A multinomial predictive model to incorporate visual surveys of red snapper lengths

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Abstract

This document updates a methodology to incorporate length composition data of red snapper obtained from a series of surveys using ROV and stationary cameras. Data from seven surveys spanning 2005-2016 exist comprising length measurements of 11,953 total fish from artificial and natural reefs primarily offshore of Alabama and Florida. The seven surveys consist of three projects conducted by Will Patterson et al, two by Dauphin Island Sea Lab (DISL), one from FWRI and one from the NMFS Panama City lab. For the Panama City lab data ROV lengths were combined with stationary camera lengths. The FWRI survey only used stationary cameras. Different surveys were then combined within a year in the multinomial regression model. Given the imbalance in the set of samples (not all areas, depths, reef types or seasons are covered in all years) we developed a multinomial regression model to predict the length composition by length bin. The final model selected included year, season, depth bin and reef type (artificial or natural). Lastly the length compositions were converted to age compositions using the static age-length key derived in 2014. We recommend that the actual length data be used directly in the Stock Synthesis modeling rather than converting to age composition data. We recommend that these length composition data be used in models for the Eastern Gulf of Mexico population as fishery-independent size composition information to inform upon cohort structure, weighted initially by the number of samples taken in each year.

Introduction

In the past 12 years several surveys have been initiated that use remotely operated vehicles equipped with a visual means to count and measure fish underwater or stationary cameras. These surveys have the benefit being fishery-independent and relatively non-selective with regards to the fish that they sample, in contrast to more size selective sampling gear such as hook and line, traps, etc. This survey gear is also able to sample high relief reef habitat that is often under- or inefficiently-surveyed by capture-based methods.

For this reason, these surveys provide insight into the ambient size structure of the population and insight into the size and relative abundance of fish on artificial or natural reefs that are often under sampled by other survey gear. Incorporating time series of the length composition from these surveys may be valuable to stock assessments. Furthermore, since many of these surveys explicitly sample artificial reef structure that is often not an explicit part of the sampling frame for many fishery-independent surveys these surveys provide direct information from these structures.

This paper presents an update of a methodology to incorporate length composition data from four surveys into the SEDAR 52 assessment of red snapper. It is an update of methodology used in SEDAR 32 and updates thereof. The initial paper involved an exploration of the information in each survey and an evaluation of the appropriateness of combining the surveys. Next the surveys were combined into a single length composition matrix for each year using a multinomial generalized linear model. Then advice for appropriately weighting the length composition information in stock assessments was obtained by calculating the total number of samples collected each year (not the total number of red snapper) to derive a weighting factor. Then the length compositions were converted to age compositions using an age-length key. The methodology remains the same as in prior assessments however the model was re-fit by including depth as a covariate and adding data from FRWI and more recent years.

Materials and Methods

1. *Data sources*

ROV and stationary camera generated length composition data was available for the years 2005-2016 from four different surveys conducted between three labs, described below. All datasets in each year are shown in Appendix figures 1 and 2.

University of West Florida/University of Florida surveys (Patterson et al. 2009)

These surveys are conducted now out of the University of Florida by Will Patterson

EELAARS- FWC-funded artificial reef research off Pensacola (2005-2010; sites sampled again in fall 2011 and late winter/early spring 2012). The FWC-funded study was conducted in the Escambia East Large Area Artificial Reef Site (EE LAARS). Twenty-seven study reefs (depth range 27-41 m) among three designs were randomly selected from 125 reefs built by the FWC in spring 2003 but not reported to the public (Fig. 1A). Sites were sampled quarterly from fall 2004 through spring 2010 with either a Videoray Pro3 or Pro4 micro ROV fitted with a red laser scale (two lasers positioned 10 cm apart). A point-count method was employed to estimate fish density; assumptions associated with this method and estimating fish length with the laser scale were tested (Patterson et al. 2009). Fish were tagged through 2007 at 9 study reefs, 9 others served as control sites, and the coordinates of a third set of 9 reefs were reported to the public in spring 2007 to test for fishing effects.

FWRIHab- FWRI-funded project in 2009-10 focused on examining differences in reef fish ecology at natural versus artificial reefs off the Florida Panhandle (but sample sites extending into waters off Alabama). The FWRI-funded project in 2009-10 was meant to be a multi-year effort but that was disrupted by the DHOS. Remotely operated vehicle sampling was conducted at 23 natural and 26 artificial reef sites in the northern Gulf of Mexico (Fig. 1B). Sites were haphazardly chosen through consultation with cooperating charterboat captains. Natural reef sites were sampled with transect sampling (see Fig. 2) and artificial reef sites were sampled either with point count or transect sampling. Sites also were fished with hook and line to test hook selectivity and to provide tissue samples for various analyses. Hook selectivity sites were continued in 2013 and 2014.

PostDWOS- Deepwater Horizon Oil Spill (DHOS) sampling of natural reef sites across the same depth and east-west range as the FWRI study. Sixteen natural reef sites were selected from the 2009-10 FWRI-funded study to examine post-DHOS effects of reef fish community and trophic structure (Fig. 1C). These sites have been sampled quarterly with a Videoray Pro4 ROV from fall 2010 to present. Data from this work are provided under the Post DHOS tab in the attached excel file. Artificial reef sites that appear in the data under this tab are eastern and western sites that bracket the EE LAARS reefs we began sampling again in fall 2011 to examine DHOS effects. The post-DWOS work has continued from 2013-2016 on both artificial and natural reefs.

Dauphin Island Sea Lab (DISL) surveys (modified from Patterson et al. 2009)-

This survey is conducted by Dauphin Island Sea Lab/ University of South Alabama under Sean Powers. It consists of ROV surveys of a number of different types of features.

SMALL FEATURES (Pyramids, Tanks, Chicken Coops, Cement Drums, Rock Outcrops)- The ROV is positioned on the bottom within 5 meters of the target feature. The heading, depth, range to target, GPS position and start time of the video are recorded for the feature. Video is shot for two minutes at the designated heading (in degrees, down current) and then flown to the opposite side of the feature for two additional minutes (on the bottom, within 5 meters of the feature). The second heading and range to feature is recorded (~180 degrees from first heading). If the current is strong the ROV is positioned ~90 degrees from the first heading. Finally, the ROV is positioned ~1 meter above the feature for a slow clockwise 360 degree spin and then video is stopped and the stop time is recorded. Total time for video recording is usually between 7-10 minutes. The ROV is equipped with parallel red lasers spaced 3 cm apart and are used to estimate fish lengths.

LARGE FEATURES (Ship Wrecks, Barges, Rock Ridges, Rock Ledges)- The protocol for large features is to fly a transect down the starboard side of the structure recording heading, GPS position, depth, and start time. After reaching the end of the structure the ROV is positioned to fly back on the port side of the structure and recording heading. The ROV is then flown to the center of the feature (~1 meter above) for a slow clockwise 360 degree spin. The video is then stopped and the time is recorded. In cases where the feature is too large to fly the total length (e.g. large natural bottom features) of a transect, the ROV is flown for two minutes along the right side of the feature (a rock ridge for example). During the first transect start time, depth, GPS position, and heading are recorded. The ROV is then moved to the left side of the ridge and flown back for two minutes in the opposite direction of the first transact (heading and stop time are recorded). Total time for video recording is usually between 7-10 minutes. The ROV is equipped with parallel red lasers spaced 3 cm apart and are used to estimate fish lengths.

Panama City NMFS surveys
ROV studies

These surveys are conducted out of the Panama City NMFS lab, originally under the direction of Doug Devries and now Chris Gardner. All Panama City Lab visual data was combined for this analysis. The PC visual data consists of data from and ROV fitted with lasers, and stationary stereo camera and video array lasers. This survey is conducted only on natural reef habitat. Descriptions of the gear follow.

