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REVIEW AND PRELIMINARY ANALYSES OF CONVENTIONAL TAGGING DATA ON ATLANTIC BLUE SHARK STOCKS (*PRIONACE GLAUCA*)

Mauricio Ortiz[1], Jesus Garcia, and Nathan Taylor

SUMMARY

Conventional tagging data of North and South Atlantic blue shark stocks were reviewed, and preliminary analyses were performed for its use within the stock evaluation. The tag releases and recapture records were revised, updated, and standardized, to summarize size distributions, time at large and distance displacement between release and recapture locations. Most of the tag releases are in the North Atlantic area, recaptures suggested a low exchange of individuals between current stock management units in the Atlantic and Mediterranean. Size distribution of tag releases and recaptures show unimodal normal distributions with a mean size of 156 and 189 SFL cm, respectively. Time at large showed recaptures up to 15 years at liberty, with a mean of 407 days at large. Stainless steel tag's reporting rates were higher than plastic double-barb streamers. And inferred movement patterns suggest a clockwise migration in the North Atlantic from the easter coast of North America to Europe following the Gulf Stream current and returning southwest to the equatorial region and the Caribbean Sea.

RÉSUMÉ

Les données de marquage conventionnel des stocks de requins peau bleue de l'Atlantique Nord et Sud ont été examinées et des analyses préliminaires ont été réalisées en vue de leur utilisation dans le cadre de l'évaluation des stocks. Les données de marquage et de récupération des marques ont été révisées, mises à jour et standardisées afin de résumer les distributions des tailles, la durée d'apposition des marques et la distance du déplacement entre les lieux de marquage et de récupération des marques. La plupart des marques ont été apposées dans la zone de l'Atlantique Nord et les récupérations suggèrent un faible échange de spécimens entre les unités actuelles de gestion du stock dans l'Atlantique et la Méditerranée. La taille des spécimens lors de l'apposition et de la récupérations des marques présente des distributions normales unimodales avec une taille moyenne de 156 et 189 cm SFL, respectivement. La durée du déploiement allait jusqu'à 15 ans, avec une moyenne de 407 jours. Les taux de déclaration des marques en acier inoxydable étaient plus élevés que ceux des marques en plastique à barbillon double. Les schémas de déplacement déduits suggèrent une migration dans le sens des aiguilles d'une montre dans l'Atlantique Nord, de la côte Est de l'Amérique du Nord à l'Europe, en suivant le courant du Gulf Stream et en retournant vers le Sud-Ouest dans la région équatoriale et la mer des Caraïbes.

RESUMEN

Se revisaron los datos de marcado convencional de los stocks de tiburón azul del Atlántico norte y sur y se realizaron análisis preliminares para su uso en la evaluación de stock. Se revisaron, actualizaron y estandarizaron los registros de colocación y recuperación de marcas para resumir las distribuciones de tallas, el tiempo en libertad y la distancia de desplazamiento entre los lugares de colocación y recuperación. La mayoría de las colocaciones de marcas se produjeron en la zona del Atlántico norte, y las recuperaciones sugerían un escaso intercambio de ejemplares entre las actuales unidades de ordenación del stock en el Atlántico y el Mediterráneo. La distribución por tallas durante la colocación y recuperación de marcas muestra distribuciones normales unimodales con una talla media de 156 y 189 cm SFL, respectivamente. El tiempo en libertad mostró recuperaciones de hasta 15 años en libertad, con una media de 407 días en libertad. Las tasas de comunicación de las marcas de acero inoxidable fueron superiores a las de las marcas de plástico de doble lengüeta. Y los patrones de movimiento inferidos sugerían una migración en el sentido de las agujas del reloj en el Atlántico norte, desde la costa oriental de América del Norte a Europa, siguiendo la corriente del Golfo y regresando al suroeste hacia la región ecuatorial y el mar Caribe.

[1] ICCAT Secretariat. Corazón de Maria 8, Madrid Spain 28002. Mauricio.ortiz@iccat.int

KEYWORDS

Conventional tagging, blue shark, size

1. Introduction

The blue shark (*Prionace glauca*) is an oceanic shark with a wide distribution worldwide, in tropical, subtropical, and temperate waters. Within the ICCAT Convention Area, it is found the Atlantic and Mediterranean Oceans, recognizing three management units, the North and South Atlantic, and Mediterranean blue shark stocks. ICCAT CPCs have regularly provided information on conventional tagging data on blue sharks since the 1960s, the data included both scientific-based and opportunistic tagging release programs and reports of recaptures from different fisheries in the Atlantic. This document review and summarizes the available information on blue shark conventional tagging data and presents a preliminary analysis of the data for the upcoming stock assessment of Atlantic blue shark stocks.

2. Data

Conventional tagging data for blue sharks have been regularly submitted by CPCs, particularly from the North Atlantic fisheries since the 1960's, although conventional tagging releases have decreased in the latest decade (**Table 1, Figure 1**), there are about 140 thousand tag releases (139,644) events and over 10 thousand recaptures (10,623) reported to the ICCAT Tagging database since 1959 for an overall recapture rate of 7.61%. The conventional tagging data is designed to follow the individual fish/shark mark-recapture event(s) throughout its life, as such there is the possibility of multiple tag-release and corresponding recapture events. It has also the functionality for recording one or more tags in each event. In the case of blue shark tagging data, most of the releases and recaptures took place from the 1990's to 2010, with about 60% of recaptures taking place during the 1st year at large and up to 97% of recaptures within 5 years at large. There have been about 150 blue sharks with recaptures after 5 or more years at large, of which 3 sharks were at large for over 15 years, tagged originally in the 1980's and recover in the early 2000's. **Table 1** summarizes the distribution of releases and recaptures by year. Of the releases, 99% (139,644) were the first initial shark tag release, while 1,310 were the 2nd re-release, and 28 were the 3rd re-release. Of the recaptures, 99.9% (10,623) were 1st recaptured with few (52) 2nd recaptures, and only 1 shark was reported to be recaptured for the 3rd time. In addition, 3,102 sharks were tagged with 2 tags and 333 with 3 tags. 127 recaptures of double-tagged blue sharks have been reported.

Following a request from the Sharks Working Group, the gender of tagged blue sharks was updated in the database in recent years. **Figure 2** shows the distribution of sex information available; of 139,644 releases 38,849 (28%) were females, 49,164 males (35%), and 51,631 (37%) unknown sex. Similarly, of the 10,623 recaptures, 2,615 (25%) were females, 3,971 (37%) were males and 4,031 (38%) unknown sex. **Figure 3** shows the spatial distribution of the tag releases, including some records outside the Atlantic Ocean. The SCRS presently recognizes 3 management stocks for blue sharks, North Atlantic stock (north of 5° latitude), South Atlantic stock (south of 5° latitude), and the Mediterranean stock. Most of the tag releases have been of the North stock (95.6%), and few in the South (3.8%) and Mediterranean (0.5%), similarly most of the recaptures are from the same stock, with few individuals recovered in a different geographic stock area (**Table 2**). Of 133,337 tag releases in the North Atlantic, 9,501 were recaptured in the North (96.51%), while 37 were recovered in the South Atlantic (0.39%), and 2 in the Mediterranean (0.02%). In the South Atlantic of 5,288 tag releases, 102 were recaptured in the same area (97.14%), and 2 in the North and 1 in the Mediterranean, while in the Mediterranean Sea, of 773 tag releases, 57 were also recovered in the Med (94.44%) and 4 in the North Atlantic (6.56%), and none in the South Atlantic. Finally, to indicate that for 246 tag releases and 954 recaptures, there was no lat-lon information provided to assign a stock geographical area.

