Summary of Harbor Porpoise Bycatch South of Cape Cod

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SUMMARY
Harbor porpoise bycatch in waters south of Cape Cod and north of 40ºN have been consistently high since about 2000, where it was particularly high in the last three years 2005 to 2007. For simplicity, in the rest of this document this area will be called the south of Cape Cod area. This manuscript documents the bycatch patterns in the waters south of Cape Cod and attempts to identify factors as to why the bycatch was high. These results might lead to potential mitigation measures to reduce future bycatch in this area.

Since the implementation of the harbor porpoise Take Reduction Plan (TRP) on January 1, 1999, out of the 2831 gillnet hauls observed south of Cape Cod, 87 harbor porpoise takes were observed, of which 24 were inside the Cape Cod South Closure, and 63 were outside. All observed takes were during the months December to May and in gear targeting monkfish or winter skate.

Bycatch rates of hauls outside the Cape Cod South Area (pingers not required) was about 50% higher than the bycatch rate within the Cape Cod South Area (pingers required): 0.102 versus 0.066 takes/metric tons (mton) of landings. Regardless of whether the haul was from inside or outside of the Closure Area, the bycatch rate of hauls that used pingers (1055 hauls) was about half that of hauls that did not use pingers (1776 hauls): 0.053 versus 0.098 takes/mton.

For the Cape Cod South Area, from March 1-31 the Area is closed to all gillnets, and during December 1 to February 28/29 and April 1 to May 31, the Area is closed to gillnets unless pingers are on the gillnets. Since January 1999, only 3 observed hauls (from 1 trip) were inside the Cape Cod South area during March (the closed month). Of the 1665 observed hauls in the Cape Cod South area during the time period that pingers should have been used, 47% of the strings had 90% or more of the required pingers, an additional 40% did not have any pingers, and the remaining 13% had some pingers but less than 90% of the required amount.

A statistical model that best predicted the bycatch rate included the following variables (in order of importance): amount of steam time, day of the year, twine size, and temporary home state. This bycatch rate model identified several relevant issues related to high bycatch that could be considered in future mitigation measures. One consideration is, when targeting monkfish (mesh sizes greater or equal to 10 inches), follow the normal practice; that is, use twine sizes greater than or equal to 0.57 mm, since the bycatch rate for twine sizes of 0.33 was extremely high. A second consideration is to continue to use the present time/area closures and pinger time periods, since the highest bycatch was in February through April, with less in the surrounding months of December, January, and May. A third consideration is to increase the region where pingers are required to include the areas of high bycatch outside the Cape Cod South Closure Area, that is, the area from the southern boundary of the Closure Area to the 40º W latitude line and to the 70ºN longitude line.

INTRODUCTION

For the waters south of Cape Cod, the harbor porpoise take reduction plan (TRP) divides the waters into the "Cape Cod South Area" and waters not regulated by the TRP. For the Cape Cod South Area, the TRP regulations state that from March 1-31 the Area is closed to all gillnets and during December 1 to February 28/29 and April 1 to May 31, the Area is closed to gillnets unless pingers are on the gillnets (Federal Register 1998) .

This paper investigates the harbor porpoise bycatch in the gillnet fishery south of Cape Cod after the TRP was in effect (January 1, 1999). Using data collected by the Northeast Fisheries Observer Program (NEFOP), the patterns in the harbor porpoise bycatch are described, the levels of compliance to the TRP mitigation measures are documented, and predicted effects of potential additional mitigation measures are evaluated. In addition, the bycatch patterns are related to gear characteristics, fishing practices and environmental factors to aid in explaining the patterns in the bycatch and to suggest potential management measures to reduce the harbor porpoise bycatch in this area.

DATA

The variables collected by the NEFOP that were used in these investigations are described in Appendix 1. In addition, to these variables for the data collected during 1999 to 2006, a variety of environmental variables which are associated with the location and date of the haul were added (Appendix 1).

The observer data used in this investigation were only hauls that have complete latitude-longitude information. Thus, this restriction eliminated some hauls that were used in other analyses (e.g., bycatch estimates), and so the statistics may not match exactly to other analyses.

Data from 2007, which include only data collected during January 1 to May 31, are still preliminary and so have not been processed as completely as the older data.

GENERAL BYCATCH PATTERNS

In the waters south of Cape Cod during January 1999 to May 2007, harbor porpoise bycatch was observed only in the months of December to May (Figure 1), the time period corresponding to the TRP mitigation measures for this area. Thus, the rest of this investigation will concentrate only on the time period January to May during the years 1999 to 2007, and December during 1999 to 2006. Only bycatch of harbor porpoises are explored in this investigation.

In this time/area, there were 2831 hauls observed, which were from 659 trips and 312 vessels, of which this was 132 unique vessels. This was 123 to 450 hauls observed per year, which were from 32 to 124 trips per year, and from 15 to 69 vessels per year (Table 1). The distribution of observed hauls each year appears to be fairly evenly distributed (Figure 2).

Bycatch rates increased over the years, where the bycatch rate from Jan to May 2007 was the highest (Table 1). Harbor porpoise were taken inside and outside of the Cape Cod South Area in a variety of years (Figure 3). Of the 2831 hauls observed in this time-area, 2761 hauls did not have any harbor porpoise bycatch, 57 hauls had 1 take, 9 hauls had 2 takes, and 4 hauls had 3

harbor porpoise takes. Hauls that took more than one harbor porpoise appear to be slightly more concentrated in or near the Cape Cod South Area (Figure 4). The bycatch rates were highest in February to May and lowest in December (Table 2).

The bycatch rate of hauls outside the Cape Cod South Area (which were not required to use pingers) was about 50% greater than the bycatch rate of hauls within the Cape Cod South Area (which were required to use pingers): 0.102 versus 0.066 takes/mton (Table 3).

Regardless of whether the haul was from inside or outside of the Closure Area, the bycatch rate of hauls that used pingers (1055 hauls) was about half that of hauls that did not use pingers (1776 hauls): 0.053 versus 0.098 takes/mton (Table 3).

The bycatch rates (number of observed takes/observed landings) for many variables are in Table 3. Close examination of these tables could suggest potential mitigation measures to reduce the bycatch. Some of the values of variables with high bycatch rates include: hauls without pingers, hauls outside of the Cape Cod South Closure Area, the year (January to May plus December) of 2006 and January to May 2007, the months of February and April, hauls that targeted monkfish and winter skate, hauls in waters that were 50-100 fathoms deep, hauls in waters that had a surface water temperature of 4-6ºC and a bottom water temperature of 4-8ºC, hauls that have a long soak duration (greater than 200 hours), used long strings (greater than 4000 ft), had a hang ratio of 0.5, used mesh sizes of 10-12 inches, had net heights of 10-15 feet where the lead line depth was 25-50 fathoms deep (net may not be touching the bottom), hauls that used additional weights, hauls conducted in times with small or large North Atlantic Oscillation (NAO) values, hauls that were 5-10 hours steam time from the temporary home port, and hauls that used the limited observer procedure (that is, observer concentrated on the net while being hauled in, instead of concentrated on recording catch statistics).

COMPLIANCE

For the Cape Cod South Area, the TRP regulations stated that from March 1-31 the Area is closed to all gillnets, and during December 1 to February 28/29 and April 1 to May 31, the Area is closed to gillnets unless pingers are on the gillnets. An operating and functional pinger must be attached at the end of each string of the gillnets and at the bridle of each net within a string of nets. Thus, if a string has 10 nets then 11 pingers are required (Federal Register 1998).

