4).

Water temperature and the soak time duration affect survival of captured fish (Davis and Olla 2001; Buchanan *et al*. 2002) in sink gillnets though physiological constraints regardless of capture method. Both variables were found to significantly affect the probability of sturgeon mortality based on Observer catch records. Investigations by several researchers suggest that (Collins *et al.* 1996; Hager, unpublished) mortality in gillnets increases significantly in water temperatures of 18°C and above. Temperatures ≥18°C occurred so rarely in the Observer data that this threshold cannot be adequately analyzed as shown in Table 1, where in fact mortality apparently declines at temperatures >18°C, which contradicts the scientific literature and observed positive relationships throughout the temperature range (see Section 4).

Table 1. **Effect of threshold temperature, 18°C, on incidence of Atlantic sturgeon mortality in the NEFSC Observer Database. Water temperatures based on Observer reports. Mortality rate is proportion of fish in temperature range that were found dead in gear.**

	Temp. ≤18°C	Temp. >18°C
Incidence of Mortality	31%	12%
Number of Observations	432	33

Soak Time and Sturgeon Mortality

A principal finding of the 2006 Sturgeon Technical Committee Workshop on sturgeon bycatch was that soak times exceeding 24 hours were associated with substantially higher mortality rates (see Section 4 for statistical analysis of soak time and other application variables). Fishers have long recognized a relationship between soak time, mortality, and water temperature, and generally reduce soak times as waters warm to minimize spoilage of catch. Numerous scientists have described this relationship, at least in part, finding that increased soak times and increased water temperatures result in higher mortality rates (Collins *et al*. 1996; Buchanan *et al*. 2002; Bettoli and Scholten 2006). The effect of soak time on sturgeon survival is evidenced in the Observer data as well (Table 2). Incidence of mortality shows a strong association with soak time but examination of only this single factor ignores the effect of or interaction between other gear variables. This is a concern because some factors like extended soak time and tie-downs are essentially inseparable in Observer data.

Table 2. **Effect of threshold soak time, 24 hr, on incidence of Atlantic sturgeon mortality in the NEFSC Observer Database. Soak time based on Observer reports.**

	Soak ≤24 hours	Soak >24 hours
Deaths	29	106
Interactions	201	264

Incidence of Mortality	14%	40%

Extended soak times and higher water temperatures may also lead to higher sturgeon deaths due to higher interaction rates. The more time a net soaks the more likely it is to intercept a given species. Soak time duration may be especially important if a given species occurs in relatively low abundance. Observers also report that sturgeon catch rates seem to increase when nets are reset in the same region where large amounts of small fish bycatch were previously discarded. If dead or decaying fish attract sturgeon, a self-baiting effect may be occurring. Extended soak times and higher water temperatures which augment mortality and decay of other entangled species may actually lead to increased sturgeon interaction rates due to this attraction to the gear.

Gear Characteristics

Abiotic gear factors (Hamley 1975; Hovgård and Lassen 2000; Yokota *et al*. 2001; Machiels *et al*. 1994; Holst *et al*. 2002) such as mesh size, twine material, twine diameter, hanging ratios, and tie-downs influence retention of not only fish but other protected species as well. Though all of these factors are identified as desired data points on NEFSC Observer data sheets, incomplete reporting limits analysis to tie-downs and average mesh size. Both were found to be significantly correlated with the probability of mortality (Table 3). Gear factors, like application factors and unlike biotic factors, offer an added advantage in that they can be regulated to achieve desired catch alterations, if applicable.

Table 3. **Gear and application factors and incidence of mortality across categories of mesh size, percent tie-down use, and soak time variation between categories. From NEFSC Sea Sampling (Observer) Program Database (2001-2006).**

Fishery	Striped Bass	Monkfish	Dogfish	Kingfish	Groundfish	All Others
Mesh sizes (inches)	2 - 9	7 - 12.5	5 - 6.83	1.25 - 3.25	3.2 - 12	2.8 - 13
% Time tie-downs used	0	98%	6%	0%	27%	3%
% Soak over 24 hours	31%	83%	31%	0%	50%	0%
Deaths	5	99	5	0	24	2
Interactions	52	224	32	24	102	31
Incidence of mortality	10%	44%	16%	0%	24%	6%
% Total mortality	4%	73%	4%	0%	18%	1%

Target specific fisheries easily fit within NEFSC mesh categories of small, medium, and large. The kingfish fishery used only small mesh, dogfish used medium mesh, and the monkfish used large mesh. The only cross over between mesh categories that occurred within a targeted species was for striped bass. It contained several 2-inch outlier records (fished by the same person four times on the same day) and one observed set with 6.5” mesh.