The reported tag data to ICCAT come from different national tagging programs, both scientific and opportunistic involving commercial and recreational fishers. **Table 3** and **Figure 4** show the distribution of tag releases and recaptures by main gear type, in the case of blue shark most tag releases were with the rod and reel gear (71%) usually associated with commercial and recreational fishing activities, followed by the longline gear (24%), and few releases from gillnets, trawling or purse seine fishing operations, about 4% of records have no information on fishing gear. For blue shark tags recaptures (**Table 3**, **Figure 6**), most reports come from longline fleets (57%), followed by rod and reel (36%) and few from gillnet fisheries (1%), about 6% of recaptures are missing gear information. By fleet/flag most of the tag releases and recaptures have been from the USA tagging programs (71% releases and 66% recaptures), followed by tagging programs from EU Ireland (12% releases and 8% recaptures), Japan, Uruguay, Canada, EU-Portugal and EU-Spain that account for up to 97% of tag releases and 95% of recaptures, respectively (**Figure 5**).

The tagging information provided by the different CPCs included the size and weight, and sex of blue sharks at release and recapture events, however, the type of measure, units, and whether it is an estimate or a measured value, varies substantially. **Figure 7** shows overall distributions of size, weight, size/weight units, and type of measures in the raw database. For analysis, all size measures were standardized to SFL units (cm) using the current SCRS conversion factors (Campana et al., 2005) of size and weight when available. About 82% of tag releases provided size information (114,588) that was converted to SFL in cm, **Figure 8** shows the size distribution of the released blue sharks. Tag-released blue sharks ranged from 50 to 429 SFL cm, with a mean of 155 cm and unimodal distribution, most individuals (50% central percentile) ranged from 127 to 179 SFL cm. The annual size distribution trends (1959 – 2018) show a rather stable trend from the 1970' to the 2000s, since 2005 mean size of tagged sharks show a declining trend until 2013, with an increasing trend in the most recent years (**Figure 9**). For the recaptured blue sharks, the mean size is 190 SFL cm with a range from 85 o 535 SFL cm, and the central 50% percentile is from 158 to 220 SFL cm (**Figure 10**). Overall there is a positive change in the size of tagged sharks, with a median of 26 cm increase and a range from -52 to 157 SFL cm. There are reports of smaller size at recapture compared to the release size, however, it should be noted that most of the measures are estimated, thus the margin of error or accuracy of reported values must be considered (**Figures 11** and **12**).

Regarding time at large, there are some inconsistencies in the reported dates or missing data, of 9,214 recaptures with both dates, 13 tags (0.1%) reported a wrong date (either tag release date or tag recapture date). Excluding records with wrong dates, the time at large of tagged blue sharks shows a typical left-skewed distribution with a median of 286 days-at-large (**Figure 13**), and the 50% central percentile range from 46 to 608 days-at-large. Of 10,190 recaptures, 151 (1.5%) were at large for more than 5 years, 11 were at large for 10 or more years, and 3 were over 15 years.

3. Results

By far blue shark has been the shark species with more conventional tag releases and recaptures in the Atlantic Ocean and the Mediterranean Sea with also a long history from 1959 until the present. However, most of the tag releases are in the North Atlantic area, with a relatively very low transfer among the current stock management areas. If any few tag records suggest an exchange between the Mediterranean and North Atlantic. From 1976 until 2013 on average more than 1,500 tagged sharks were released annually, with a peak in 1995-97 with over 6,000 tagged individuals per year. Unfortunately in recent years (2018-21) conventional tagging has drastically reduced (**Table 1**). **Figure 1** shows the annual trends of releases and the corresponding recapture rates for a given year, clearly, with the increase of tag-releases the percentage of recaptures increased, from 1960 to 1980 with about 1000 tag releases annually, recapture rates were about 3-4%, but in the 1990s with an average, about 5,000 annual tag releases recapture rates increased to 8.5% during the turn of the century, and this high recapture rates continued in the 2000s albeit the number of releases started to decrease to about 2,000 annually. Since 2010 with decreasing number of releases, the number of recaptures also decreased and the percentage of recaptures has dropped about 4% in the latest years.

Time at large is also a feature of the blue shark conventional tagging data with relatively long retention of tags, on average a tagged individual is expected to be recovered about 9 months after release, but longer recoveries (after 3, 5, or 10 years) have been recorded. Blue shark recaptures (i.e. days-at-large) follows closely a fitted negative binomial distribution (**Figure 13**) with a mean estimate time at large of 405 days. Retention of conventional tags is a function of several factors, including the type and material of the actual tag, procedures of tagging, etc. In the case of blue sharks, most of the tagged individuals have been tagged with stainless steel tags from or provided by the Apex Predator tagging program NOAA/USA (Apex Predator Tagging Program). These tags have been specifically designed for sharks and represent about 83% of the tag releases in the database (116,733 out of 140,982 records), with 8,612 recaptures for an overall percent recapture of 7.37% (**Table 3**). By comparison, the other type of tag used is the double barb plastic streamline tag (ST-Dart1 large size) that has been implanted on 4,335 sharks, with only 64 recaptures being reported, with an overall rate of recovery of about 1.48% percent recapture, substantially lower compared to the stainless steel tags. Although there are 3123 records of blue sharks with 2 or more tags implanted at release and 124 recaptures from double-tagged sharks. Unfortunately, in most of these events, they used the same type of tag or did not report the type of tag, thus preventing further analysis of retention rates by tag type.

Most of the blue shark tag releases have been a combination of scientific and opportunistic tag programs, using in particular recreational o sport fisher taggers in both USA and Europe as indicated by CPCs tagging reports. Rod and reel usually associated with sport/recreational fisheries is by far the most common gear for tag-release events (71%), followed by releases from longline fisheries (24%) only commercial fishers (**Figure 6**, top). However, recaptures of blue sharks, are mostly from commercial longline fisheries (57%), followed by rod and reel (36%) (**Table 3, Figure 6**). These results highlight the importance of tagging outreach for longline fisheries to obtain the most recaptures. Blue shark size distributions at release and recapture show a unimodal distribution with a rather normal distribution (**Figures 8 and 10**). **Figure 9** shows the annual size distributions of shark releases and recaptures (at the year of release), confirming the size increase of tagged sharks during time-at-large, of course, the size increase is a function of the time at large, **Figure 14** shows the overall distributions of time at large (days) and size difference between recapture and release (SFL cm). As noted before, negative days-at-large indicates the wrong date(s) of tag release and or recapture, and besides close revision by CPC providers, the data has been excluded from further analysis. In the case of size, is expected a positive change in size, as is the overall case for blue shark tagging data. However, is noted that negative sizes were observed for short times at large in particular. This could be the result of one or more factors, it should be noted that most of the tag sizes at release are estimated by taggers, and not actual measures, thus the precision of measures is rather low, also the actual tagging event may impact the normal growth patterns of individuals, and finally not to discount possible errors in size, units or measure type in the reports. Nonetheless, overall for every year, recaptured sharks had on average larger size compared to the average size at release (**Figure 11**). The next step was to review if the increase in size observed from conventional tagging agreed with the current SCRS blue shark growth models. As a preliminary approach, if it is assumed that the size at release is correct and that individuals follow the growth models for N-ATL blue shark (Skomal and Natanson, 2002) by sex or combined sex, then knowing the time at large we can predict the expected size at recapture and compare with the actual observations reported. **Figures 15** and **16** show the predicted size at capture (solid line) and the reported size at recapture for all recaptures (combined sex), and by sex, respectively. Overall, the observed size at recapture are consistent with the current growth models by sex or combined, there is a large variability of size at recapture, but the variance is distributed both above and below the predicted values following a rather uniform pattern (**Figure 17**) for all ages of tagged blue sharks, the estimated ratio of observed over predicted size (**Figure 18**) shows a unimodal distribution with a mean/mode closer to one.