The Panama City NMFS lab first started collecting video and size data of reef fishes using a mini ROV in 2007 in a study entitled "Habitat-linkages, spatial demographics and food web components of the Northeastern Gulf Fisheries Ecosystem" funded by the Northern Gulf Institute. Primary goals were to delineate and quantify hard bottom reef habitats from near shore to the shelf break off the Florida panhandle, and to examine fish community structure, trophic dynamics, demographics, and habitat associations on those habitats. Video data on species composition, abundance, and size structure were collected seasonally (summer, fall, and winter) with an ROV with scaling lasers at each of 9 natural reef sites - 3 each in 3 depth strata (23 m = inshore, 37 m = midshelf , and 49 m = offshore) – located in a cross-shelf transect that had been mapped with multibeam sonar (Figure 1). Sites within a stratum were similar in morphology and relief, and no more than 2 nm apart. Offshore and midshelf reefs were very low relief (~0.5 m max), while inshore reefs were mostly low relief but also had 1-1.5 m ledges. A total of 68 ROV dives were made in Mar, Jun, and Oct 2007; Feb-Mar and Oct-Nov 2008; and Mar, Jun, and Oct 2009. Beginning in 2010 sampling of these sites was reduced to fall only (Dec in 2010, Oct in 2011). Video data on species composition, abundance, and size structure were collected at each site each season from 2-4 strip transects, 25-40m in length. Transect length was restricted by the ROV tether length or was ended when reef habitat ended. Every effort was made to sample portions of the reef not already surveyed in prior transects that day. Additional data on size structure and cryptic and rarer species were gathered using the ROV during a 20-30 min random search following the transect work, and those data were included in the dataset submitted for SEDAR31. Spacing between the ROV lasers was 50 mm.

In 2011 the study was expanded to an area (called 3 by 5's) dominated by much higher (up to 10 m) relief hard bottom habitat about 50-70 km SE of the original low relief sites; those sites are being surveyed twice annually -- fall and late winter/early spring. Red snapper lengths from the high relief area were collected in Feb and Mar of 2011 and Mar of 2012.

Since 2013 the Panama City surveys have consisted only of the stereo video cameras (Table 1).

NMFS stationary camera survey

The Panama City NMFS lab began a video survey in 2005 targeting natural reefs off Panama City and in Apalachee Bay, areas separated by Cape San Blas - an established hydrographic and likely zoogeographic boundary (Zieman and Zieman 1989). Sampling design was systematic through 2009 because of a very limited sample site universe, but was changed to stratified random in 2010 after side scan sonar surveys produced an order of magnitude increase in that universe (Fig. 2). To ensure uniform geographic and bathymetric coverage, 2-stage sampling is used, the first being 5 x 5 min blocks known to contain reef sites, then secondly 2 sites a minimum of 300 m apart are randomly chosen within each selected block. Depth coverage has evolved from ~10-30 m through 2008 to ~10 – 45 m since then (Fig. 3). Sampling is conducted from 1 hr after sunrise until 1 hr before sunset from late May to mid-October.

From 2005 through 2008, visual data were collected using a stationary camera array composed of 4 high definition (HDEF), digital video cameras mounted orthogonally 30 cm above the bottom of an aluminum frame. From 2007 to 2009, parallel lasers (100 mm spacing) mounted above and below each camera were used to estimate the sizes of fish which crossed the field of view perpendicular to the camera. In 2009 and 2010, one of the HDEF cameras was replaced with a stereo imaging system (SIS) consisting of two high resolution black and white still cameras mounted 8 cm apart, one digital video (mpeg) black and white camera, and a computer to automatically control these cameras as well as store the data. The SIS provides images from which fish measurements can be obtained with the Vision Measurement System (VMS) software. Beginning in 2011, a second SIS facing 180º from the other SIS was added, reducing the number of HDEFs to two; both SIS's were also upgraded with HDEF, color mpeg cameras.

Soak time was 30 min the years when only HDEF cameras were used (through 2008) to allow sediment stirred up during camera deployment to dissipate and ensure tapes with an un-occluded view of at least 20 min duration (Gledhill and David 2003), and then 45 min thereafter to allow sufficient time for the hard drive in the SIS to shut down before retrieval. Prior to 2009, tapes of the 4 HDEF cameras were scanned, with the one with the best view of the habitat analyzed in detail. If none was obviously better, one was randomly chosen. In 2009 only the 3 HDEF video cameras were scanned and the one with the best view of the reef was analyzed. Starting in 2010, all 4 cameras - the 2 HDEFs and the 2 SIS MPEGs - were scanned, and again, the one with the best view of the habitat was analyzed. Twenty min of the tape were viewed, beginning when the cloud of sediment disturbed by the landing of the array has dissipated. All fish captured on videotape were identified to the lowest discernable taxon. If the quality of the mpeg video derived from the SIS was less than desirable (a common problem), fish identifications were confirmed on the much higher quality still frames concurrently taken by the SIS.

FWRI ROV surveys

The FWRI reef fish survey was initially conducted on natural reef habitats in an area of the west Florida shelf (WFS) bounded by 26^o and 28^o N latitude and depths from 10 – 110 m, which corresponded to the SEAMAP statistical zones 4 and 5 (Figure 1). The time series for the video survey in these zones starts in 2010 and has already contributed to assessments of reef fish in the GOM, both as an independent index and combined with video surveys carried out by the NMFS Pascagoula and Panama City labs. Starting in 2014, this survey expanded through NFWF funding to include SEAMAP zones 9 and 10, which corresponds to the western edge of the Florida Panhandle. In 2014, the FWRI survey also began incorporating artificial reef habitats into the survey, whereas previous years focused on natural (geologic and biogenic) reef habitats. Finally, in 2016 sampling was further expanded into all SEAMAP statistical zones along the Florida coastline (from 2-10), and area that is bounded in the southern portion by the Florida Keys and Dry Tortugas and extend to the Florida/Alabama border (Figure 1).

Very little is known regarding the fine-scale distribution of reef habitat throughout much of the eastern GOM, and due to anticipated cost and time requirements, mapping the entire WFS survey area was not feasible prior to initiating the WFS reef fish survey. A variety of methods were initially used to target reef habitat throughout the GOM, but from 2010 onward an adaptive strategy where a three-pass acoustic survey was conducted covering an area of 1 nm to the east and west of the pre-selected sampling unit prior to sampling. Acoustic surveys were conducted using an L3- Klein 3900 side scan sonar. If these acoustic surveys produced evidence of reef habitat in a nearby sampling unit, but not in the pre-selected sampling unit, sampling effort was randomly relocated to the nearby sampling unit. Habitats observed via side-scan sonar were classified as geoforms following the NOAA Coastal and Marine Ecological Classification Standards (CMECS 2012) geoform and surface geological component classifications. Geoforms identified via side-scan sonar are coded as categorical variables with 36 potential values; these Geoforms can then be further classified as natural or anthropogenic.

At each sampling station, 1 – 2 stationary underwater camera arrays (SUCAs) were deployed based on the quantity and distribution of identified reef habitat. SUCA deployments and collection and processing of field data followed established NMFS protocols. Each SUCA consisted of a pair of stereo imaging system (SIS) units positioned at an angle of 180º from one another to maximize the total field of view. Each SIS unit consisted of an underwater housing containing a digital camcorder to record video and a pair of stereo cameras to capture still images at a rate of one per second. Each SUCA was baited (generally Atlantic Mackerel) and deployed for thirty minutes to assure that twenty minutes of continuous video and stereo images were recorded. Video data from one SIS per SUCA deployment were processed to quantify the relative abundance of Red Snapper (MaxN, or the maximum number of Red Snapper observed on a single video frame). When video conditions allowed, individual Red Snapper were measured using stereo still images using Vision Measurement System software (VMS) or SeaGIS software; measurements obtained could best be described as fork length (FL). All individual gear deployments were spaced a minimum of 100 m apart.

2. *Determining appropriate weighting factors for length composition data (input sample size) from habitat information.*

We recommend using simply the number of samples taken rather than an area-weighted sample size. Caculating the minimum convex polygon distance results in substantial unsampled area in the assumed area of influence (Figure 2) and still is an ad hoc measure of sample weighting.