Table 4. **Gear and application factors and incidence of mortality across categories of small, medium and large mesh (according to NMFS definitions). From NEFSC Sea Sampling (Observer) Database (2001-2006).**

Mesh Size	Small Mesh (≤5")	Medium Mesh (>5" – <7")	Large Mesh (≥7")
Sturgeon Deaths	1	16	118
Interactions	55	80	330
Incidence of Mortality	2%	20%	36%
% of Total Deaths	1%	12%	87%
% Tie downs Used	0%	9%	74%
% Soak Time >24 hrs	4%	38%	70%

Mortality rates and percent of total mortalities were much higher in large mesh fisheries (see also Sections 4 and 5) but again it is hard to separate the effect of large mesh, tie-downs, and soak time. For instance, tie-downs were used with large mesh nets 74% of the time and soak times of over 24 hours occurred 79% of the time when tie-downs were used with large mesh. Such large overlaps in gear and application methods within mesh size and fisheries categories limit the extent to which each factor's influence can be examined.

There is likely a relationship between method of capture, fish size, and mesh size that is not well understood (see Section 4). A comparison between reported mesh size and sturgeon size distribution between different studies supports this view and may also point out the inherent weaknesses in using an average when reporting mesh size. The report of a 2-inch mesh size average being used to target striped bass (Table 4) offers a good example. Such a mesh size will not catch a legal striped bass but, more importantly, for our purpose it implies that nets consisted of more than one mesh and the actual size that retained the sturgeon is unknown. This factor might explain some of why size distribution has less correlation to mesh size based on Observer reports (Figure 1) than is indicated by size distributions based on Virginia Sea Grant's collection efforts (Figure 2) when exact mesh size was reported and gear attribute variation was reduced.