Of the 10,623 blue shark recaptures, there are 9,135 (86%) records with both lat-lon information for the release and recapture events. Using standard geostatistics algorithms it was estimated the distance between points of release and recapture (displacement km) and the direction of movement (bearing 0 to 360° degrees). With conventional tagging is of course not possible to infer the travel route of individuals, or migratory patterns, however, it can provide insights into spatial and temporal distributions and general movement patterns of the stocks. **Figure 19** shows the overall distributions of displacement a direction, respectively. The longest displacement (7,921 km) registered is from a shark tagged off the Ireland coast in the summer of 1990 and recapture in the Gulf of Mexico, off Campeche Mexico after 3 years (1162 days at large) in Nov-1993. The next longest (7,400 and 6,972 km) displacements are two blue sharks tagged off the New England coast of the USA and recapture in the equatorial mid-Atlantic area (-2.7° Lat, -16.8° Lon), below the equator after 291 and 569 days at large, respectively. These two sharks crossed the current boundary (5° Lat) between the North and South Atlantic stock units. Of 9135 recaptures, 155 sharks traveled more than 5000 km between points of release and recapture, the median of displacement is about 417 km, but the distribution is bimodal with a large proportion (57%) of individuals recapture within 500 km of release, however, a second peak was observed between 2000 and 3000 km and most of these sharks were at large less than a year. The direction of displacement can also be inferred from the distribution of the bearing (**Figure 19**), a bimodal distribution with peaks at about 90° (easterly direction) and 200°-240° (southwesterly, westerly direction), the non-parametric density plots suggest than longest displacements were in the easterly direction, from the North America coast towards northeast Atlantic and European west coast (**Figure 20**). A series of maps of releases (left column) and recaptures (right column) shows that from the main area of releases off the New England coast of the USA, as time at large increases, blue sharks tend to move easterly following the northern Gulf stream current, arriving at the Iberian peninsula, Gulf of Biscay and the southern English and Ireland coast within 6 months a large, between 6 months and 1 year at large, blue sharks cover the main fishing grounds of the North Atlantic, Western European coast and even within the Mediterranean Sea. Some individuals show up in the Atlantic equatorial region and the northern coast of South America and the Caribbean Islands, likely following the Canary and north equatorial Atlantic currents. In the South Atlantic and Mediterranean Sea, unfortunately, because of the low number of tags is not possible to ascertain movement patterns. However, the available data in the South Atlantic coincides with a comparable movement as in the north, following the northeastern currents off Uruguay to the equatorial Atlantic region off Brazil then showing up in the eastern South Atlantic after 1 or 2 years at liberty (**Figure 20**).

4. Conclusions

There is relatively sufficient conventional tagging data for blue sharks since the 1960s, with about 130 thousand releases and close to 10 thousand recaptures for an average percent recapture of about 7%. Unfortunately, conventional tagging has drastically been reduced in recent years. Most of the tagging data is from the North Atlantic region, recaptures indicated a limited exchange of individuals between the current stock management units of the blue shark, partially supporting the exchange between the North Atlantic and Mediterranean stocks. Mean size and size distribution of tagged sharks have been rather constant throughout the years, with variations when the number of tag releases is low (less than 1000 per year), similar information is provided from the recaptures, with unimodal size distribution and larger mean size than at release. A preliminary analysis indicated that the increase of the size at liberty is within the predicted size range of the current growth models for the North Atlantic blue shark. Recaptures of tagged blue sharks follow closely a negative binomial distribution model with a mean days-at-large of 407 days, but with expectations of recoveries after 5 or 10 years of tagging. The stainless steel tags show and indicated higher recapture rates and longer time at liberty compared to the double barb plastic streamer tags, although double tagging experiments with each tag type are needed to confirm these retention rates.

Inference of movement patterns suggests that blue sharks follow a clockwise movement in the North Atlantic following the Gulf Stream current from the east coast of North America to the European western coast, returning to the southwestern equatorial region and moving into the Caribbean and Gulf of Mexico areas. Finally, it is important to highlight the recaptures from longline fleets of blue sharks and the advantage of outreach programs to recover tags from these fleets. The case of the blue shark demonstrates that long-term support and outreach for conventional tagging programs provide important scientific and fisheries data for highly migratory species in particular.

Literature Cited

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Table 1. Atlantic blue shark (*Prionace glauca*) summary of conventional tag releases by year and recaptures by year and years at large. This table includes multiple releases/recaptures of a single animal and records with missing date information.

Number of tag Blue shark (*Prionace glauca*)													
			Years at liberty										
Year	Releases	Recaptures	< 1	1 - 2	2 - 3	3 - 4	4 - 5	5 - 10	10+	15+	Unk	ERROR	% recapt*
1959	14												
1962	43												
1963	134	2	2										1.5%
1964	134	3	2		1								2.2%
1965	255	9	5	4									3.5%
1966	407	6	4		1		1						1.5%
1967	836	17	15		2								2.0%
1968	794	11	7	2	1			1					1.4%
1969	1469	54	46	6	1						1		3.7%
1970	497	15	7	4	2		1	1					3.0%
1971	544	16	11	5									2.9%
1972	921	25	18	5	1	1							2.7%
1973	355	12	8	3	1								3.4%
1974	629	16	13	2	1								2.5%
1975	803	40	30	5	2	1	1				1		5.0%
1976	1086	56	47	4	2		2				1		5.2%
1977	2813	111	92	12	4	2		1					3.9%
1978	3210	164	153	5	3	2					1		5.1%
1979	3807	138	107	20	7			1			2	1	3.6%
1980	3327	88	70	13	2	2	1						2.6%
1981	3118	109	87	9	8	1	2	2					3.5%
1982	2695	69	41	16	9	1				1	1		2.6%
1983	4274	117	59	32	14	5	1	3		1	2		2.7%
1984	2405	57	31	17	5	3					1		2.4%
1985	4471	167	128	20	12	3	2	2					3.7%
1986	2976	106	72	11	9	4	5	3			2		3.6%
1987	2781	82	48	23	8			3					2.9%
1988	3255	140	99	19	8	2	5	1			6		4.3%
1989	2779	143	98	16	11	9	1	4			4		5.1%
1990	3401	170	116	29	9	7		5			4		5.0%
1991	4661	230	162	39	11	2	5	5			6		4.9%
1992	6161	385	249	67	30	9	11	9			9	1	6.2%
1993	5493	373	249	65	19	15	6	7			12		6.8%
1994	5573	438	290	50	37	17	3	9	2		30		7.9%
1995	6940	567	249	137	89	33	12	12	2	1	31	1	8.2%
1996	7622	754	386	193	83	36	13	13			30		9.9%
1997	7307	714	384	159	91	34	11	5			30		9.8%
1998	4359	418	219	110	33	20	11	6			19		9.6%
1999	3762	343	196	87	23	17	3	8			9		9.1%
2000	3057	316	192	71	26	8	4	4	1		9	1	10.3%
2001	2635	283	151	60	33	14	2	3			19	1	10.7%
2002	2394	241	141	48	24	8	7	3	3		7		10.1%
2003	2675	242	121	66	26	12		2			15		9.0%
2004	2392	225	119	60	16	10	3	7			10		9.4%
2005	2199	215	116	48	18	13	5	5			10		9.8%
2006	1601	178	94	46	14	9	2	3			9	1	11.1%
2007	3065	299	150	71	41	17	6	3			11		9.8%
2008	3198	255	106	65	36	32	7	2			7		8.0%
2009	3195	235	113	68	34	9	3	2	1		5		7.4%
2010	3284	200	105	48	24	13	2	1	1		6		6.1%
2011	2442	132	68	17	21	9	7	3			7		5.4%
2012	2405	159	71	46	23	7	4	7			1		6.6%
2013	2813	180	87	46	25	7	7	2			6		6.4%
2014	1812	85	46	25	11	1					2		4.7%
2015	1106	55	38	8	7						2		5.0%
2016	1270	67	41	16	2	1	5	1			1		5.3%
2017	739	26	14	4	3	5							3.5%
2018	155	10	9	1									6.5%
2019	413	9	6	3									2.2%
2020	275	3	2	1									1.1%
2021	159	0											
Unk	2348	1067									1067		45.4%
Grand Tot	151743	10647	5590	2007	924	401	161	149	10	3	1396	6	7.0%

Table 2. Blue shark summary of conventional tag releases (Rel) and recaptures (Cap) by Stock geographic area.

Stock Area	Rel	Cap	% Cap	North	% North	South	% South	Med	% Med
North	133337	9501	7.13%	9169	96.51%	37	0.39%	2	0.02%
South	5288	105	1.99%		0.00%	102	97.14%	1	0.95%
Med	773	63	8.15%	4	6.35%	0	0.00%	57	90.48%
Unk	246	954							
Total	**139644**	**10623**	**7.61%**	**9173**		**139**		**60**	

Table 3. Blue shark summary of conventional tag releases and recaptures by main gear type (top) and corresponding estimated overall percent of recaptures (bottom).