3) Statistical modeling.

Given the imbalance in the data and the absence of samples from all years in all areas it was necessary to develop a model to combine data across the set of samples. To do so we employed a statistical modeling approach similar to standardization of CPUE. We developed a multinomial regression model to predict the probabilities associated with each total length category. Total lengths were converted to maximum total length (Max TL= 1.079 *natural total length) and then were partitioned into the following 4 cm size bins: 14 18 22 26 30 34 38 42 46 50 54 58 62 66 70 74 78 82 86 90 94 98 102. As only 13 fish existed for sizes above 106 cm we removed these fish from the modeling as they created very sparse size bins with almost always zero fish, which lead the modeling to fail to converge. Given that different sources of data had different sampling methodology, different platforms and other unquantifiable differences we included a model factor related to the source of the data.

The multinomial regression model was run with the R function multinom() from the neural network (nnet) library for R (Ripley 2012, http://www.stats.ox.ac.uk/pub/MASS4).

The following initial model factors considered were:

TLcat ~ YEAR +SEASON + Reef.type + depth bin + source

Where: YEAR = 2005, 2006, 2007, 2008, 2009, 2010,2011, 2012, 2013, 2014, 2015, 2016
SEASON = 1 (Jan-April, 2 (May-Aug), 3 (Sept-Dec)
Reef.type = “natural”, “artificial”
Depth bin= 0, 20, 30, 40, 50, 60, 130 meters
Source= FWRI, DISL, NMFSPC, UF-Patterson

We used the stepAIC() function in R to conduct stepwise model selection to choose the best-fitting model on the basis of Akaike’s Information Criterion. On the basis of AIC, the best-fitting model was:

TLcat ~ YEAR +SEASON+ Reef.type + depth bin + source

A factor related to longitude: Longitude Bin = (-89,-85.3] (-85.3,-83] was explored but due to the small numbers of fish in the Eastern bin this factor could not be reliably estimated. Model coefficients and standard errors are shown in Tables 2 and 3.

4) Converting length composition to age composition.

Estimated length compositions were converted to age composition using an age-length key derived from all gears and all years of age data combined for the Eastern Gulf of Mexico, updated through 2016. This ALK did not have any age-0 fish so the fish below the minimum size bin (24 cm) seen in the ROV survey were not converted to age, which presumably would be age-0. In each year, between 1 and 5.5% of the ROV length compositions were less than or equal to 24 inches.

Results

Similar to SEDAR31AW08, the survey information was pooled across surveys by year and compared between reef types (artificial or natural). In a previous analysis no clear differences were observed between survey and reef type (Walter et al 2013). However to preserve the potential for differences in length composition by reef type, this factor was retained for the multinomial modeling. The final model had **year, reef type, season, depth** and **source** as factors.

Model predicted size differed by season, depth and over time with an expansion of the size composition over time (Figure 3). There was a slight difference in predicted sizes by reef type with no clear difference in either larger or smaller fish in artificial versus natural reefs (Figure 3). The model predicted length compositions differ from the input for years 2005 and 2006, largely due to these years having very few samples in only a few locations. In other years the imbalance across depths is handled by the models (Figure 4).

Annual age compositions over time (Figure 5) indicate an expansion of the age composition over time, likely as a result of reductions in fishing mortality. Indeed the implied Z obtained from longitudinal catch curves for cohorts assumed born in years 2005-2012 indicate that there has been a substantial decrease in total mortality, likely a result of strict catch restrictions (Figure 6).

Annual weights for samples

Given that the calculation of total habitat area covered by the surveys required an assumption of the total area occupied by red snapper and as the minimum convex polygon calculations included a lot of unsampled area (Figure 3) we streamlined the calculation of the weights to use for the samples. Rather than use the total number of fish samples we recommend using the total number of samples taken in each year as an initial sample size input (Table 2). This reduces the need to make some assumption about the spatial footprint of an ROV survey as was conducted for Walter et al 2013).

Discussion

Overall the age compositions indicate that the ages 2-4 fish are the most common ages sampled on the reefs. The expansion of the age composition over time can be seen in the greater proportions of older fish in recent years which seems partially due to reductions in fishing mortality as the apparent Z implied by catch curves on the 2005-2012 cohorts has decreased slightly (Figure 5).

Overall the lack of significant or clearly interpretable differences between the surveys suggests that they may be combined into a single dataset and applied within the stock assessment as a single ‘fleet’ or survey, depending upon model structure.

The benefits of the ROV data are that it is collected *in situ*, that it is not size-selective and that it is relatively efficient at measuring a large number of fish in areas that are not well represented (artificial and natural reefs) in the current stock assessment data. Including this data should help to incorporate the signals in year class strength seen in these habitat types into the stock assessment.

There does appear to be some evidence of cohort structure and the ROV survey clearly samples fish in the 20-100 mm size range. The expansion of the size/age structure appears to reflect reductions in fishing mortality over time.

Overall

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Table 1. ROV Counts of red snapper by year, habitat, survey.

	DISL (Powers et al)			FWRI		Patterson (UF)		PC	total
year	art	nat	unid	art	nat	art	nat	nat	
2005						452			452
2006						1597			1597
2007						770		169	939
2008								192	192
2009						130	95	289	514
2010	89				8	324	269	98	788
2011	409	90			7	558	270	192	1526
2012	336	22			17	239	139	74	827
2013	211	35			36	611	155	80	1128
2014	104			91	112	272	31	13	623
2015	211	6		56	131	56	31	72	563
2016	1667	7	14	236	633	166	21	60	2804

Table 2. Calculations to determine relative weighting factors. We recommend using just the number of samples.

year	number of fish	number of samples	mcp area	percent of	wts (samples*percent of area)
2005	452	40	48960769	0.001	0.042
2006	1597	71	56378495	0.001	0.087
2007	939	89	2.487E+09	0.054	4.798
2008	192	36	1.006E+09	0.022	0.785
2009	514	92	2.613E+10	0.566	52.108
2010	788	119	3.464E+10	0.751	89.358
2011	1519	231	1.694E+10	0.367	84.845
2012	827	171	2.041E+10	0.442	75.653
2013	1109	146	2.372E+10	0.514	75.090
2014	617	189	6.912E+10	1.498	283.201
2015	554	211	8.136E+10	1.764	372.150
2016	2766	414	8.951E+10	1.940	803.343

Table 3. Model-based length frequencies by year.

	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
	40	71	89	36	92	119	231	171	146	189	211	414
X.14.18.	0.033	0.026	0.062	0	0.023	0.015	0	0.01	0.002	0.009	0.004	0.024