During 1999 to 2007, of the 2831 hauls observed in the area (of which 1665 hauls were inside the Cape Cod South area), there were only 3 observed hauls (from 1 trip) that were inside the Cape Cod South area during March (the closed month). The log states the nets were set on March 1 and hauled in on March 4, 2007. The locations of these hauls were very close to the southern border of the Cape Cod South Area. These three strings were each 20 nets long, had 20 pingers/string (1 short of the regulation number), and no harbor porpoise bycatch.

In the Cape Cod South Area during January, February, April, May, and December (the months pingers are required), about 40% (657 hauls) of the observed hauls did not use any pingers. These 657 observed hauls were from 185 trips from 53 different vessels, which were from MA, NY, and RI. These 657 hauls took 13 harbor porpoises in 12 hauls, 8 trips and 7 vessels during

2003 (1 haul), 2004 (4 hauls), 2006 (4 hauls), and 2007 (3 hauls). These 12 hauls with harbor porpoise takes were in January (2 hauls), April (1 haul), May (8 hauls), and December (1 haul).

In contrast, there were 47 hauls (13 trips and 8 vessels) that were outside of the Cape Cod South area that used pingers, even though they were not required. These hauls had no harbor porpoise takes. These hauls were from various years: 1 haul in 2001, 3 in 2002, 27 in 2003, 7 in 2005, and 9 in 2007.

Of the 1665 observed hauls in the Cape Cod South area during the time period pingers should have been used, 47% used 90% or more of the required pingers, an additional 40% did not use any pingers, while the remaining 13% used some pingers but less than 90% of the required amount.

BYCATCH RATES AS RELATED TO OTHER FACTORS

To suggest other possible mitigation actions to reduce the bycatch in this time-area, the following is an investigation into which gear characteristics, fishing practices, and environmental factors were most highly correlated to the bycatch rate. Fishing and environmental factors were regressed against the bycatch rate using generalized additive models (if the factor is continuous) and using generalized linear models (if the factor is categorical), assuming a quasi Poisson distribution[1]. The bycatch rate was defined as total observed takes per total observed landings, where landings were measured as metric tons[2] + 0.001[3]. Generalized additive models allow a non-linear relationship between the factor and the bycatch rate, if the data support a non-linear relationship. See Orphanides' manuscript on the bycatch estimates for more details on this type of regression bycatch estimation method and the observer data. A forward stepwise selection method was employed, using the Akaike Information Criterion (AIC) as the selection criterion. That is, a model with a lower AIC fits the data better than a model with a larger AIC. The forward stepwise selection method is as follows: first, all variables were individually regressed against the bycatch rate. The variable most highly significant was then identified and added to the model to create a 1-variable model. Then all other variables were individually added to the 1-variable bycatch rate model to identify the next most significant variable. This variable was then added to the model to create a 2-variable model. The final model is the model resulting from the stepwise selection method that could not be improved further, that is the AIC did not decrease by at least 2%.

The model that best predicted the bycatch rate included the following variables (in order of importance): amount of steam time, day of the year, twine size, and temporary home state (Table 4). The values of each variable that are most highly correlated to the bycatch rate are values of

[1] A Poisson distribution is used because the numbers of observed takes are counts ranging from 1 to 3. A quasi distribution is used to properly account for dispersion, if it is needed. The Poisson distribution assumes the variance of the bycatch is equal to the mean of the bycatch. If the variance is greater than the mean, then the data are called over-dispersed. The quasi distribution calculates correct variances of the model parameter estimates, if there is dispersion.

[2] Metric tons of landings is the only variable that is available that can be used as a unit of effort for gillnet fisheries. See separate paper on this topic for more details.

[3] Add 0.001 metric tons of landings to landings recorded for each haul to insure the amount of landings for each haul is greater than zero.

the variable (x-axis) that have a y-axis value greater than zero, that is, above the red line (Figure 5).

A description and discussion about the variables follows.

The steam time variable was the most highly correlated with the bycatch rate. This variable appears to indicate that some areas have higher bycatch rates than other areas. The range of steam times that had the highest bycatch rates was 4.6 to 9.4 hours (Figure 5). Mapping the observer data by steam time indicates the area with the highest bycatch rate (area with steam times of 4.6 to 9.4 hours) is the area south of the Cape Cod South Area, from the southern boundary of the Closure Area south to about the 40º W latitude line (Figure 6).

The second most highly correlated variable was day of the year. The bycatch was highest in February through April (Figure 5), as was mentioned above (Table 2).

The next variable added to the model was twine size. Twine sizes less than 0.5 mm had the highest bycatch rate (Figure 5 and Table 3). There were 9 observed hauls that used 0.33 twine size, of which five of the hauls had a total of 11 incidentally taken harbor porpoises. These five hauls were from the same trip that targeted monkfish using long strings (6000 feet long) that soaked for a long time (72 or 144 hours/string). Using small twine sizes when targeting monkfish is not typical; about 1.5% of the observed hauls that targeted monkfish used twine sizes less than 0.57mm. Three of the 5 hauls with takes were inside the Cape Cod South Closure Area and used 20 nets and 19 pingers. The other two hauls with takes were outside of the Closure Area and did not use pingers. In conclusion these 5 strings with bycatch are probably not typical fishing gear used to target monkfish and also have several characteristics that were related to high bycatch (twine size, string length, and soak duration). Thus, it is not obvious that twine size is the only driving factor for this high bycatch.

The last variable added to the model was temporary home state (Table 3 and Figure 5). By mapping out the location of the hauls by their home state (Figure 7), it appears that this variable is refining the definition of the areas with high bycatch. For example, within the area of steam times of 4.6 to 9.4 hours (Figure 6), the highest bycatch rates are by vessels from New York (Table 5), which were west of 71º 30N (Figure 8 in pink circle), and the bycatch rates of vessels from Massachusetts are slightly lower (though still over the average level) and are located east of the 71º N longitude line (Figure 8 in black circle).

In conclusion, this bycatch rate model identified several relevant issues related to high bycatch that could be considered in future mitigation measures. One consideration is, when targeting monkfish (mesh sizes greater or equal to 10 stretched inches), follow the normal practice; that is, use twine sizes greater than or equal to 0.57 mm, since the bycatch rate for twine sizes of 0.33 was extremely high. A second consideration is to continue to use the present time/area closures and pinger time periods, since the highest bycatch is still in February through April. A third consideration is increase the region where pingers are required to include the areas of high bycatch outside the Cape Cod South Closure Area, that is, the area from the southern boundary of the Closure Area to the 40º W latitude line and to the 70º N longitude line.

REFERENCE

Federal Register 1998. Taking of Marine Mammals incidental to commercial fishing operations: Harbor porpoise take reduction plan regulations. Vol. 63, No 231 pg 66464-66490.

Appendix 1. Variables used in the bycatch rate model.