		Gear_Recapture						
Gear_Rel	**Tot Rel**	**LL**	**RR**	**UN**	**GILL**	**TR**	**PS**	**Total**
RR	99588	4027	3349	464	37	29	2	**7908**
LL	33624	1133	205	101	5	7	0	**1451**
UNK	6201	857	267	112	7	3	0	**1246**
TR	108	2	4	0	0	2	0	**8**
GILL	89	3	4	0	2	0	0	**9**
PS	34	1	0	0	0	0	0	**1**
Total	**139644**	**6023**	**3829**	**677**	**51**	**41**	**2**	**10623**

Percent recaptures						
LL	**RR**	**UN**	**GILL**	**TR**	**PS**	**Total**
4.04%	3.36%	0.47%	0.04%	0.03%	0.00%	7.94%
3.37%	0.61%	0.30%	0.01%	0.02%	0.00%	4.32%
13.82%	4.31%	1.81%	0.11%	0.05%	0.00%	20.09%
1.85%	3.70%	0.00%	0.00%	1.85%	0.00%	7.41%
3.37%	4.49%	0.00%	2.25%	0.00%	0.00%	10.11%
2.94%	0.00%	0.00%	0.00%	0.00%	0.00%	2.94%

Table 4. Blue shark summary of conventional tag releases and recaptures by tag type; stainless steel (ST-Steel) tags and double-barb plastic streamer (St-Dart1) tags, with overall percent of recapture.

Tag Type	Releases	Recaptures	% recap
ST-Steel	116773	8612	7.37%
St-Dart1	4335	64	1.48%
No info	19874	2000	
Total	**140982**	**10676**	

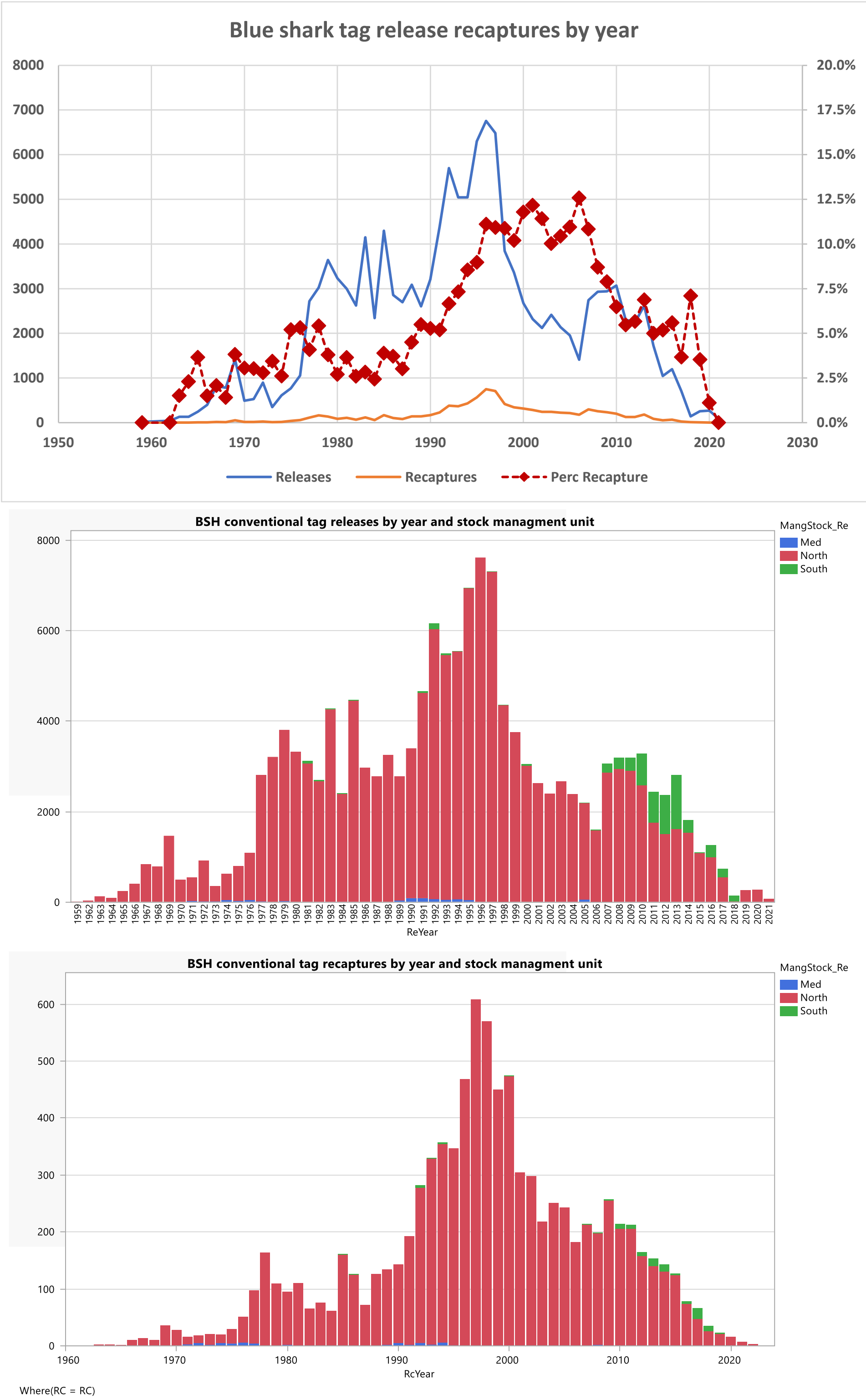


Figure 1. Blue shark conventional tag releases (top) and recaptures (bottom) by year and management stock unit.

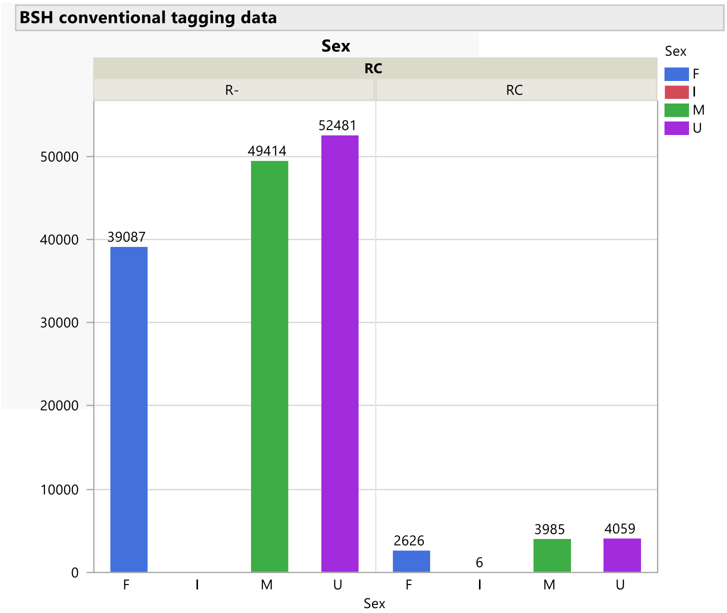


Figure 2. Blue shark sex information distribution of the conventional tag releases (R-) and recaptures (RC).