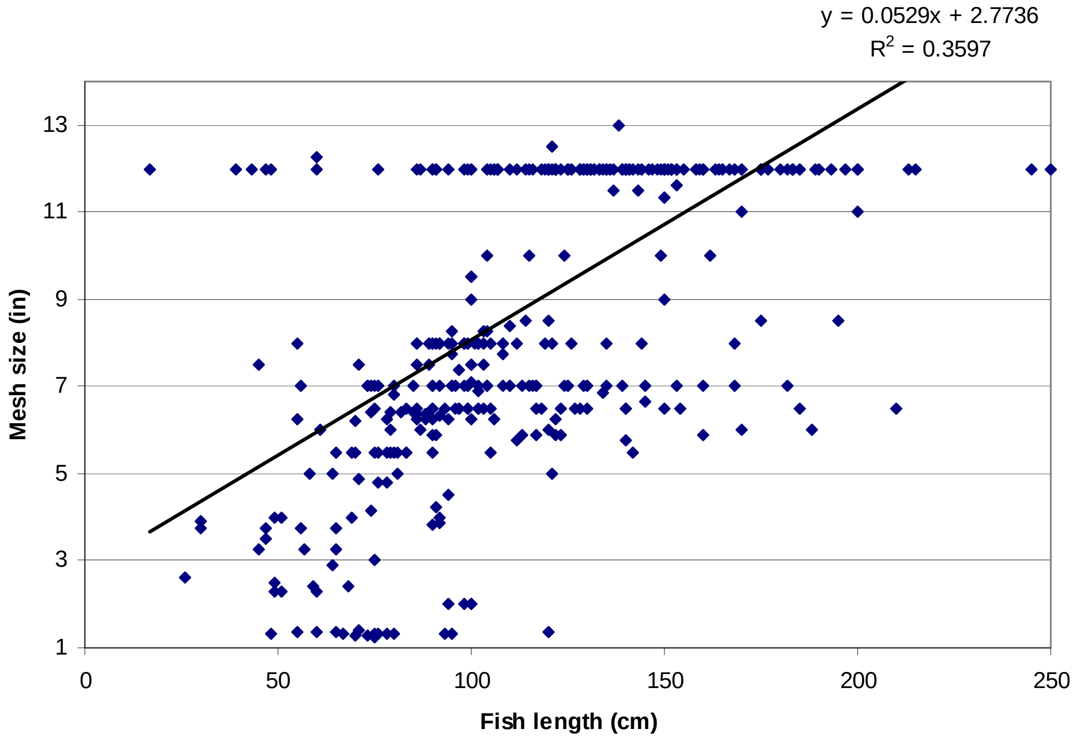

Figure 1. NMFS sink gillnet mesh-specific length distributions of sturgeon.

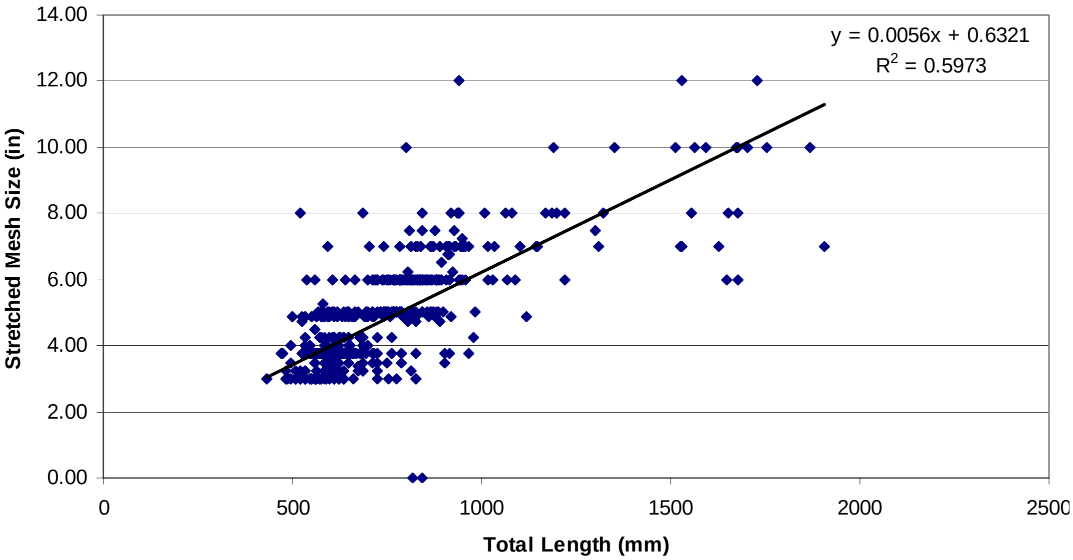

Figure 2. Virginia Sea Grant sink gillnet mesh specific length distributions of sturgeon.

Sturgeon morphology and behavior likely affect retention in gear, thus resulting in a greater disparity in size distributions. It is a common misconception that gillnets retain fish by simply gilling them. That is, fish are simply prevented from backing out of the webbing by a mesh caught behind the gill cover. This is untrue, fish can be retained by wedging—being held by a mesh or meshes around the body. Fish with unique morphological attributes can become entangled by the teeth, maxillaries, snood, or other projections without necessarily penetrating the net (Hamley 1975). Vastly different methods of retention likely effect the sink gillnet sturgeon data collected on mesh sizes from 2-8" stretched mesh by the USFWS (Moser *et al.* 2000). Considerable overlap between size distributions of sturgeon suggested in this study that mesh sizes greater than 6.4mm (2.5") all result in similar frequencies with regard to post yearling fish (Moser et al. 2000). By contrast, other work has shown reasonably well-distinguished efficiency curves for 4, 6, and 7-inch mesh used to target short nosed sturgeon (Woodland and Secor 2007). Interestingly, these nets were chosen for the study based on work by Dadswell (1979) that stated that all sizes of shortnose sturgeon larger than 48 cm were susceptible to capture in such meshes.