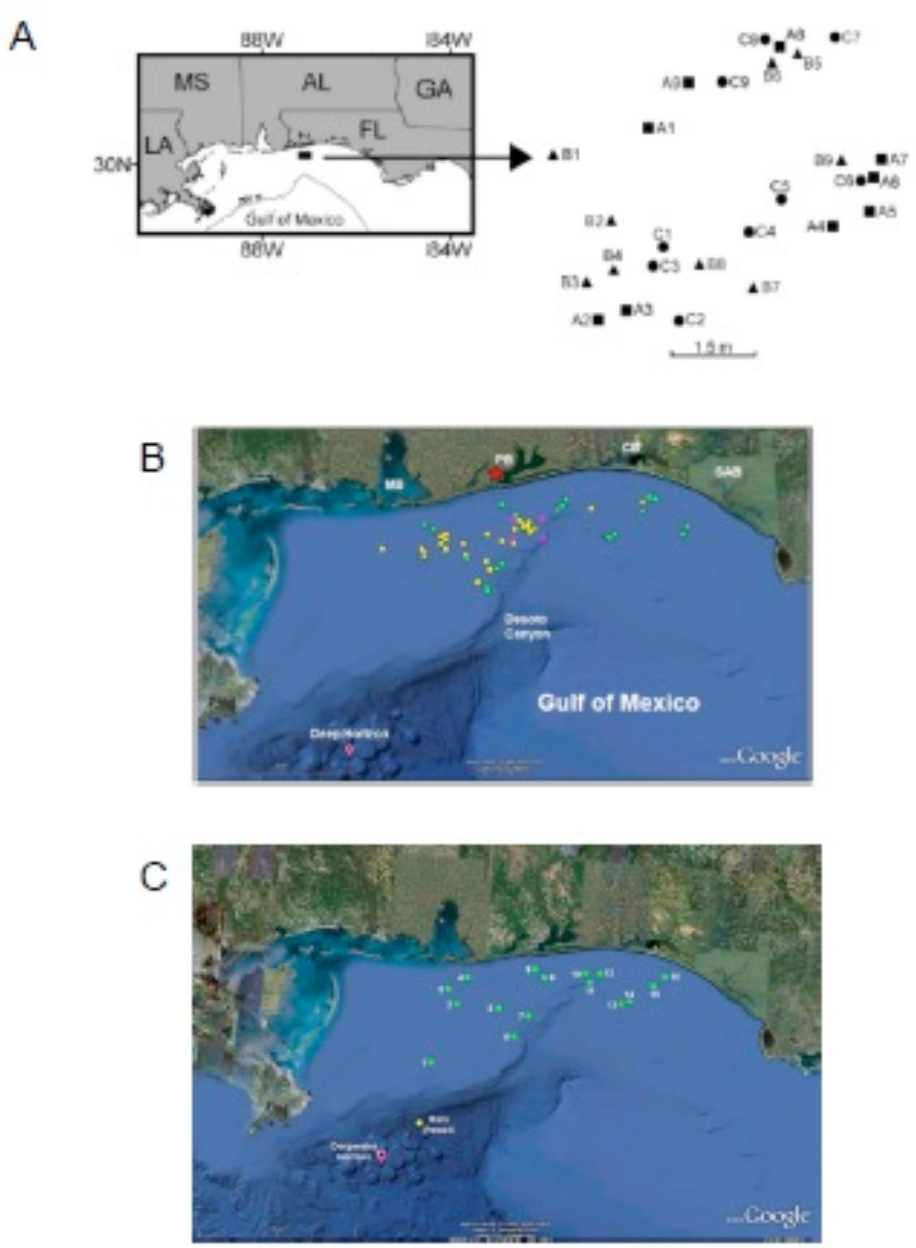
X.18.22.	0.02	0.052	0.021	0.025	0.004	0.018	0.003	0.011	0.01	0.008	0.009	0.022
X.22.26.	0.06	0.085	0.061	0.139	0.032	0.042	0.018	0.025	0.025	0.037	0.017	0.053
X.26.30.	0.148	0.199	0.117	0.136	0.047	0.071	0.037	0.046	0.044	0.063	0.078	0.101
X.30.34.	0.159	0.229	0.226	0.162	0.083	0.084	0.064	0.067	0.064	0.062	0.064	0.136
X.34.38.	0.194	0.178	0.268	0.247	0.155	0.126	0.108	0.119	0.088	0.07	0.071	0.149
X.38.42.	0.181	0.098	0.11	0.122	0.204	0.127	0.117	0.09	0.153	0.084	0.089	0.122
X.42.46.	0.09	0.035	0.067	0.075	0.125	0.099	0.116	0.093	0.165	0.114	0.078	0.092
X.46.50.	0.067	0.028	0.02	0.051	0.103	0.097	0.136	0.104	0.136	0.11	0.076	0.053
X.50.54.	0.027	0.02	0.014	0.021	0.072	0.133	0.116	0.087	0.121	0.069	0.092	0.042
X.54.58.	0.005	0.007	0.006	0.008	0.049	0.05	0.09	0.085	0.06	0.092	0.079	0.041
X.58.62.	0.004	0.01	0	0.008	0.036	0.039	0.06	0.042	0.034	0.067	0.046	0.026
X.62.66.	0.005	0.014	0.008	0.005	0.033	0.043	0.057	0.073	0.016	0.043	0.065	0.025
X.66.70.	0	0.012	0.005	0	0.017	0.014	0.03	0.037	0.022	0.021	0.028	0.015
X.70.74.	0.002	0.004	0.005	0	0.007	0.016	0.015	0.025	0.011	0.026	0.037	0.019
X.74.78.	0.003	0.002	0.003	0	0.006	0.007	0.012	0.019	0.011	0.027	0.035	0.014
X.78.82.	0	0.001	0.006	0	0	0.002	0.009	0.013	0.01	0.021	0.017	0.012
X.82.86.	0	0	0.002	0	0	0.007	0.003	0.019	0.01	0.04	0.031	0.018
X.86.90.	0	0	0	0	0	0.001	0.003	0.008	0.006	0.013	0.02	0.009
X.90.94.	0	0	0	0	0.003	0.002	0.003	0.01	0.004	0.022	0.014	0.013
X.94.98.	0	0	0	0	0	0.005	0.002	0.011	0.005	0.002	0.023	0.009
X.98.102.	0	0	0	0	0	0.001	0.001	0.002	0	0.002	0.007	0.003
X.102.106.	0	0	0	0	0	0	0.001	0.003	0.001	0	0.021	0.003

Table 4. Model-based age frequencies by year.

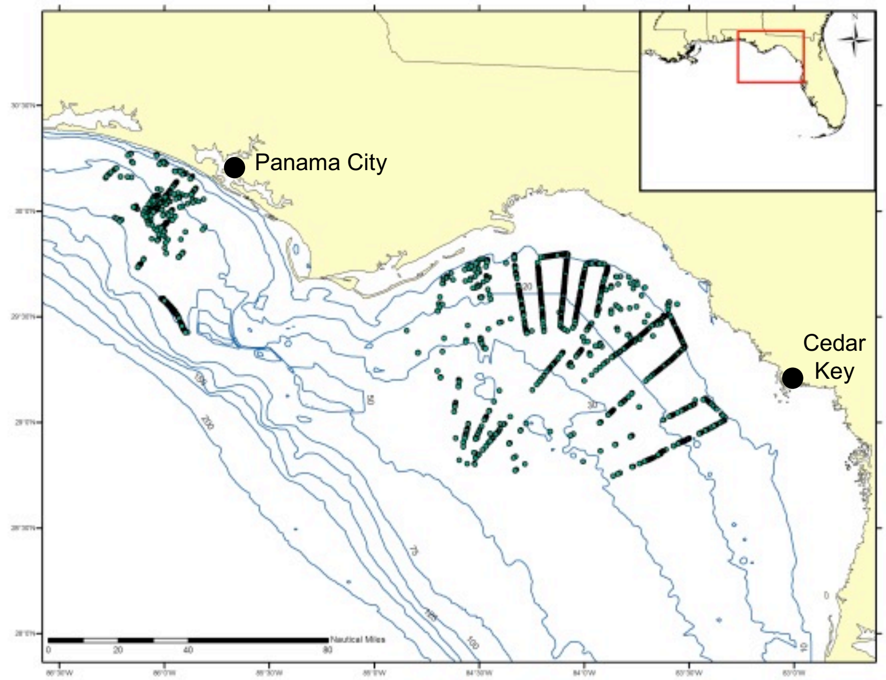
Year	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
sample size	40	71	89	36	92	119	231	171	146	189	211	414
1	0.123	0.173	0.120	0.181	0.052	0.070	0.034	0.044	0.043	0.059	0.049	0.095
2	0.319	0.374	0.368	0.324	0.199	0.185	0.138	0.145	0.147	0.132	0.136	0.243
3	0.342	0.278	0.336	0.314	0.332	0.272	0.259	0.231	0.297	0.214	0.191	0.272
4	0.139	0.096	0.106	0.118	0.201	0.205	0.228	0.192	0.231	0.190	0.170	0.142
5	0.044	0.036	0.031	0.038	0.103	0.117	0.144	0.131	0.118	0.125	0.120	0.074
6	0.017	0.021	0.014	0.014	0.054	0.064	0.083	0.085	0.061	0.077	0.083	0.045
7	0.008	0.011	0.009	0.006	0.028	0.036	0.048	0.054	0.036	0.052	0.058	0.030
8	0.004	0.006	0.006	0.003	0.015	0.021	0.028	0.034	0.022	0.038	0.041	0.022
9	0.002	0.003	0.004	0.001	0.008	0.013	0.017	0.025	0.015	0.033	0.033	0.018
10	0.001	0.001	0.002	0.000	0.002	0.005	0.007	0.013	0.008	0.019	0.019	0.011
11	0.000	0.000	0.001	0.000	0.001	0.002	0.003	0.006	0.004	0.011	0.010	0.006
12	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.001	0.004	0.004	0.002
13	0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.005	0.003	0.005	0.009	0.005
14	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.003	0.001	0.006	0.005	0.003