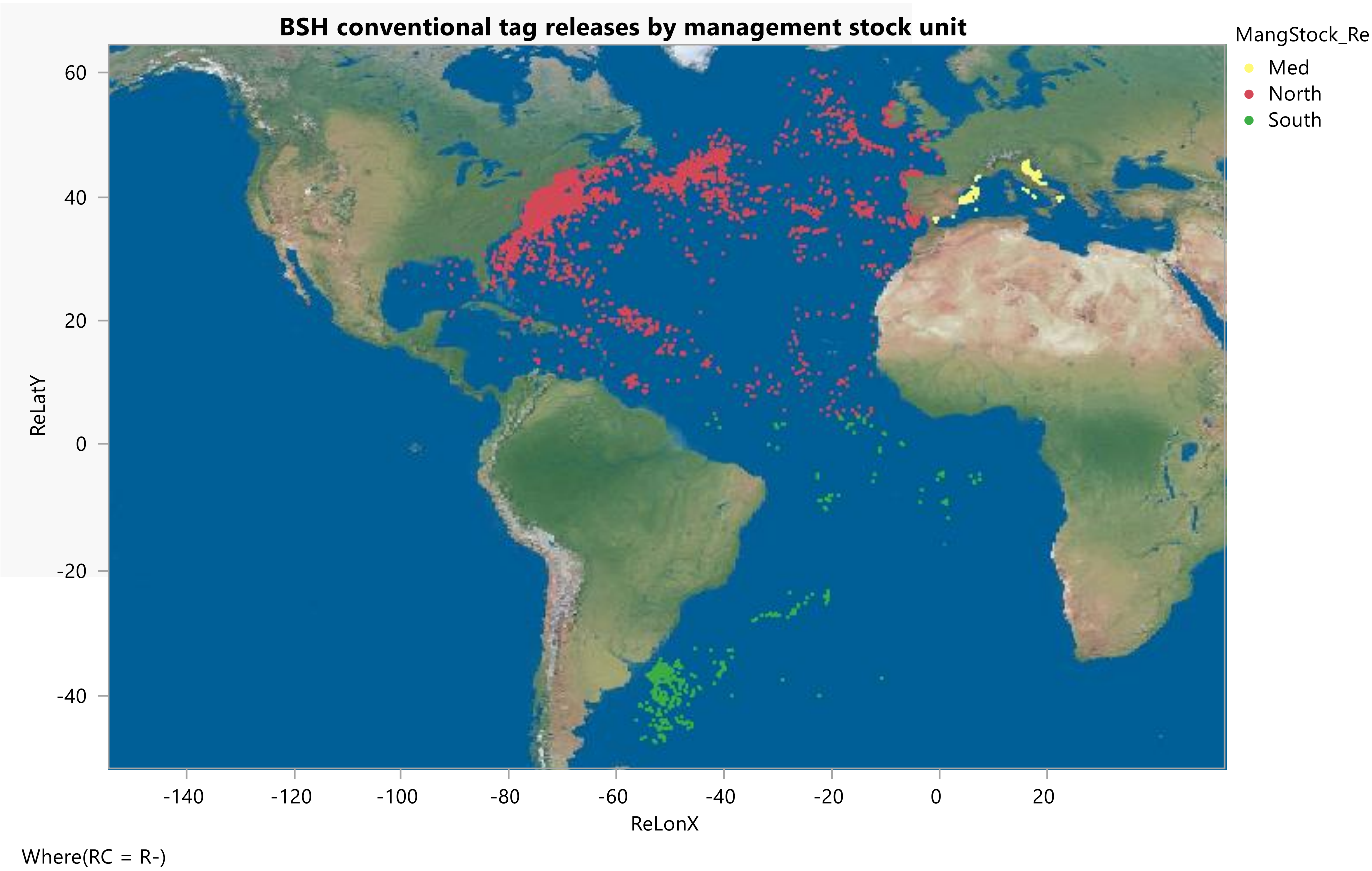


Figure 3. Atlantic blue shark conventional tag releases by management stock unit spatial distribution 1959 - 2019.

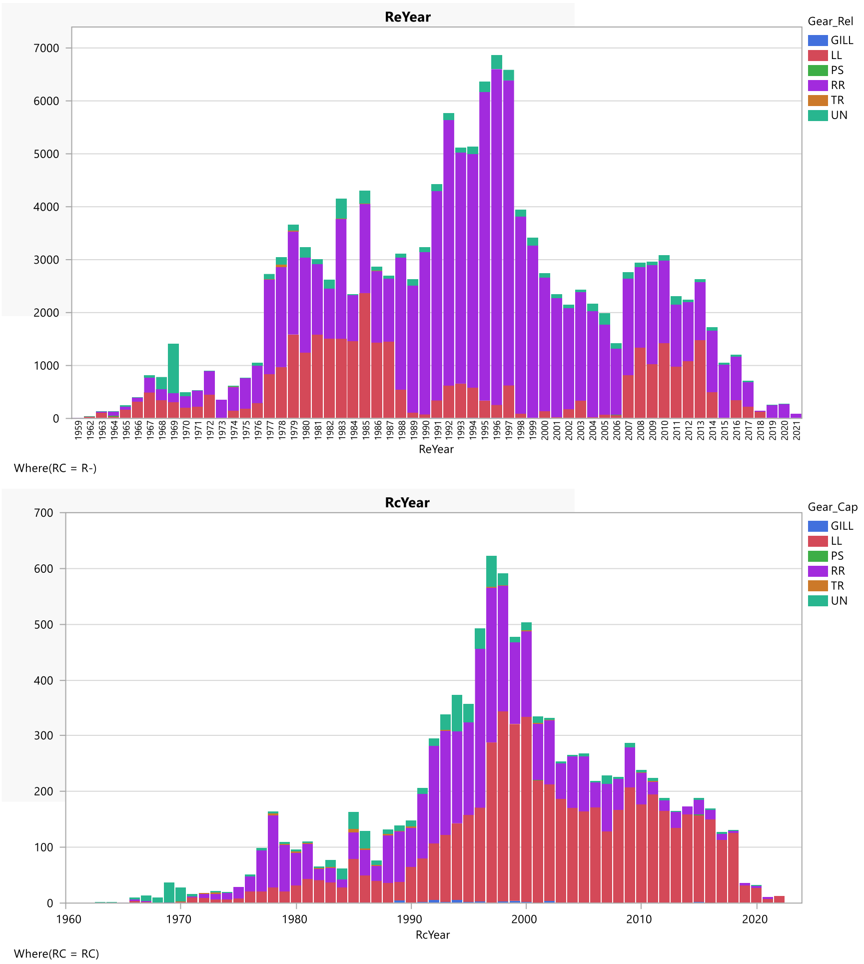


Figure 4. Atlantic blue shark conventional tag releases (top) and recaptures (bottom) distribution by main gear type and year.

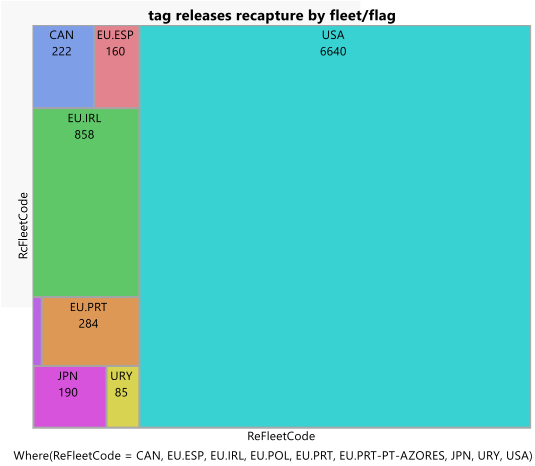
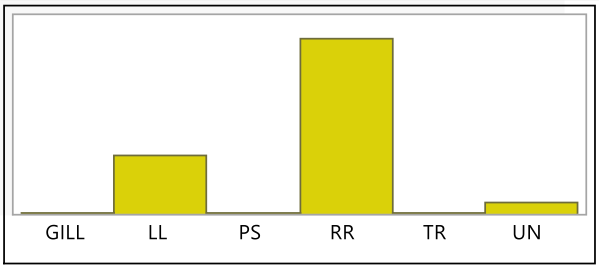


Figure 5. Blue shark conventional tag recaptures distribution by fleet/flag of release and recapture.