Sturgeon morphology is unique and the variety of modes of capture by sink gillnets likely reflects this. The protruding scutes and snouts that sturgeons possess likely make them more susceptible to capture by entanglement. Hanging ratio has been found to be one of the most important factors that effect catch (Hamley 1975; Hovgård and Lassen 2000; Dickson 1989). At low hanging ratios, nets contain a high mesh to area ratio that provide a greater opportunity for entanglement of fish across a wider range of sizes, by contrast, increasing this ratio provides a greater likelihood of gilling and thus a more defined effective size range (Gray *et al*. 2005).

Tie-Downs

Tie downs alter sink gillnet presentation in several ways. They increase the mesh to area ratio within a given space, like decreasing hanging ratio does, by reducing vertical profile but not mesh number. Tie downs also create bags in the gear between each vertical line. What is created is a sink gillnet that consists of a series of bags of webbing that are loser than the same webbing would be if no tie-downs were present. Once a bag is entered, finding a way over, under, or around the mesh by tracking along the net becomes extremely difficult. No tie-downs were used on gillnet interaction plotted on Figure 2. Tie-downs were used 54% of the time in Figure 1 but use was not equally distributed between mesh sizes (Table 4). The wide size distribution of fish retained in 12-inch mesh in (Figure 1) may reflect a greater susceptibility to being captured in sink gillnets with large mesh, tie-downs, or extended soak times. Tie-downs were observed in this mesh size for 98% of the samples and soak times exceeded 24 hours 82% of the time, consequently, there is no way to separate the effect of each factor within this mesh size without over-thinning data. Examination of tie-down use across fisheries (Table 5) suggests that both the rate at which mortality occurs and the total percentage of recorded mortality is substantially higher when tie-downs are used. The percentage of time tie-down nets are left over 24 hours, however, is very high, and, as suggested earlier, soak time is likely the controlling factor with regard to mortality. The importance of soak time is again highlighted by comparisons between the mortality rates occurring within tie-down nets. Mortality increases from 27% to 47 % when nets are left for soaks exceeding 24 hours.

Table 5. **NEFSC Sea Sampling (Observer) Program Database (2001-2006).**

	No Tie-downs	Tie-downs
Deaths	29	106
Interactions	215	250
Incidence of Mortality	13%	42%
% of Deaths	21%	79%
% Soak Time >24 hrs	32%	78%
% Incidence of Gear Type	46%	54%

Experiments on the Effect Sink Gillnet Gear Characteristics on Sturgeon Retention

Sink gillnet gear variation likely affects sturgeon retention, however, even when materials and methods are strictly controlled and differences in plentiful targets examined, it is difficult under field conditions to determine if gear alterations or uncontrollable parameters are the cause of catch variability. As the availability of the species of interest declines, separating the factors that lead to interaction and retention become increasingly difficult. Engineering more selective sink gillnet, with regard to Atlantic sturgeon, requires a better understanding of technical gear factors and their effect on retention that cannot be attained through field observations. In order to examine alterations in hanging ratio and twine size that were not adequately recorded in Observer data and to take a closer look at the effect of tie-downs on sturgeon retention, Virginia Sea Grant and VIMS conducted a sink gillnet interaction experiment on captive sturgeon under controlled conditions in the spring of 2007. Low hanging ratios increase likelihood of entanglement rates of most fish (Gray *et al*. 2005) and reduced twine sizes have been recognized to increase sturgeon capture rates and increase likelihood of harm due to capture as well (Moser *et al*. 2000). No direct studies on the effect of tie-downs on sturgeon have been conducted.

All sturgeon were collected from the field using 5-6” stretched mesh sink gillnet and subsequently held in captivity for a minimum of five days before exposure to gear of varied twine sizes, hanging ratios, and tie-down construction in a controlled experiment. No fish were held for more than a month. Eight fish were placed in a 14 by 21 foot oval tank and exposed to each experimental net section for 30 minutes. Fish that were retained by the net in a given experiment were removed and not used in subsequent experiments in the same day. Trials were repeated until a minimum of 30 fish interacted with the each net section. Net sections were nine feet long and deployed in the middle of the 14-foot section of the tank so that fish could pass around section at will. Nets were also altered by application of tied downs at a height of 30 inches or allowed to free float at a natural height of 45 inches. Interactions were observed and classified to determined degree of interaction and fate. An interaction was defined by a fish coming in contact with the net. The fish could then turn around (T) or become entangled (E). If entangled, the fish either back out (BO), force their way through by violently struggling and breaking free (F), or they are retained (R). Net parameters, categories, and rates are given below.