Variable Name	Description
LOCATION/TIME VARIABLES	
Day of year	Day of year: 1 = Jan. 1 for each year
Year	Year: 1999 to 2007
Month	Month: January to April
Longitude	Longitude
Latitude	Latitude
Steam time	Time spent steaming to fishing grounds from port
Bottom depth	Bottom depth (fathoms)
Distance to 50m	Distance to the 50 m depth contour
Distance to 100m	Distance to the 100 m depth contour
Distance to 200m	Distance to the 200 m depth contour
Distance to 500m	Distance to the 500 m depth contour
Distance to the coast	Distance to the nearest coastline (m)
N. Atlantic Oscillation	N. Atlantic Oscillation (NAO) monthly value
NAO - 1	NAO value including a 1 year lag
NAO - 2	NAO value including a 2 years lag
Winter NAO	Winter NAO monthly value
Winter NAO - 1	Winter NAO monthly value with 1 year lag
Winter NAO - 2	Winter NAO monthly value with 2 years lag
SST	Sea surface temperature (celcius)
Bottom water temperature	Bottom water temperature (celcius)
Bottom slope	Bottom slope
Chlorophyll	Chlorophyll level (from satellite)
log10(Chlorophyll)	log10(Chlorophyll level) (from satellite)
Sediment	Type of bottom sediment
FISHING PRACTICES	
Soak duration	Time net in the water (hrs)
Target species	Species captain said they were trying to get
Temporary home port	Temporary home port
Vessel gross tonnage	Vessel gross tonnage
Vessel length	Length of fishing vessel
Haul duration	Length of time of haul back (hrs)
Days absent	Number of days absent from a port
State landed	State that catch were landed in
Weather	Weather conditions
Wave height	Wave height

Appendix 1. continued. Variables investigated for the bycatch rate model.

Variable Name	Description
GEAR CHARACTERISTICS	
Twine size	Size of the twine (mm)
Mesh count	Number of meshs in the vertical direction of the net
Gear length	Total length of gear and spaces between nets
Net height	Height of net
Average mesh size	Average mesh size (inches)
Hang ratio	Hang ratio
Number of nets set	Number of nets that were set
Number of nets hauled	Number of nets that were hauled back
Used tie downs?	Were tie downs used: yes, no, unknown
Length tie downs	Length of tie downs
Used anchors?	Were anchors used: yes, no, unknown
Number of anchors	Number of anchors used on the string
Type of anchor	Type of anchor used
Anchor weight	Total weight of anchors (pounds)
Used additional weights?	Were additional weights used: yes, no, unknown
Additional weights	Amount of additional weights used (pounds)
Used droplines?	Were droplines used: yes, no, unknown
Lead line depth	Depth the lead line of the net is at (fathoms)
Weight of lead line	Total weight of the lead line
Used spaces?	Were spaces between the nets: yes, no, unknown
Space width	Width of spaces between nets
Number of spaces	Number of spaces between nets
Color of net	Color of net
Float distance	Distance between floats
Total number of floats	Total number of floats
OBSERVER PRACTICE	
Type of trip	Observer protocol: complete, limited

Table 1. Descriptive statistics about the bycatch of harbor porpoises in waters south of Cape Cod during January to May 1999 to 2007, and December 1999 to 2006.

	Year									Total
	1999	2000	2001	2002	2003	2004	2005	2006	2007*	
Number of observed hauls	292	346	123	157	145	499	369	450	450	2831
Number of observed trips	56	70	32	46	32	99	78	122	124	659
Number of observed vessels	17	15	16	15	22	53	39	69	66	312
Number of observed hauls with one or more take	1	5	0	2	3	12	11	13	23	70
Total number of observed takes	1	5	0	3	3	13	12	18	32	87
Bycatch rate (observed total takes/observed number of hauls)	0.003	0.015	0	0.019	0.021	0.026	0.033	0.040	0.071	0.031
Bycatch rate (observed total takes/observed mt of landings)	0.028	0.092	0	0.081	0.046	0.058	0.095	0.119	0.124	0.089

* 2007 data are from 01 January to 31 May; other years include data from January to May and December.

Table 2. By month, the number of observed hauls and takes and resulting bycatch rates using data from January to May 1999 to 2007 and December 1999 to 2006.

	Month					
	Jan	Feb	Mar	Apr	May	Dec*
Number of observed hauls	257	290	158	573	1191	362
Number of observed takes	3	17	7	34	25	1
Bycatch rate (obs takes/obs hauls)	0.012	0.059	0.044	0.059	0.021	0.003
Bycatch rate (obs takes/obs mt of landing)	0.044	0.160	0.065	0.145	0.068	0.011

* 2007 data are from 01 January to 31 May; other years include data from January to May and December.

Table 3. Bycatch rates (Byc Rate) and number of observed hauls (Num Obs) with various gear characteristics, fishing practices and environmental factors. The bycatch rate is defined as observed number of takes per the observed landings (in mtons). The overall average bycatch rate is 0.089 takes/mtons. Categories of variables with * in the Num Obs column have less than 11 mtons of landings (thus, there is a small chance of observing one take given the overall bycatch rate). Bycatch rates that are greater than 0.1 takes/mtons are highlighted. Data used was January to May 1999 to 2007 and December 1999 to 2006.

Categories	*Num Obs*	*Byc Rate*
LENGTH OF TIE DOWN (feet)		
0-2	254	0.047
2-4	2071	0.093
4-6	129	0.096
6-10	21*	0.000
NUMBER OF ANCHORS		
1	8*	0.000
2	2082	0.083
4	30	0.000
VESSEL GROSS TONNAGE		
0-20	458	0.082
20-40	343	0.157
40-60	63	0.000
60-80	34	0.000
80-140	30	0.428
AMT FISH DISCARDED		
0-500	884	0.048
500-1000	55	0.082
1000-5000	27	0.054
SEDIMENT TYPE		
cl-st/sd	545	0.089
gr-sd	194	0.000
sd	1441	0.057
sd-cl/st	191	0.119
sd/st/cl	10*	0.200
Winter N. Atlantic Ossilation		
-0.4 to 0	671	0.088
0 - 0.2	110	0.072
0.2 - 0.4	972	0.073
0.4 - 0.6	248	0.033
0.6 - 1.2	380	0.085
USED PINGERS?		
yes	1055	0.053
no	1776	0.098

Categories	*Num Obs*	*Byc Rate*
NET HEIGHT (feet)		
0-5	97	0.000
5-10	759	0.068
10-15	1353	0.108
15-25	37*	0.000
NUMBER OF SPACES		
0-5	348	0.108
5-10	657	0.106
10-15	458	0.075
15-20	161	0.104
20-25	38	0.032
25-40	23	0.209
ANCHOR WEIGHT (pounds)		
0-50	1441	0.087
50-100	870	0.105
100-150	314	0.036
150-200	147	0.152
200-350	33	0.000
MTONS LANDED		
0-1	2625	0.106
1-2	138	0.058
2-3	27	0.046
3-4	5	0.114
4-7	7	0.000
N. Atlantic Ossilation		
-2.0 to -1.5	19*	0.227
-1.5 to -1	431	0.091
-1 to -0.5	204	0.000
-0.5 to 0	518	0.081
0.0 - 0.5	361	0.054
0.5 - 1.0	200	0.022
1.0 - 1.5	385	0.123
1.5 - 2.0	263	0.000

Categories	*Num Obs*	*Byc Rate*
USED ANCHORS		
no	14*	0.000
yes	2817	0.089
USED ADDED WEIGHTS		
no	2077	0.086
yes	116	0.300
unk	637	0.067
ANCHOR WEIGHT TYPE		
unk	25*	0.000
Danforth-styl	507	0.066
Dead Weight	2298	0.095
LEAD LINE DEPTH		
0-25	985	0.028
25-50	557	0.167
50-75	392	0.073
75-100	109	0.018
100-200	83	0.000
AMT OF CHLOROPHYLL		
0 - 1	477	0.094
1 - 2	688	0.050
2 - 3	328	0.100
3 - 12	132	0.075
LOG10(AMT OF CHLOROPHYLL)		
-0.6 to -0.2	171	0.069
-0.2 to 0	306	0.113
0.0 - 0.2	430	0.062
0.2 - 0.4	459	0.068
0.4 - 0.6	216	0.056
0.6 - 1.2	43*	0.000
IN CLOSURE AREA?		
yes	1665	0.066
no	1166	0.102