Distributions

Gear_Rel



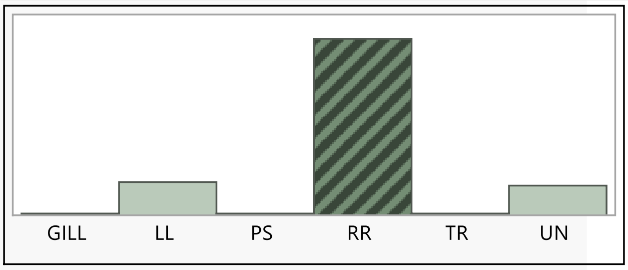
Frequencies

Level	Count	Prob
GILL	92	0.00065
LL	33719	0.23917
PS	34	0.00024
RR	100806	0.71503
TR	112	0.00079
UN	6219	0.04411
Total	140982	1.00000

N Missing 0
6 Levels

Distributions

Gear_Rel

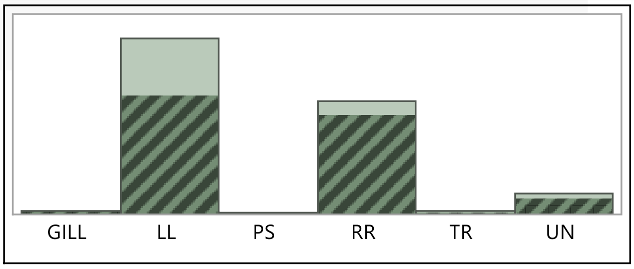


Frequencies

Level	Count	Prob
GILL	9	0.00084
LL	1451	0.13591
PS	1	0.00009
RR	7963	0.74588
TR	4	0.00037
UN	1248	0.11690
Total	10676	1.00000

N Missing 0
6 Levels

Gear_Cap



Frequencies

Level	Count	Prob
GILL	54	0.00506
LL	6028	0.56463
PS	2	0.00019
RR	3871	0.36259
TR	42	0.00393
UN	679	0.06360
Total	10676	1.00000

N Missing 0
6 Levels

Figure 6. Atlantic blue shark distribution of tag releases by main gear (top) and recaptures. The recaptures from the original rod & reel releases (middle row) are highlighted to indicate the gear of recapture (bottom row).

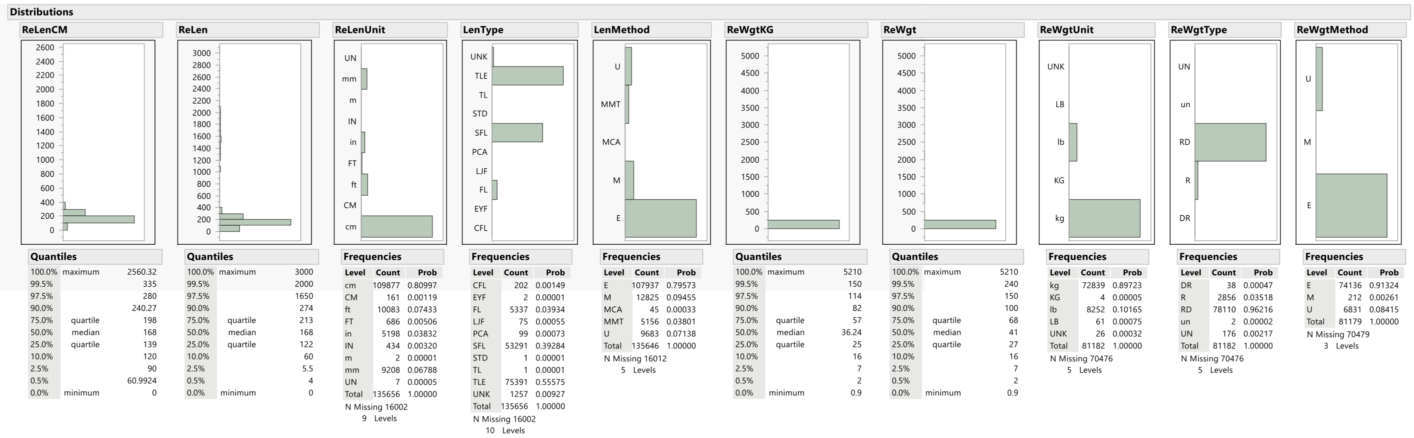


Figure 7. Atlantic blue shark size (Len) and weight (wgt) distributions of reported measures, type of measure, units, and measurement methods for tag releases.

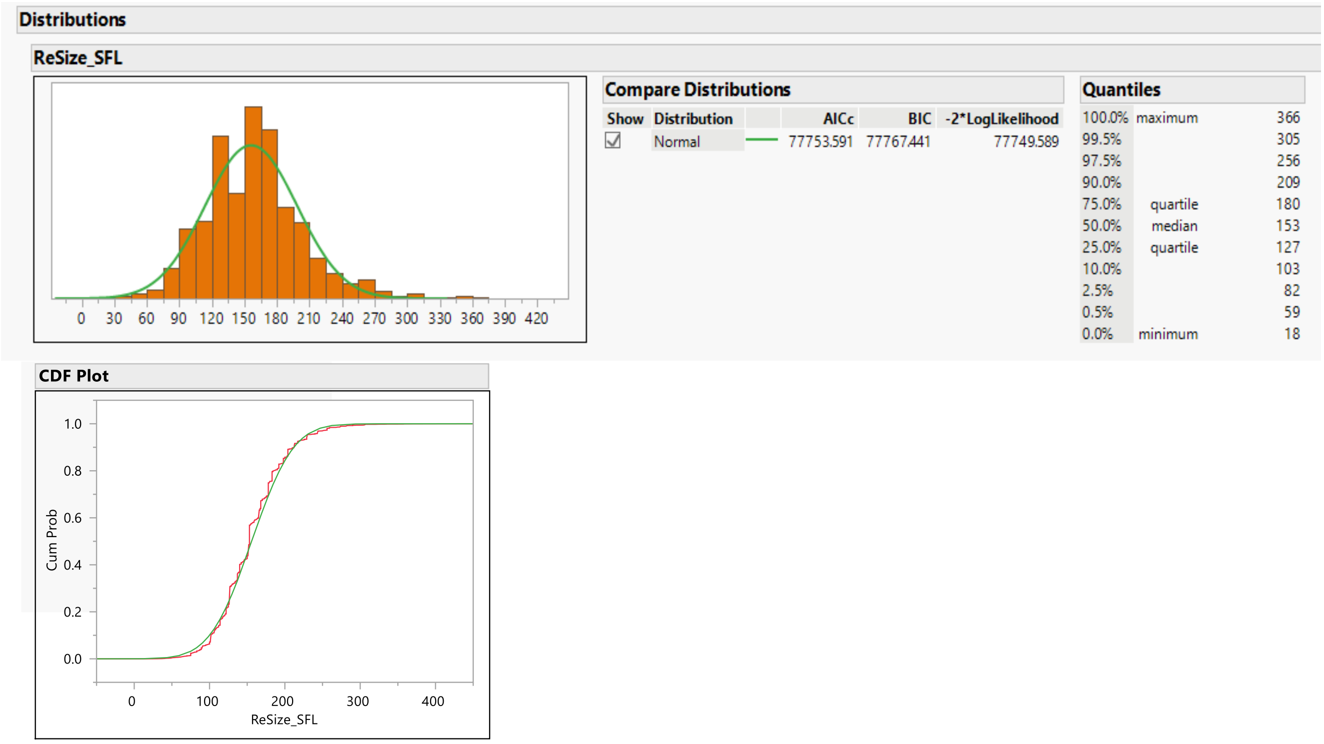


Figure 8. Atlantic blue shark size (SFL cm) distribution of conventional tag releases 1959-2019. Solid line is the fitted normal distribution to the observed data.