Table 6. Results of VIMS SGN Sturgeon Retention Experiments.

Twine Size (mm)	Hanging Ratio	Net Height	Interact	Turned	Entangled	Retained	Forced	Backed Out	R/I	R/E
0.4	6	tie-down 30"	35	0	35	28	7	0	0.80	0.80
0.52	6	tie-down 30"	51	6	45	27	12	6	0.53	0.60
0.52	4	tie-down 30"	54	8	46	22	16	8	0.41	0.48
0.4	6	none 45"	31	2	29	21	7	1	0.68	0.72
0.52	6	none 45"	55	11	44	23	10	11	0.42	0.52
0.52	4	none 45"	36	11	25	5	10	10	0.14	0.20

Interaction analysis (Chi-square tests) revealed that enlarging twine, increasing hanging ratio, and removing tie-downs all significantly altered fish retention ratios in that more sturgeon escaped gear. In a separate field test, identical increases in twine size and hanging ratios did not significantly alter retention of striped bass. In fact, more striped bass were taken in nets with larger twine sizes and ratios. In addition, fewer sturgeon were captured when alterations were made but small sample sizes prevented meaningful analysis. Such findings suggest that gear alterations can serve as a method of significantly reducing sturgeon retention and associated mortality, potentially without reducing CPUE of targeted species.

APPENDIX 1: MODEL PARAMETER ESTIMATES AND DIAGNOSTICS

Trawl- all sturgeons captured

	Parameter	Estimate	Standard Error	lower 95% CI	Upper 95% CI	Chi-square	Pr > ChiSq
Intercept		-1.103	0.967	-2.998	0.791	1.300	0.254
landings		-0.088	0.097	-0.278	0.102	0.830	0.363
meshsize		-0.001	0.003	-0.006	0.005	0.100	0.748
depth		-0.039	0.012	-0.063	-0.015	10.020	0.002
year	2001	-0.461	0.521	-1.482	0.561	0.780	0.377
year	2002	-2.080	0.815	-3.678	-0.482	6.510	0.011
year	2003	-0.990	0.506	-1.981	0.002	3.830	0.050
year	2004	-0.530	0.360	-1.235	0.175	2.170	0.141
year	2005	-0.817	0.391	-1.583	-0.051	4.370	0.037
year	2006	0.000	0.000	0.000	0.000		
qtr	1	0.418	0.497	-0.556	1.392	0.710	0.400
qtr	2	1.034	0.357	0.335	1.734	8.400	0.004
qtr	3	-0.735	0.482	-1.679	0.209	2.330	0.127
qtr	4	0.000	0.000	0.000	0.000		
division	51	-2.881	0.690	-4.232	-1.530	17.460	<.0001
division	52	-2.604	0.901	-4.371	-0.838	8.350	0.004
division	53	-2.672	0.712	-4.067	-1.277	14.100	0.000
division	61	-0.860	0.582	-2.002	0.282	2.180	0.140
division	62	-1.213	0.682	-2.551	0.124	3.160	0.075
division	63	0.000	0.000	0.000	0.000		
Scale		1.089	0.000	1.089	1.089		