15	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.002	0.001	0.004	0.003	0.002
16	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.002	0.001	0.001
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.002	0.002	0.001
18	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.002	0.003	0.002
19	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.001	0.001	0.003	0.001
20	0.000	0.000	0.000	0.000	0.002	0.007	0.006	0.023	0.010	0.023	0.061	0.024

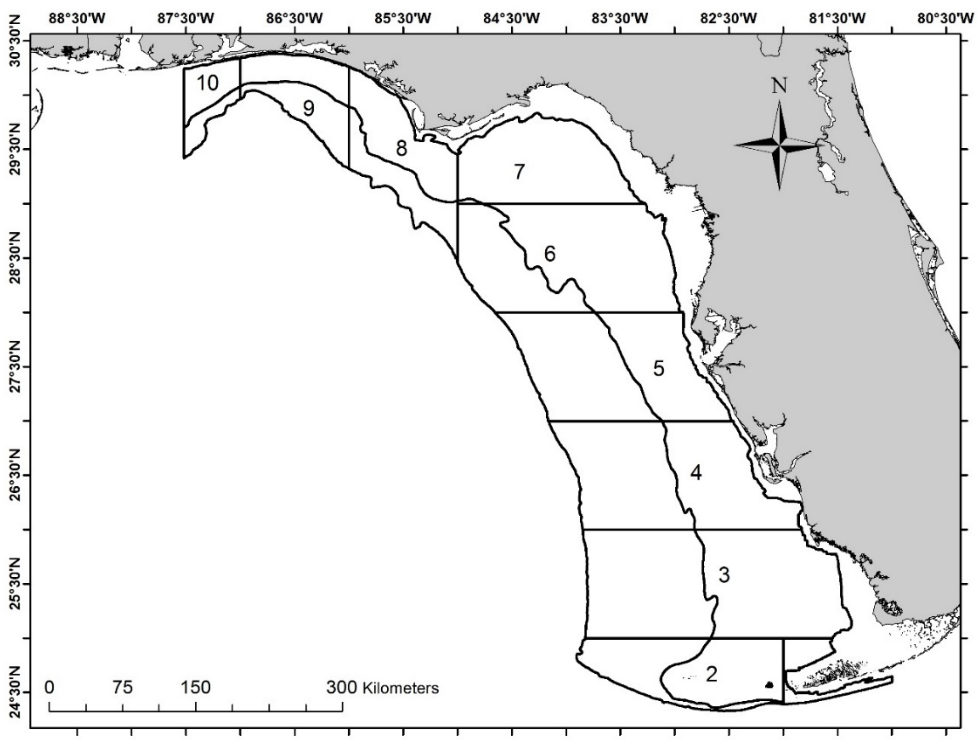
Figure 1. Maps of study reef locations in the northern Gulf of Mexico for A) FWC-funded artificial reef study, B) FWRI-funded reef fish ecology study, and C) Post-DHOS sampling of natural reef sites. Green symbols indicate natural reef locations and yellow symbols indicate artificial reef locations, D) Locations of all natural reefs in the sampling universe of the Panama City NMFS reeffish video survey as of May 2012, E) FWRI sampling universe.



D.



Number of sites: 722 W. of Cape San Blas – 1637 E. of Cape San



e.

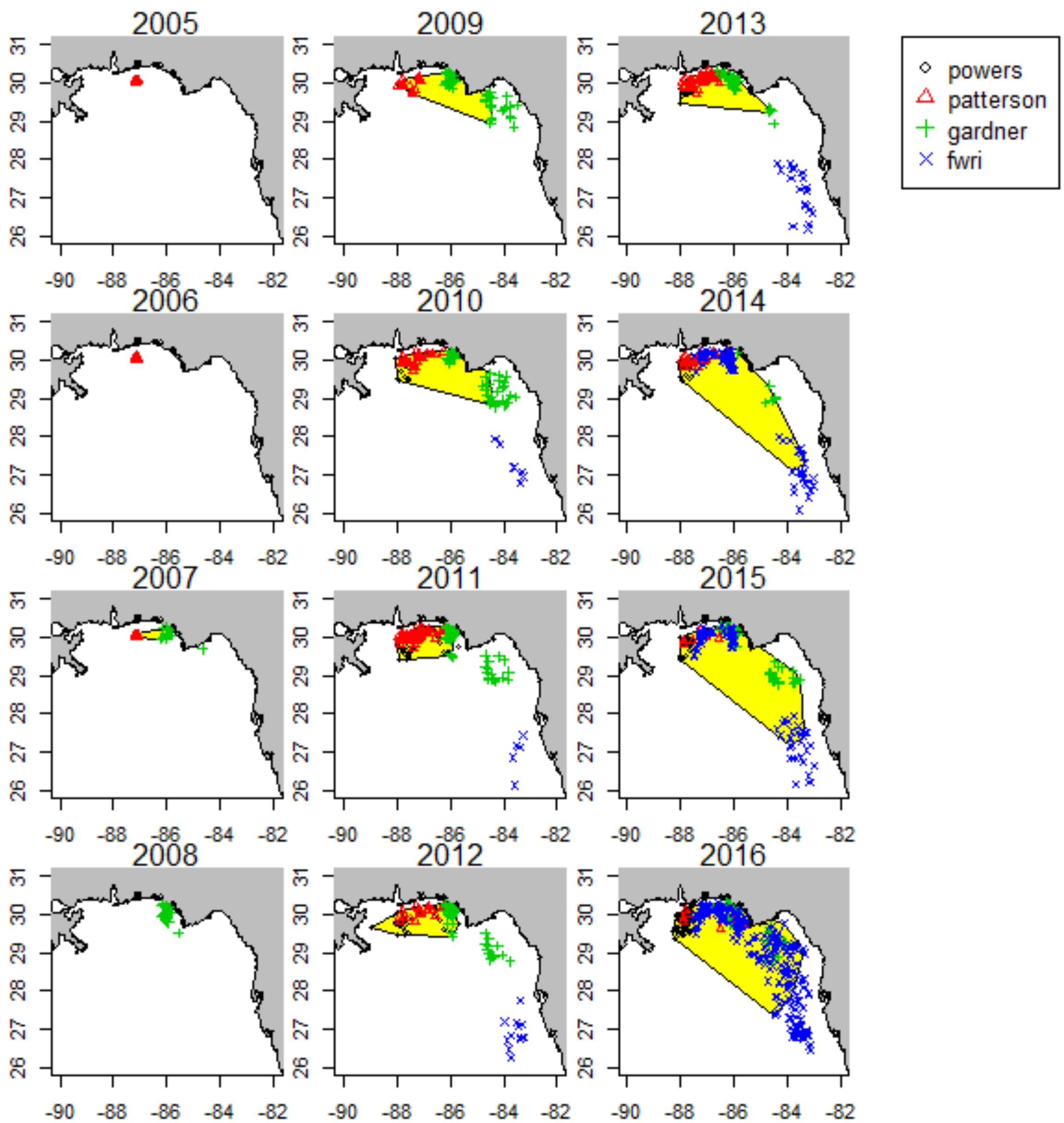


Figure 2. Data locations used in this study. Yellow polygon is the 95% minimum convex polygon used to determine the area sampled by the surveys in each year.