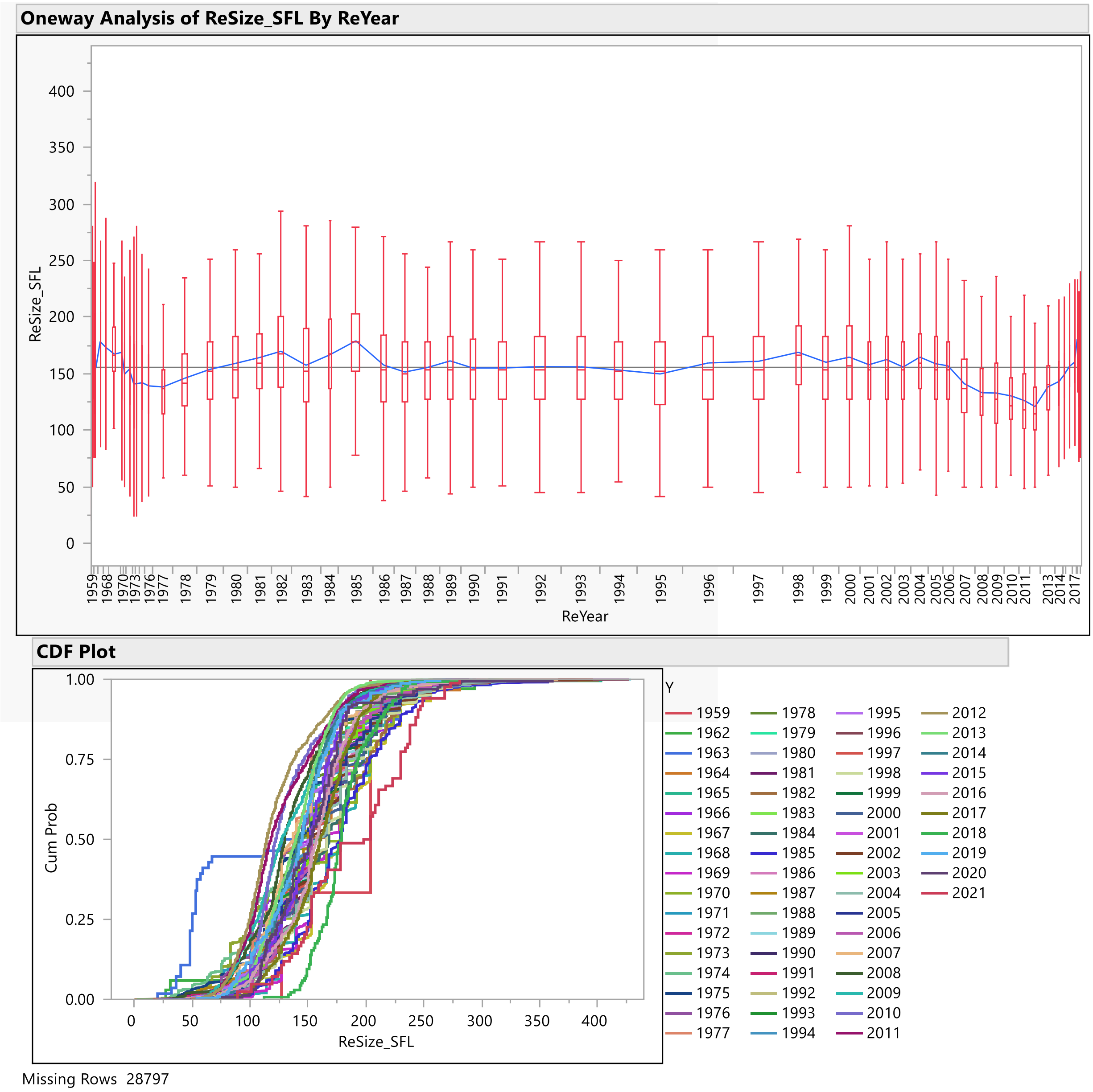
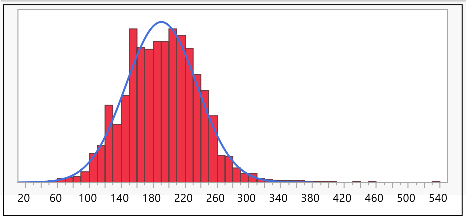


Figure 9. Atlantic blue shark annual size (SFL cm) distributions of tag releases (top) and cumulative probability distribution (bottom). Solid blue line indicate the average size trend, with of boxplots is proportional to the number of tag releases.

Distributions

CpSize_cm



Compare Distributions

Show	Distribution		AICc	BIC	-2*LogLikelihood
☑	Normal		98604.324	98618.631	98600.323

Quantiles

100.0%	maximum	535
99.5%		318
97.5%		275
90.0%		245
75.0%	quartile	220
50.0%	median	190
25.0%	quartile	158
10.0%		132
2.5%		107
0.5%		85
0.0%	minimum	40

Summary Statistics

Mean	190.47414
Std Dev	44.540862
Std Err Mean	0.4581142
Upper 95% Mean	191.37214
Lower 95% Mean	189.57613
N	9453
N Missing	142205
Minimum	40
Maximum	535

Fitted Normal Distribution

Parameter		Estimate	Std Error	Lower 95%	Upper 95%
Location	μ	190.47414	0.4581142	189.57625	191.37202
Dispersion	σ	44.540862	0.0485416	44.445824	44.549914

Measures	
-2*LogLikelihood	98600.323
AICc	98604.324
BIC	98618.631

CDF Plot

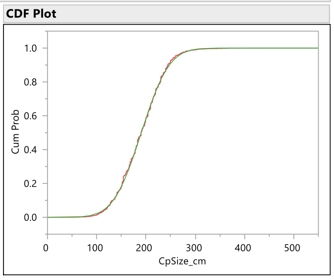


Figure 10. Atlantic blue shark size (SFL cm) distribution of conventional tag-recaptures 1959-2019. Solid line is the fitted normal distribution to the observed data.

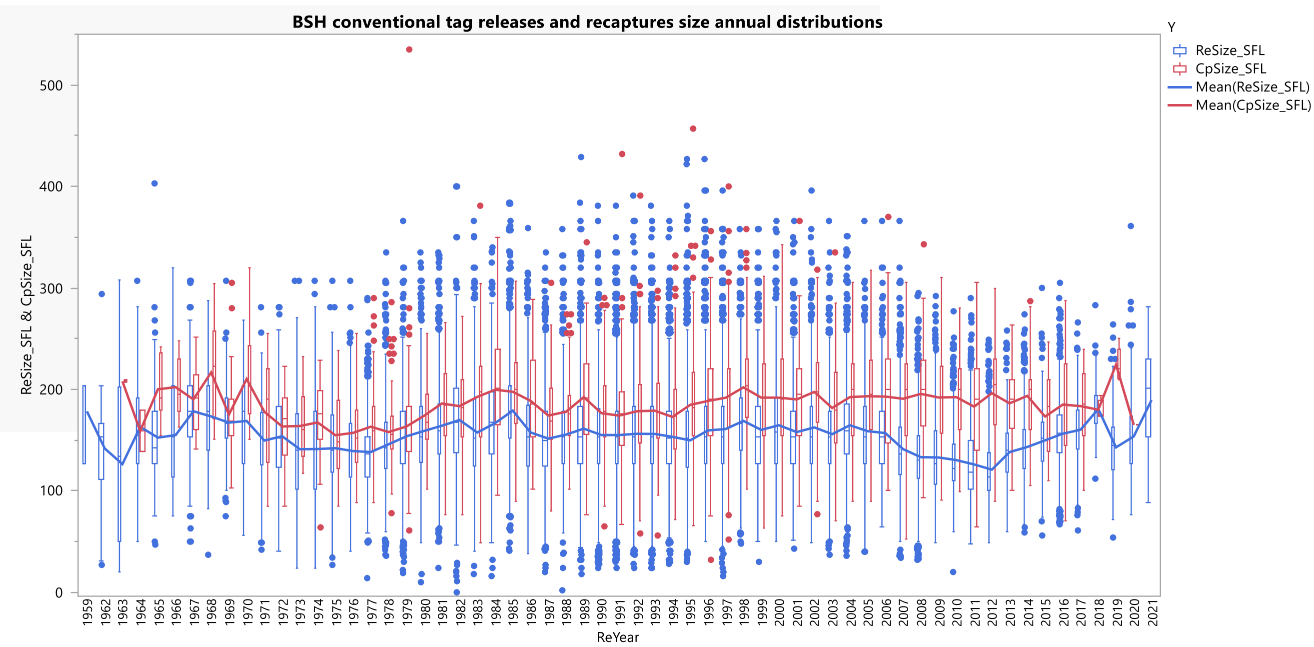


Figure 11. Atlantic blue shark annual size distributions of tag releases (blue) and recaptures (red) by year of release. Solid lines show the mean trends from 1959 to 2019.