Categories	Num Obs	Byc Rate		Categories	Num Obs	Byc Rate		Categories	Num Obs	Byc Rate
MONTH				**TARGET SPECIES**				**TOT LENGTH OF STRING (feet)**		
Jan	257	0.044		Monkfish	2107	0.097		0-2000	517	0.047
Feb	290	0.160		Bluefish	8*	0.000		2000-4000	1224	0.060
Mar	158	0.065		Atl. Cod	170	0.000		4000-6000	805	0.122
Apr	573	0.145		Wint. Flounder	55*	0.000		6000-8000	206	0.071
May	1191	0.068		Sum. Flounder	275	0.000		8000-14000	60	0.081
Dec	362	0.010		Unk. Flounder	5*	0.000				
				Pollock	17*	0.000		**HANG RATIO**		
YEAR				Scup	18*	0.000		<0.33	59	0.000
1999	292	0.028		Bl. Sea Bass	2*	0.000		0.33	421	0.093
2000	346	0.092		Weakfish	5*	0.000		0.5	2247	0.093
2001	123	0.000		Spiny Dogfish	23*	0.000		>0.5	6*	0.000
2002	157	0.081		Unk. Skate	16	0.000				
2003	145	0.046		Wint. Skate	91	0.087		**TWINE SIZE (mm)**		
2004	499	0.058		Striped Bass	1*	0.000		0.28	17	0.000
2005	369	0.095		Tautog	21*	0.000		0.33	9*	2.474
2006	450	0.119		Unk. Groundfis	15*	0.000		0.40	1*	0.000
2007	450	0.123		Unk. Fish	2*	0.000		0.45	5*	0.000
								0.47	15*	0.000
TYPE OF TRIP				**SURFACE WATER TEMP (degC)**				0.52	43*	0.000
FISH	1014	0.050		2-4	8*	0.000		0.57	173	0.018
MM (limited)	1815	0.118		4-6	477	0.126		0.62	330	0.000
				6-8	511	0.09		0.66	154	0.044
WIND SPEED (knots)				8-10	641	0.087		0.70	149	0.000
0-10	1411	0.104		10-12	524	0.031		0.74	22*	0.106
10-20	933	0.092		12-14	194	0.000		0.81	186	0.047
20-40	174	0.000		14-16	25*	0.000		0.9	1440	0.083
								1.05	12	0.000
STEAM TIME (hrs)				**BOTTOM WATER TEMP (degC)**				unk	270	0.149
0-5	1727	0.032		2-4	170	0.068				
5-10	624	0.200		4-6	547	0.182		**MESH SIZE (inches)**		
10-15	415	0.015		6-8	754	0.102		4-6	53*	0.000
15-40	57	0.096		8-10	389	0.035		6-8	551	0.000
				10-12	483	0.034		8-10	34	0.000
				12-14	20	0.000		10-12	2118	0.097
WAVE HEIGHT (feet)								12-14	71	0.000
0-2	1127	0.120		**BOTTOM SLOPE**						
2-4	1022	0.086		0-1	2263	0.082		**USED TIE DOWNS**		
4-6	316	0.047		1-2	77	0.023		no	320	0.000
6-8	95	0.072		2-4	25	0.049		yes	2499	0.094
8-10	46	0.000		4-8	16*	0.000		unk	12*	0.000
DEPTH (fathoms)				**SOAK DURATION (hrs)**				**USED SPACES**		
0-50	1794	0.080		0-100	1971	0.074		no	1121	0.080
50-100	544	0.141		100-200	723	0.095		yes	1699	0.099
100-150	336	0.044		200-300	112	0.154		unk	11	0.000
150-200	91	0.016		300-500	18*	0.214				
200-350	54	0.000						**USED DROP LINES**		
								no	2188	0.091
								yes	5*	0.000
								unk	637	0.067

Table 4. Stepwise models used to develop the bycatch rate model. Model 1 was the null model, model 2 uses steam time to predict the bycatch rate, model 3 uses steam time and day of the year to predict the bycatch rate, etc. The last column is the difference in the AIC from the line above; the larger the difference the more that variable contributed to explaining the bycatch rate patterns.

Model number	Variable	AIC	Diff from above
1	None	631.2	00.0
2	Steam time	579.3	51.9
3	Day of the year	543.1	36.2
4	Twine size	519.1	24.0
5	Temp Home State	500.2	18.9

Figure 1. Location of observed hauls without takes (small dot) and those with takes (colored circles), where the month the take was from is identified. Data are from January to May 1999 to 2007, and December 1999 to 2006.