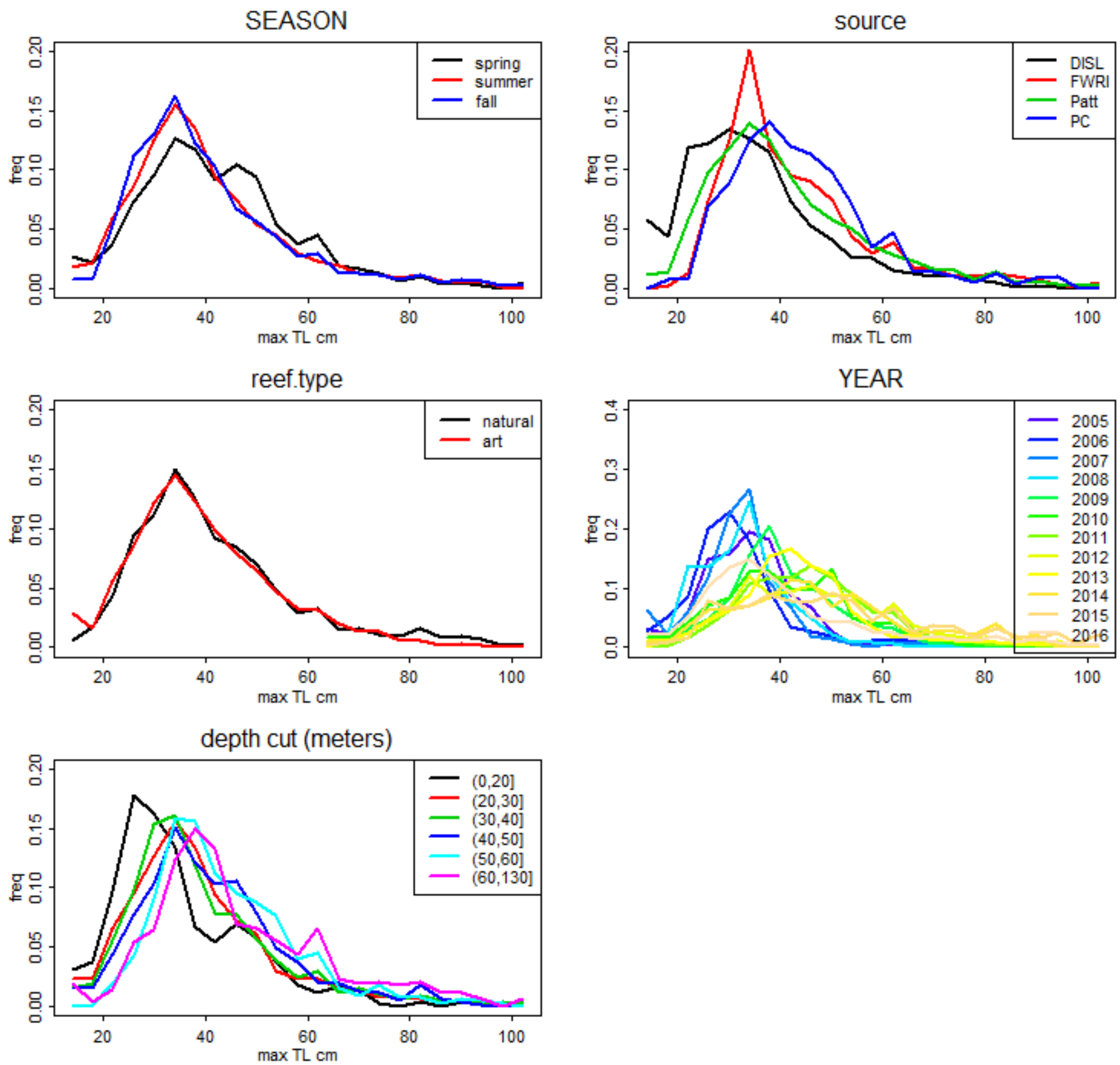


Figure 3. Predicted length frequencies by season, reef type and year.

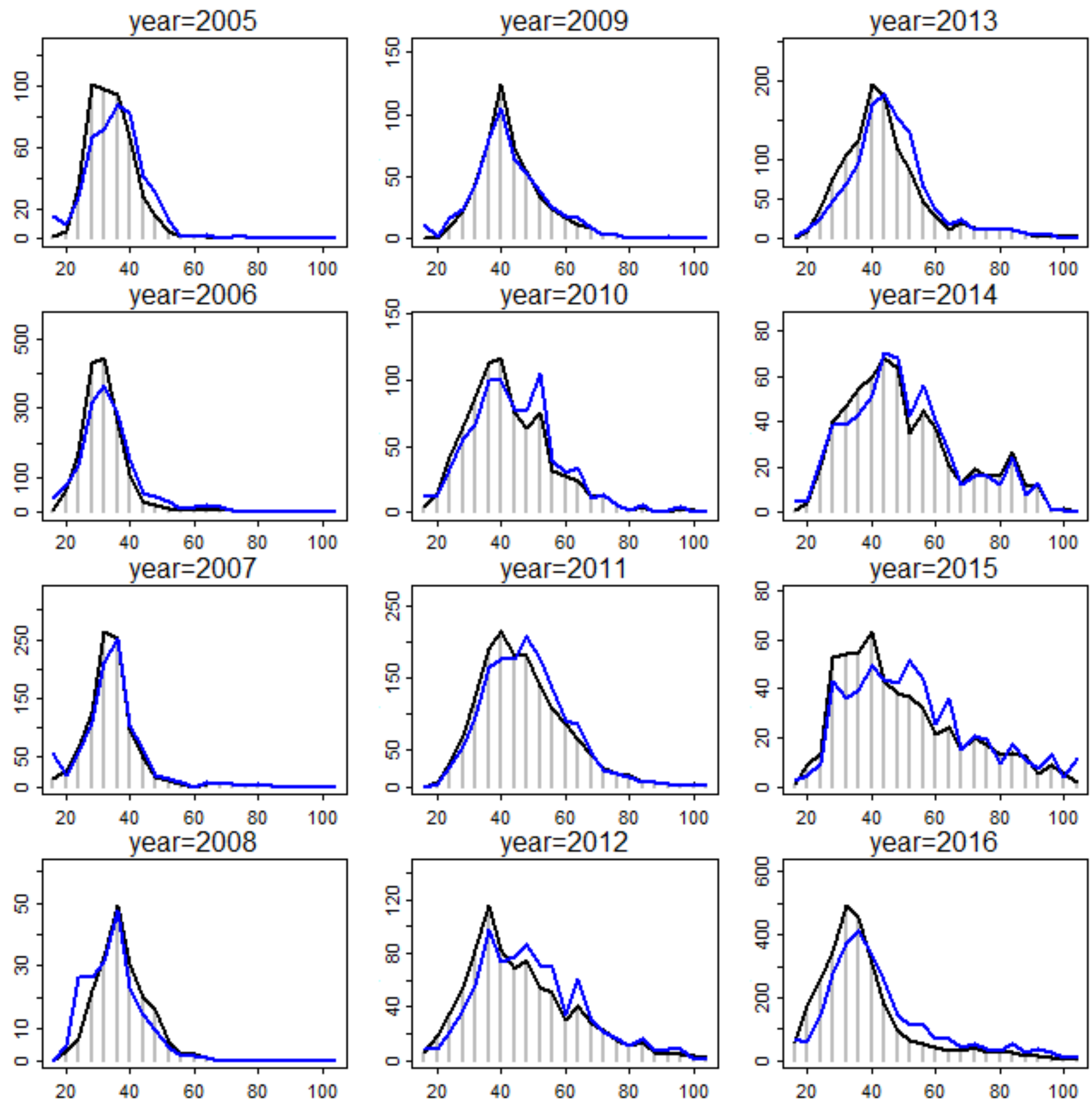


Figure 4. Observed (black) and predicted (blue) length compositions by year.