Gillnets - all sturgeons captured

	Parameter	Estimate	Standard Error	lower 95% CI	Upper 95% CI	Chi-square	Pr > ChiSq
Intercept		-4.227	0.348	-4.909	-3.545	147.62	<.0001
landings		0.162	0.049	0.067	0.258	11.05	0.0009
meshsize		0.244	0.023	0.200	0.288	117.35	<.0001
depth		-0.054	0.008	-0.070	-0.039	46.26	<.0001
year	2001	-0.714	0.214	-1.133	-0.294	11.13	0.0009
year	2002	-0.289	0.238	-0.755	0.178	1.47	0.225
year	2003	0.022	0.223	-0.415	0.459	0.01	0.9217
year	2004	0.118	0.179	-0.233	0.470	0.44	0.5089
year	2005	-0.519	0.215	-0.940	-0.099	5.86	0.0155
year	2006	0.000	0.000	0.000	0.000		
qtr	1	0.096	0.180	-0.257	0.449	0.29	0.5923
qtr	2	0.423	0.155	0.120	0.726	7.47	0.0063
qtr	3	-1.107	0.278	-1.652	-0.562	15.85	<.0001
qtr	4	0.000	0.000	0.000	0.000		
division	51	-1.057	0.244	-1.536	-0.578	18.71	<.0001
division	52	-2.202	0.321	-2.830	-1.574	47.22	<.0001
division	53	-2.564	0.342	-3.235	-1.893	56.13	<.0001
division	61	-0.503	0.188	-0.871	-0.136	7.21	0.0073
division	62	-1.063	0.213	-1.480	-0.646	24.97	<.0001
division	63	0.000	0.000	0.000	0.000		
Scale		1.332	0.000	1.332	1.332		

Gillnets - dead sturgeons only

	Parameter	Estimate	Standard Error	lower 95% CI	Upper 95% CI	Chi-square	Pr > ChiSq
Intercept		-6.751	0.713	-8.148	-5.353	89.660	<.0001
landings		0.000	0.000	0.000	0.000	10.960	0.001
meshsize		0.365	0.052	0.262	0.467	48.540	<.0001
depth		-0.065	0.018	-0.100	-0.030	13.370	0.000
year	**2001**	-0.043	0.582	-1.183	1.097	0.010	0.941
year	**2002**	0.306	0.609	-0.887	1.500	0.250	0.615
year	**2003**	0.197	0.610	-0.998	1.393	0.100	0.746
year	**2004**	1.278	0.464	0.369	2.187	7.590	0.006
year	**2005**	0.270	0.534	-0.777	1.317	0.260	0.613
year	**2006**	0.000	0.000	0.000	0.000	.	.
qtr	**1**	-0.919	0.510	-1.919	0.081	3.250	0.072
qtr	**2**	-0.080	0.280	-0.629	0.468	0.080	0.774
qtr	**3**	-2.074	0.632	-3.313	-0.836	10.780	0.001
qtr	**4**	0.000	0.000	0.000	0.000	.	.
division	**51**	-0.432	0.589	-1.587	0.723	0.540	0.463
division	**52**	-0.906	0.540	-1.964	0.152	2.820	0.093
division	**53**	-1.629	0.612	-2.829	-0.428	7.070	0.008
division	**61**	0.626	0.419	-0.195	1.447	2.230	0.135
division	**62**	-0.054	0.526	-1.086	0.978	0.010	0.918
division	**63**	0.000	0.000	0.000	0.000	.	.
Scale		1.396	0.000	1.396	1.396		

Gillnet - all sturgeon captures :

value/df

	neg. binomial	poisson	quasi-poisson
Deviance	0.100	0.196	0.196
scaled deviance	0.100	0.196	0.110
Chi-square	1.283	1.775	1.775
scaled chi-sq	1.283	1.775	1.000
log likelihood	-1558.777	-1757.075	-989.815
dispersion	8.082		
scale		1.000	1.332

Trawl - all sturgeon captures :

value/df

	neg. binomial	poisson	quasi-poisson
Deviance	0.024	0.051	0.051
scaled deviance	0.024	0.051	0.043
Chi-square	0.933	1.185	1.185
scaled chi-sq	0.933	1.185	1.000
log likelihood	-273.576	-308.247	-260.165
dispersion	18.140		
scale		1.000	1.089

Gillnet - dead sturgeon captures :

value/df

	neg. binomial	poisson	quasi-poisson
Deviance	0.046	0.072	0.072
scaled deviance	0.046	0.072	0.037
Chi-square	1.518	1.949	1.949
scaled chi-sq	1.518	1.949	1.000
log likelihood	-560.796	-592.547	-304.061
dispersion	5.761		
scale		1.000	1.396

- Comparable trawl model failed to converge

APPENDIX 2

Table A1. **Number of Atlantic sturgeon bycatch observations when tie-downs were present or absent, by target species.**

	Dogfish	Groundfish	Kingfish	Monkfish	Striped bass	Other
No Tie-down	30	74	24	5	52	30
Tie-down	2	28	0	219	0	1

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