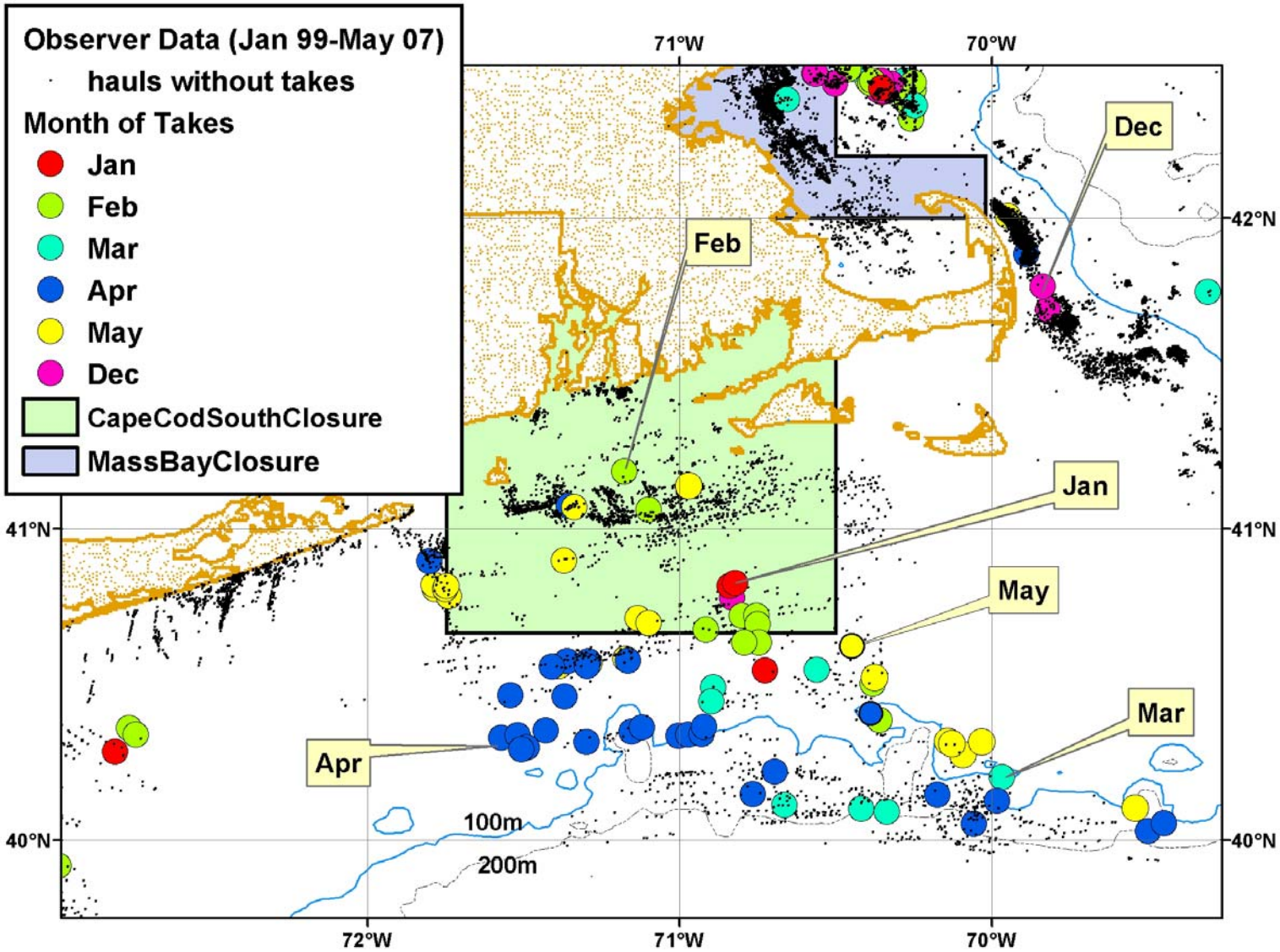

Figure 2. By year, locations of observed hauls (colored circles) during January to May 1999 to 2007, and December 1999 to 2006. The "Cape Cod South Closure" is shaded in yellow and depth contours are 50, 100, 200, and 1000m.

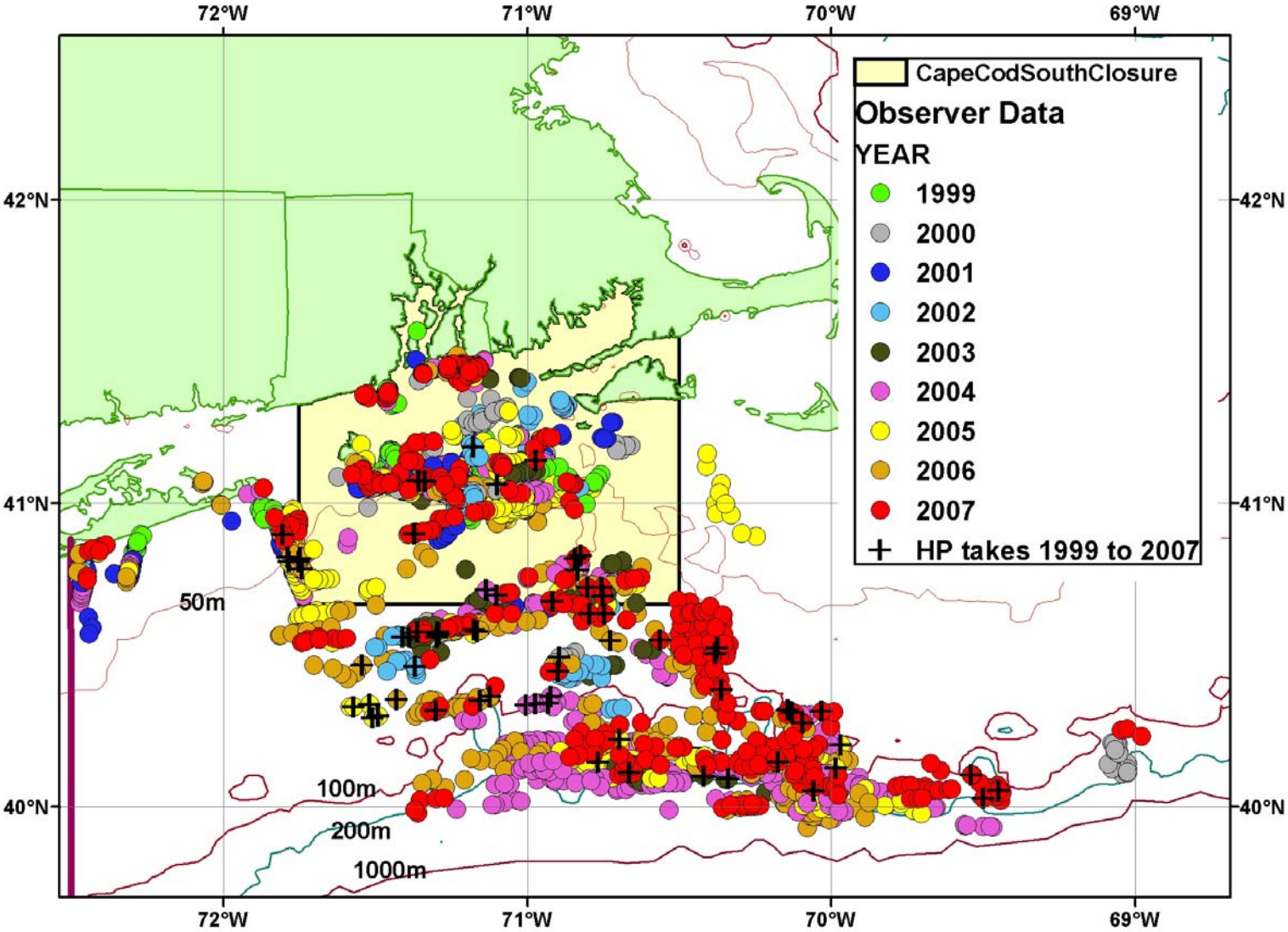

Figure 3. Location of hauls without takes (small dot) and hauls with takes (colored circles) identified to year of the take.