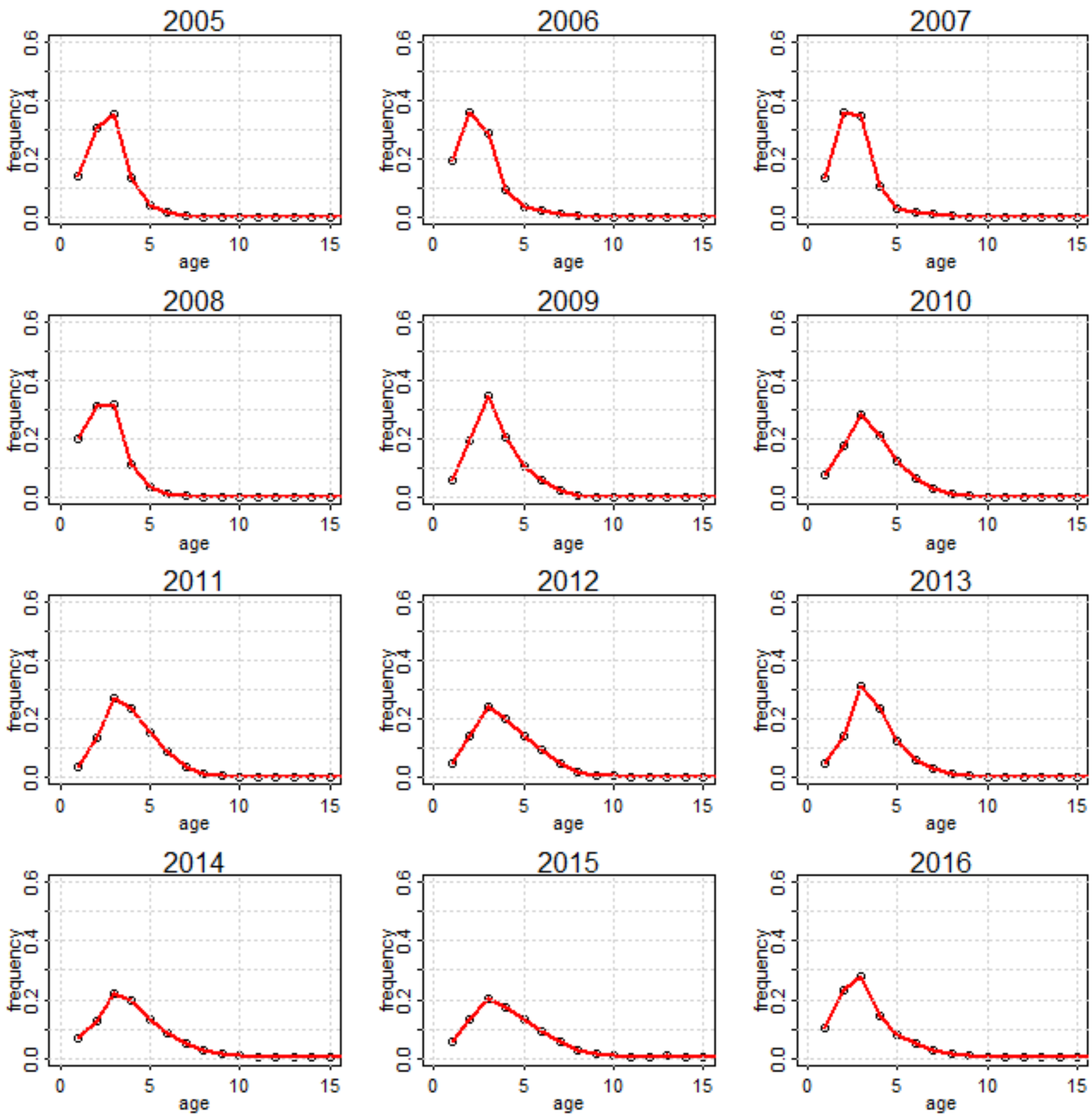


Figure 5. Predicted age composition of ROV surveys by year.