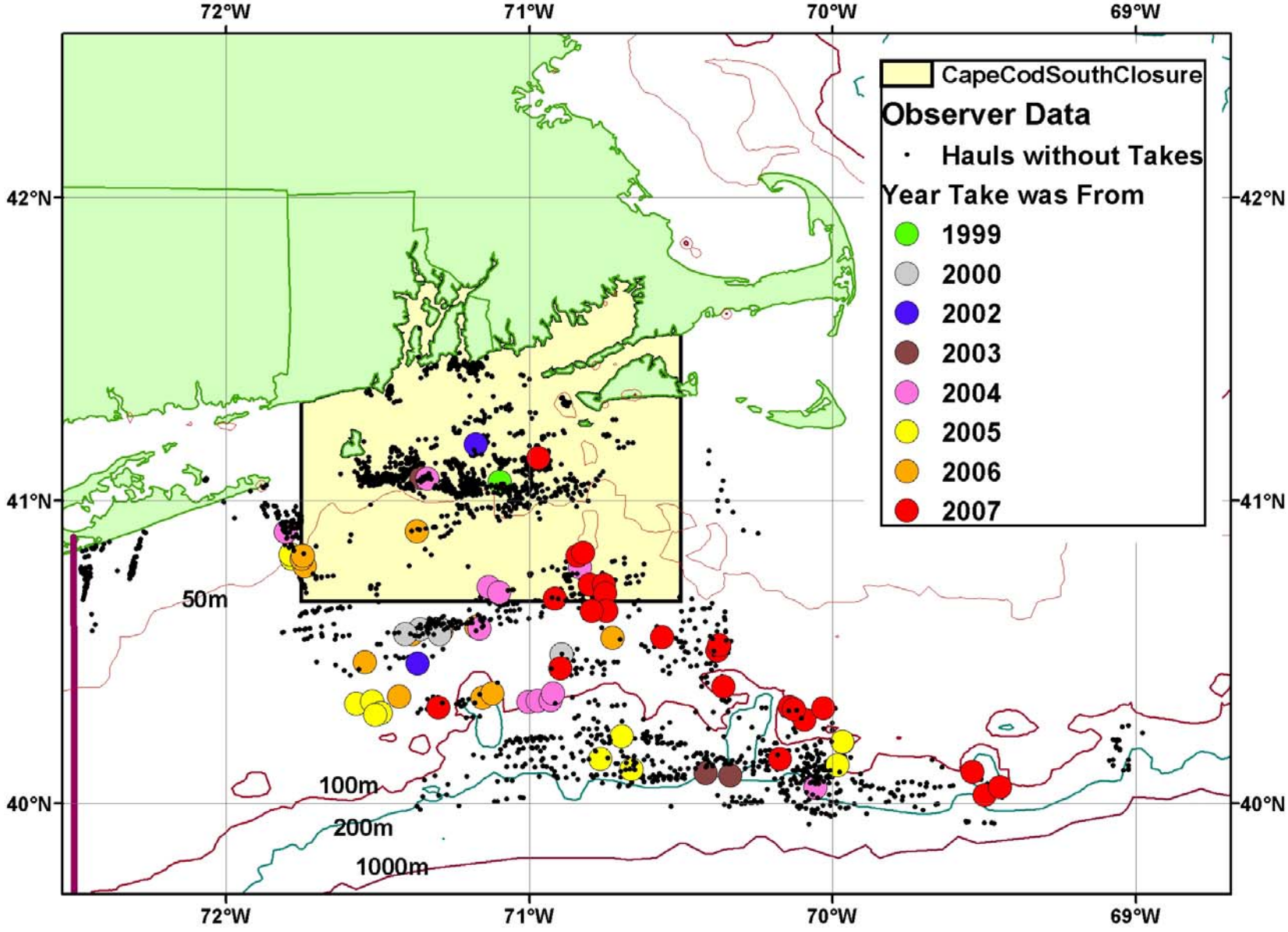

Figure 4. The location of harbor porpoise takes and number of takes per haul (size of stack: dash is no takes, tallest stack is 3 animals per haul).

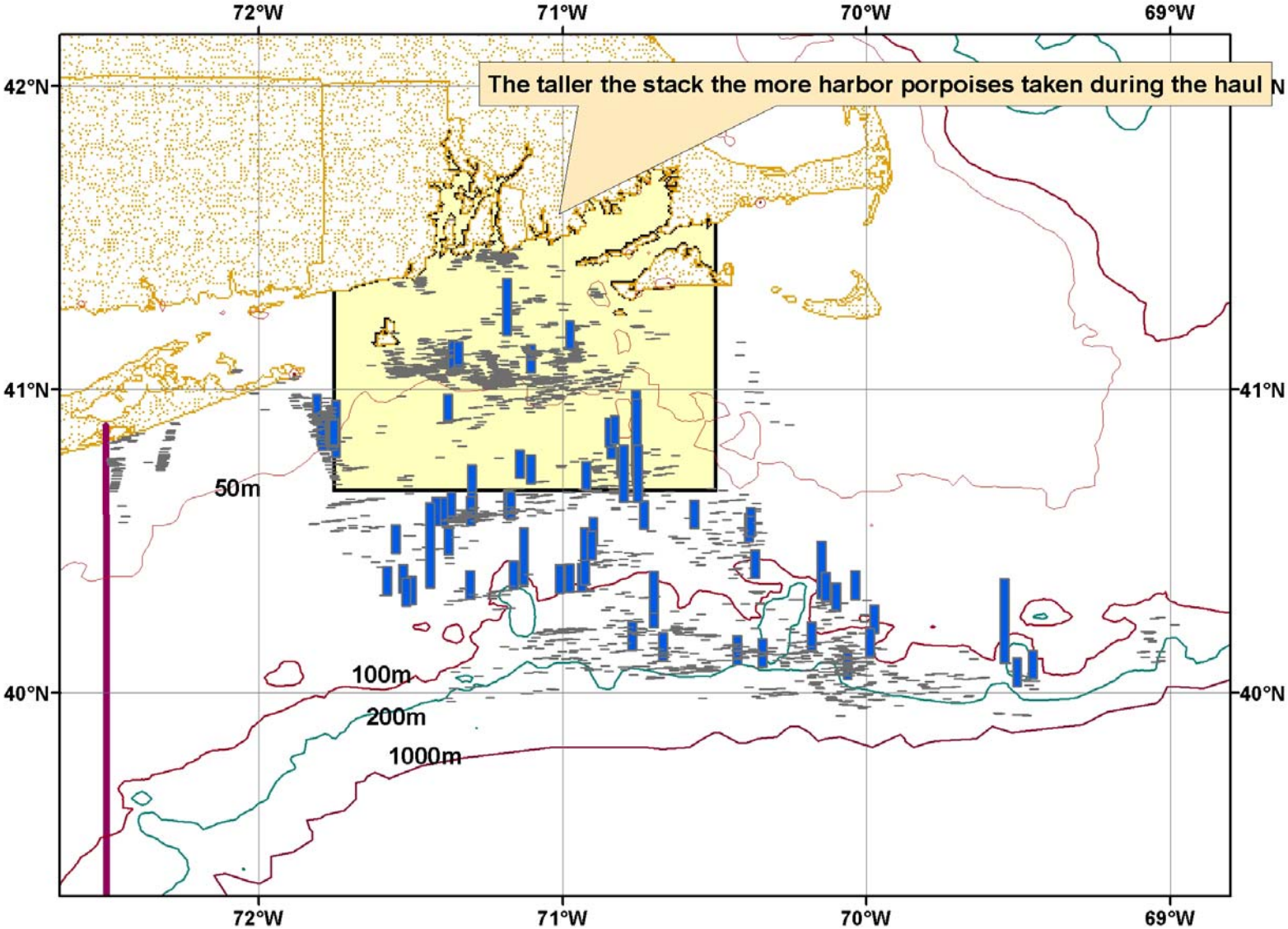

Figure 5. Results of model describing the bycatch rates. There is one plot per variable in the model. Values of the variable that are above the red line have a correlation with higher than average bycatch rates. The tick marks on the bottom of each plot is the location of the observations, which were jittered to break ties.

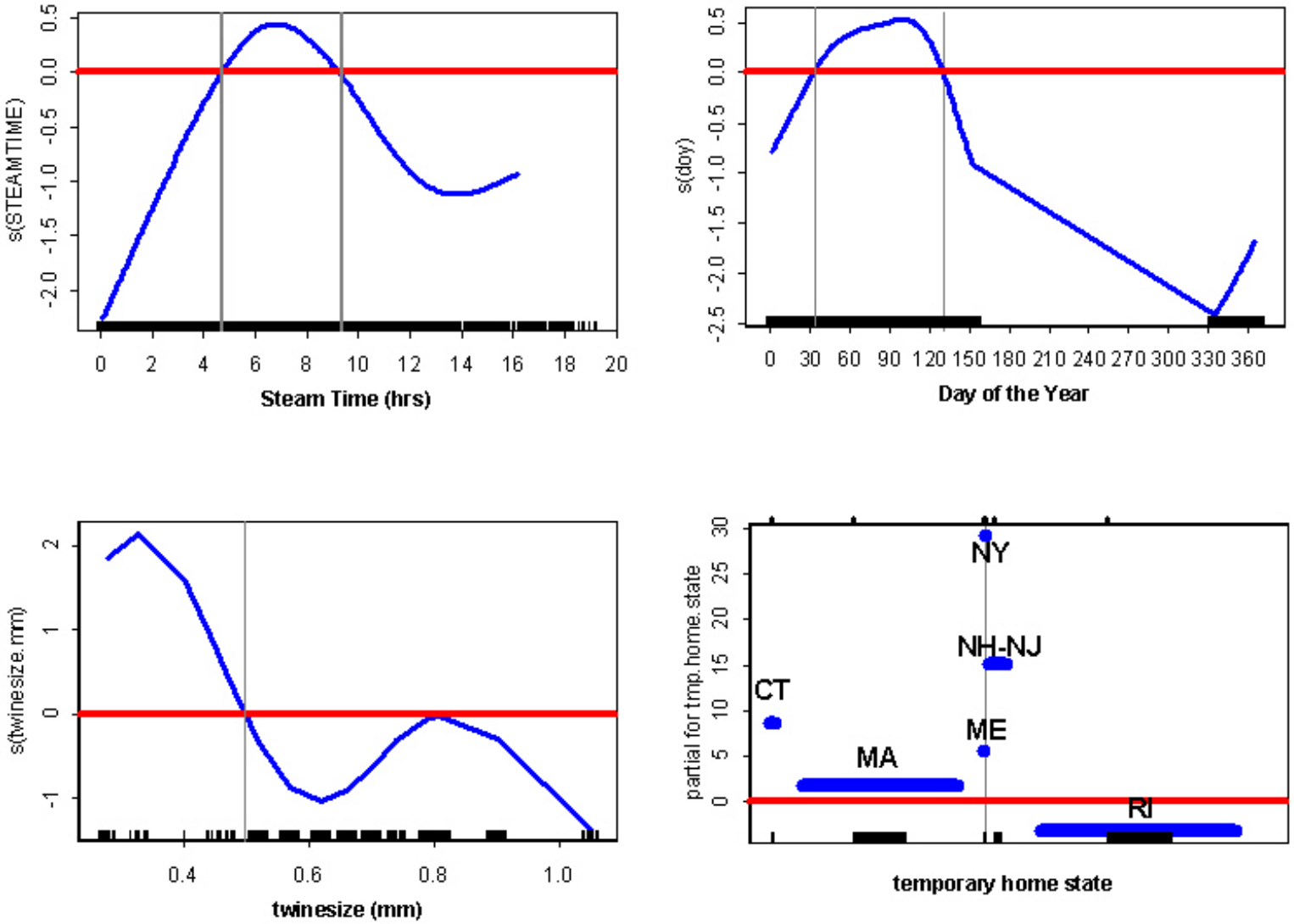

Figure 6. Distribution of hauls by their steam time (in hours) from their port. Hauls with steam times of 4.6 to 9.4 hours (green boxes) had the highest bycatch rate and these hauls are located from the southern boundary of the Closure Area south to about the 40ºW latitude line.

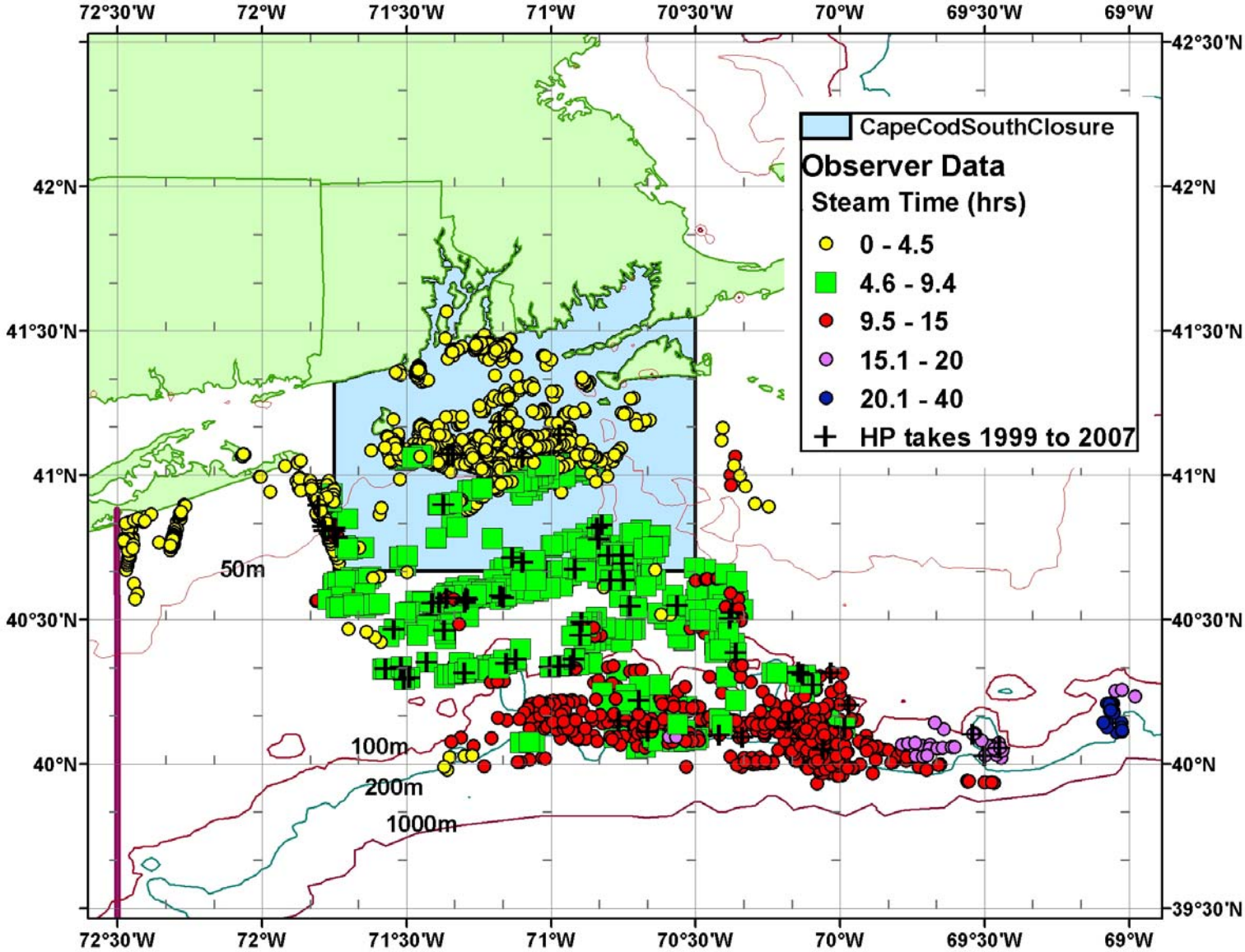

Figure 7. Distribution of hauls by their temporary home state.