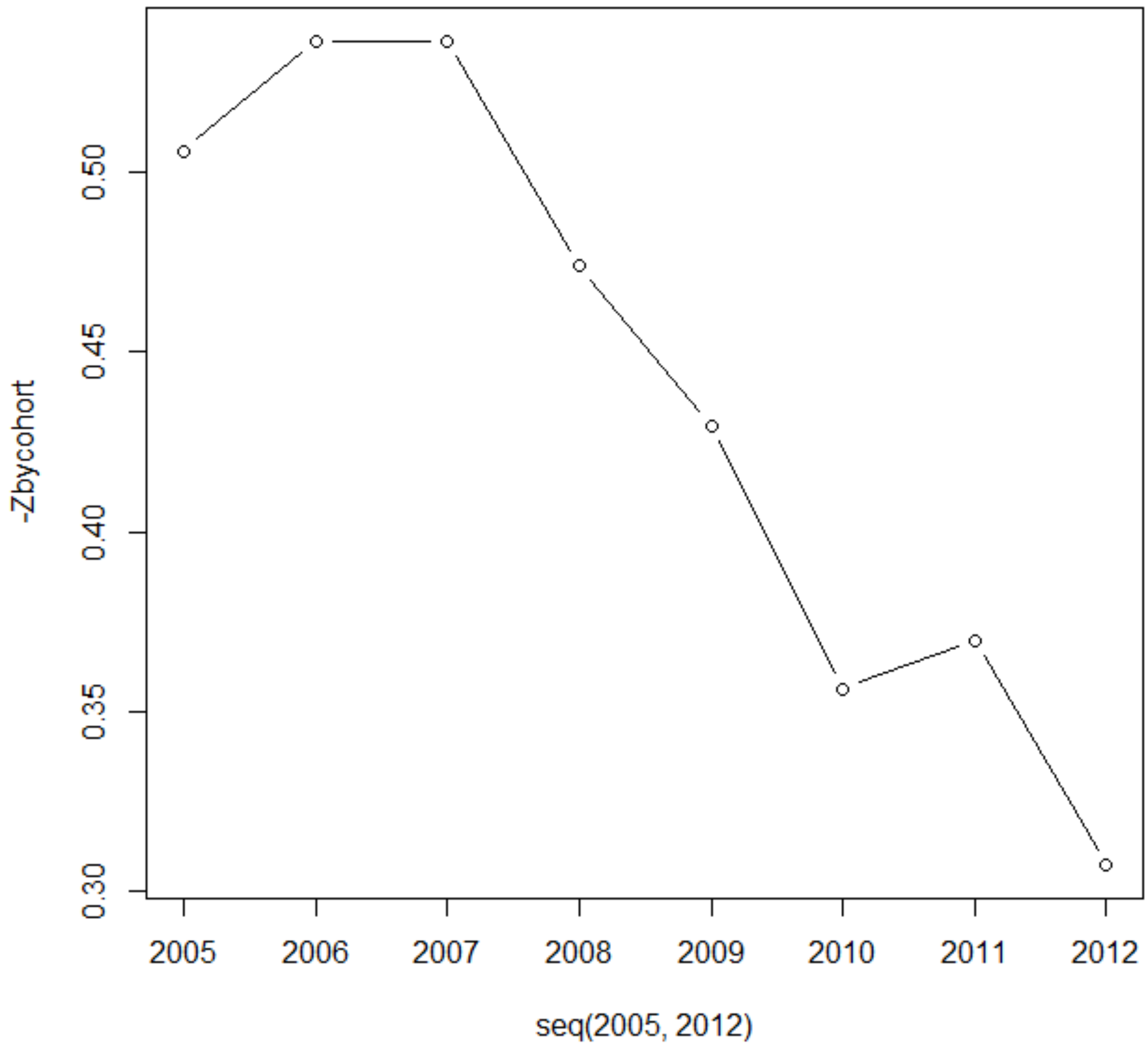
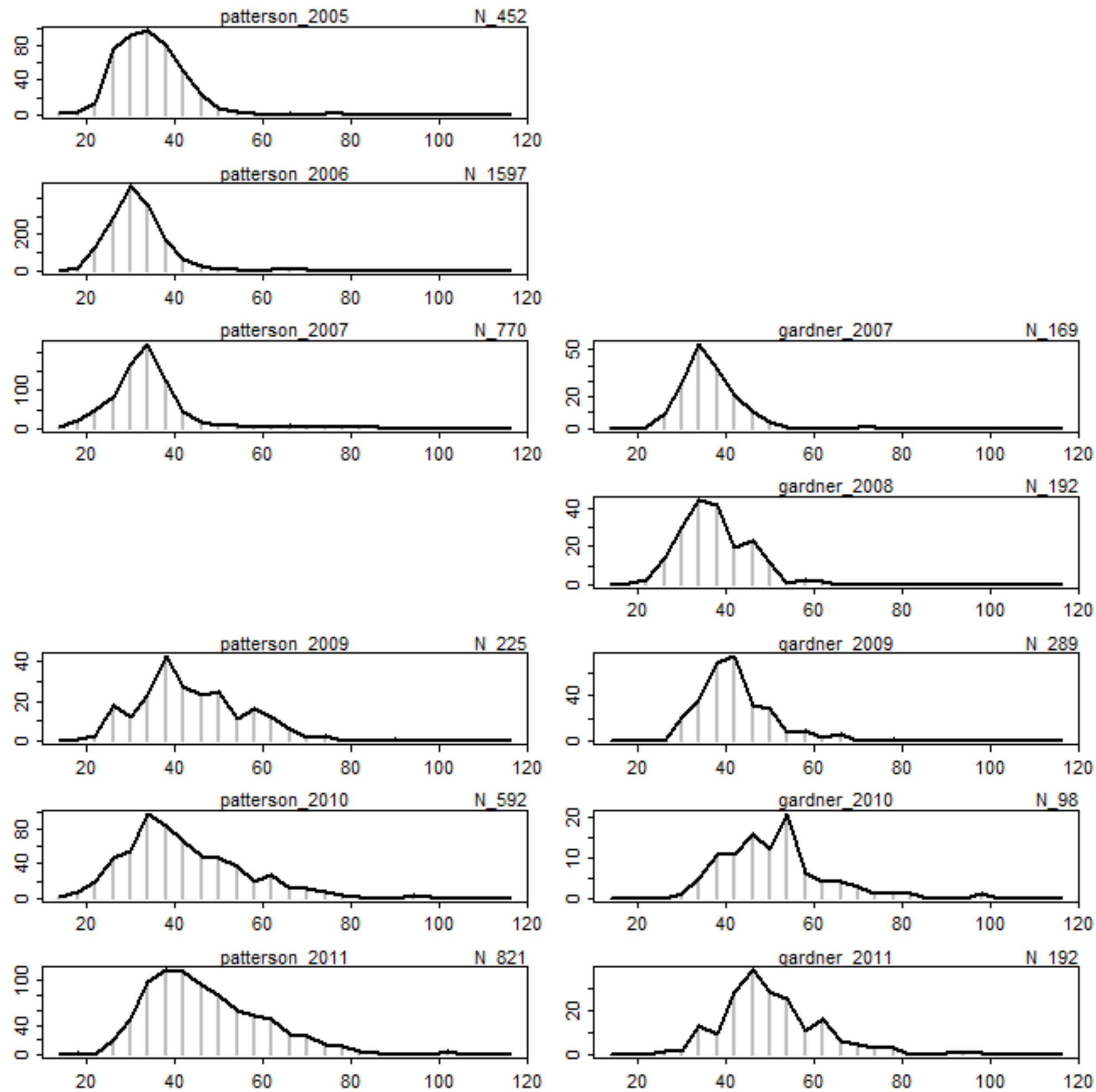
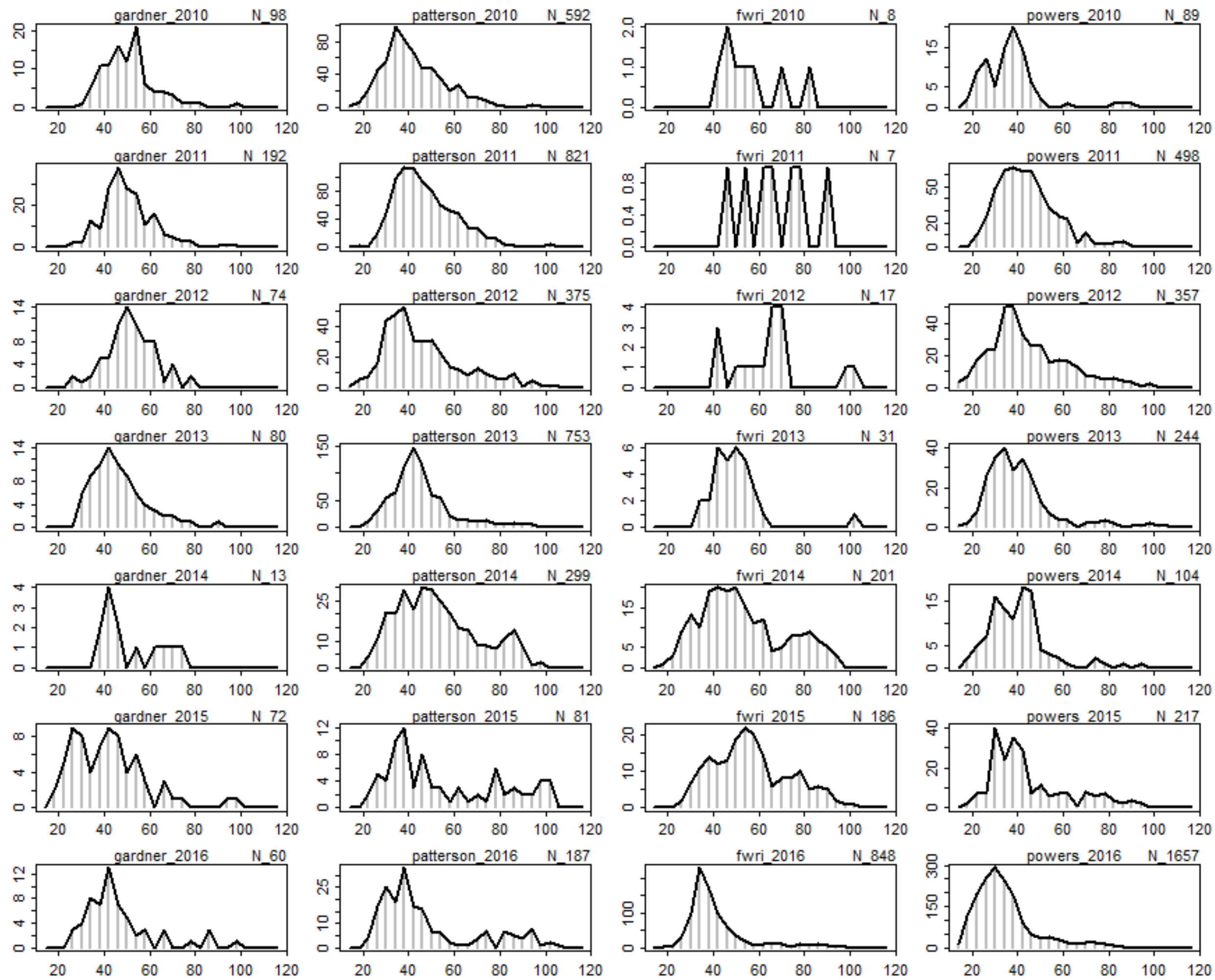


Figure 6. Implied Z by cohort.



Appendix Figure 1. Early data, 2005-2011.



Appendix Figure 2. More recent data, 2010-2016.