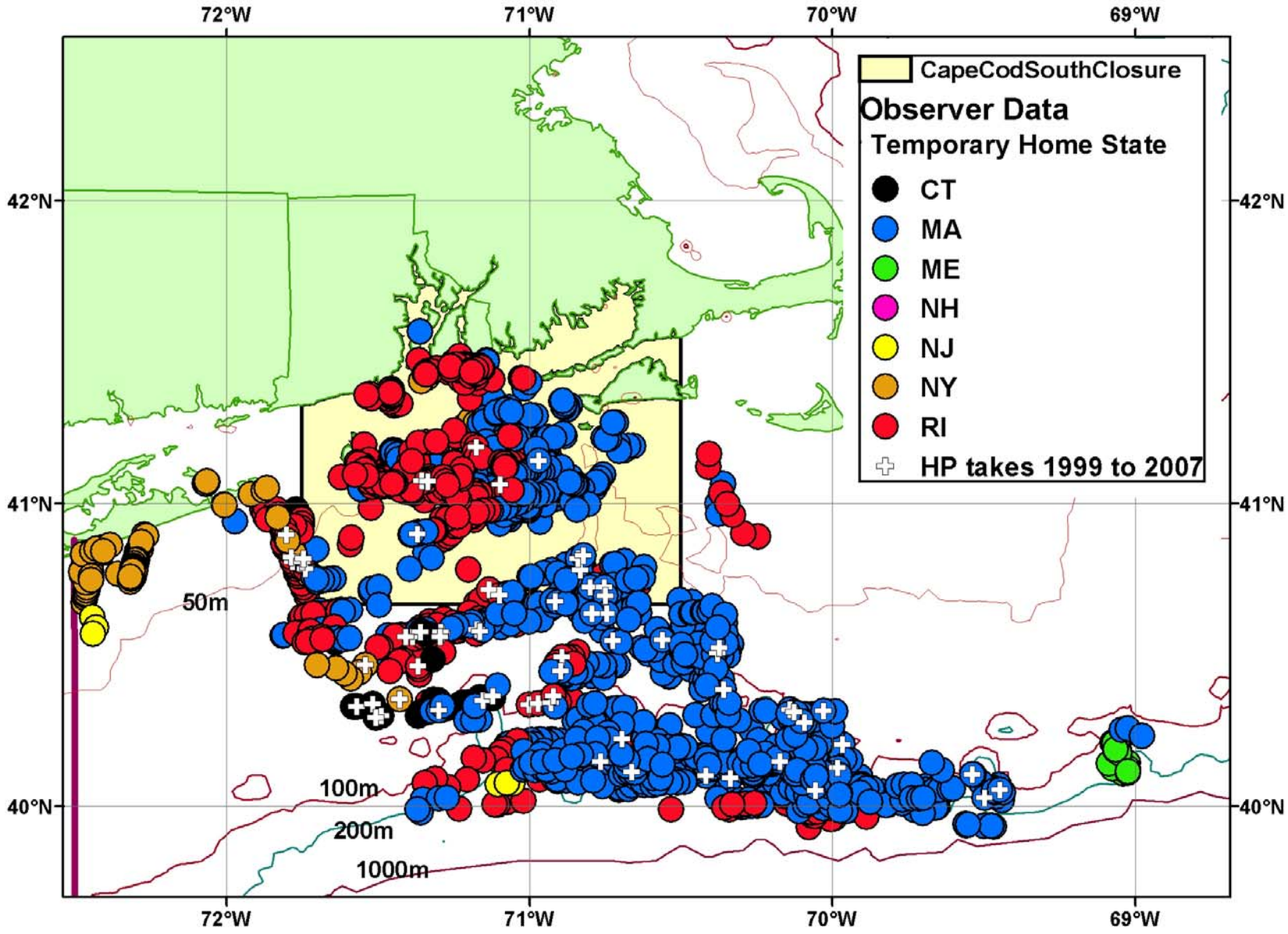
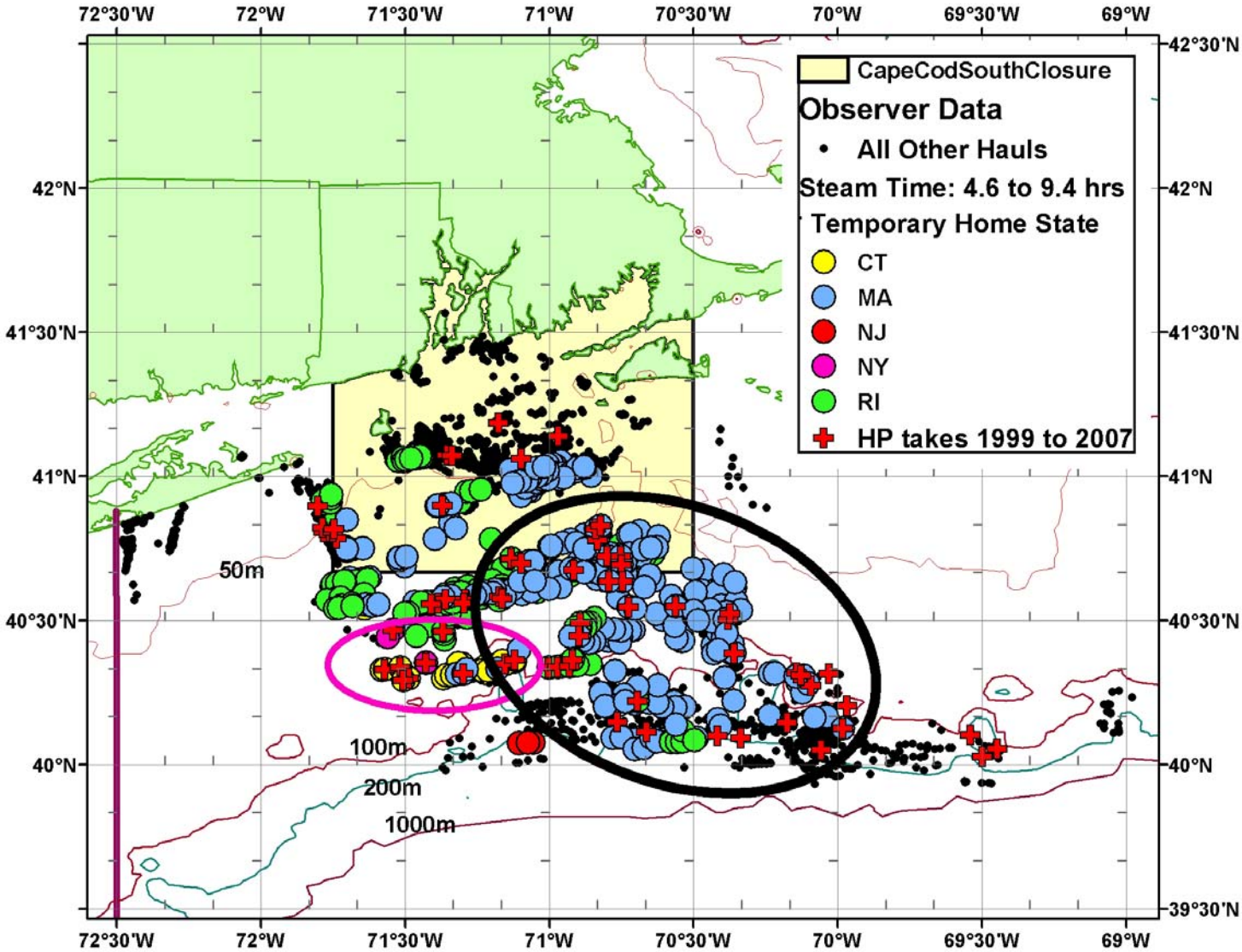
Figure 8. Distribution of hauls by their steam time (in hours) and home state. Hauls with steam times of 4.6 to 9.4 hours (area with highest bycatch rate) divided by home state (defining finer resolution of areas with highest bycatch rates). Area in small pink circle has highest bycatch rate. Area in larger black circle has the next highest bycatch rate.