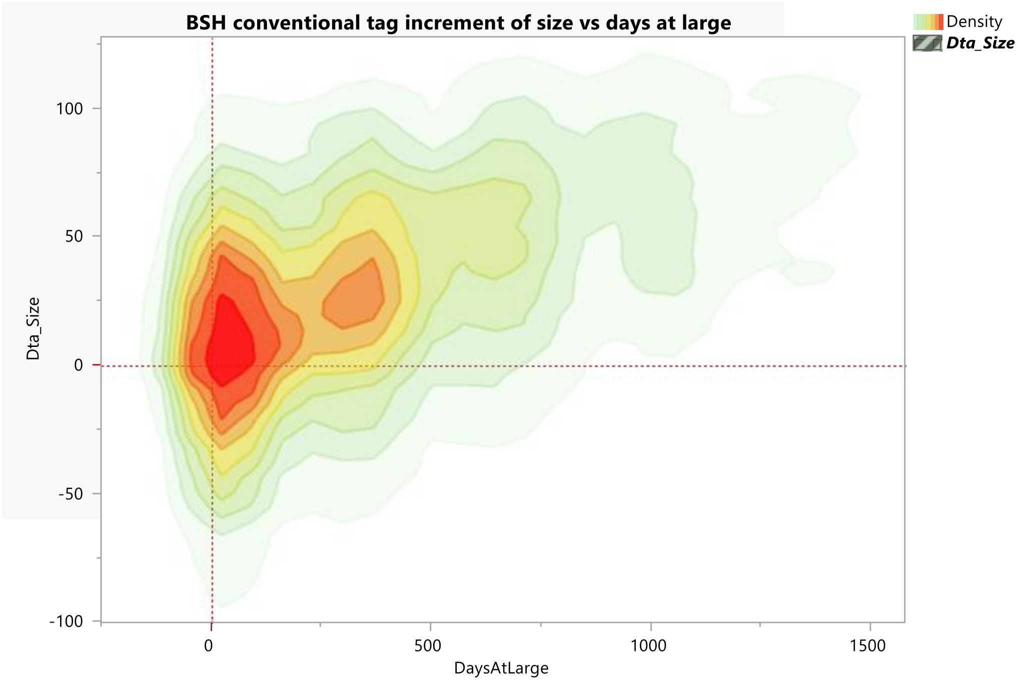


Figure 12. Non-parametric density distribution of increase of size (Dta_Size, cm SFL) and days-at-large for Atlantic blue shark conventional tag release-recaptures 1959-2019. Warm colors indicate a higher density of observations, plots also include tags with incorrect dates of release or recapture, thus the negative values in days-at-large.

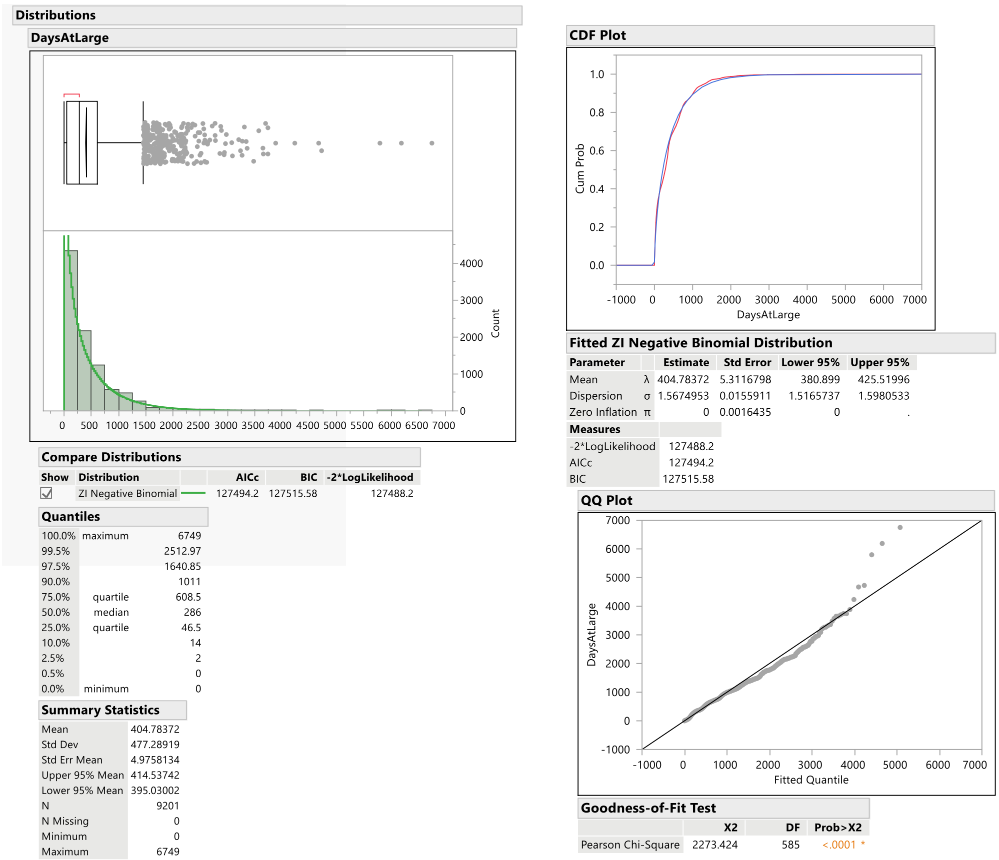
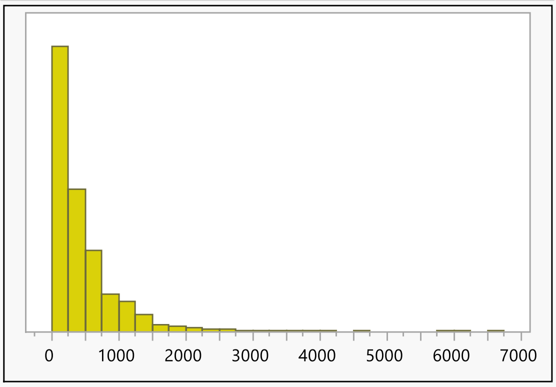


Figure 13. Atlantic blue shark days-at-large distribution of conventional tag recaptures, quantiles, summary statistics, and cumulative density plot. Solid green line represents the fitted ZI negative binomial distribution of the observed data.

Distributions

DaysAtLarge



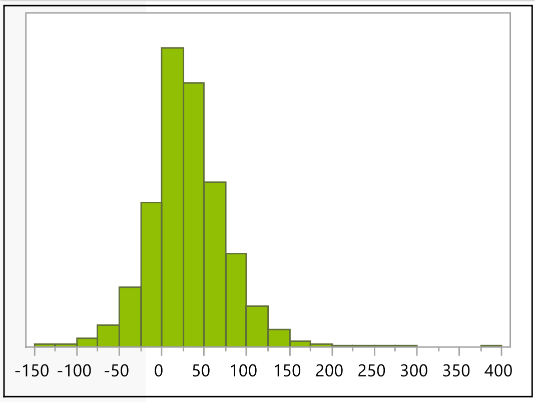
Quantiles

100.0%	maximum	6749
99.5%		2512.97
97.5%		1640.85
90.0%		1011
75.0%	quartile	608.5
50.0%	median	286
25.0%	quartile	46.5
10.0%		14
2.5%		2
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	404.78372
Std Dev	477.28919
Std Err Mean	4.9758134
Upper 95% Mean	414.53742
Lower 95% Mean	395.03002
N	9201
N Missing	0
Minimum	0
Maximum	6749

Dta_Size



Quantiles

100.0%	maximum	382
99.5%		156.26
97.5%		122
90.0%		84.2
75.0%	quartile	55
50.0%	median	26
25.0%	quartile	1
10.0%		-21
2.5%		-52
0.5%		-88.26
0.0%	minimum	-143

Summary Statistics

Mean	29.045343
Std Dev	43.058329
Std Err Mean	0.5166049
Upper 95% Mean	30.058047
Lower 95% Mean	28.03264
N	6947
N Missing	2254
Minimum	-143
Maximum	382

Figure 14. Distributions of days at large (right) and size increase (Dta_Size) for Atlantic blue shark tag releases and recaptures 1959 - 2019.

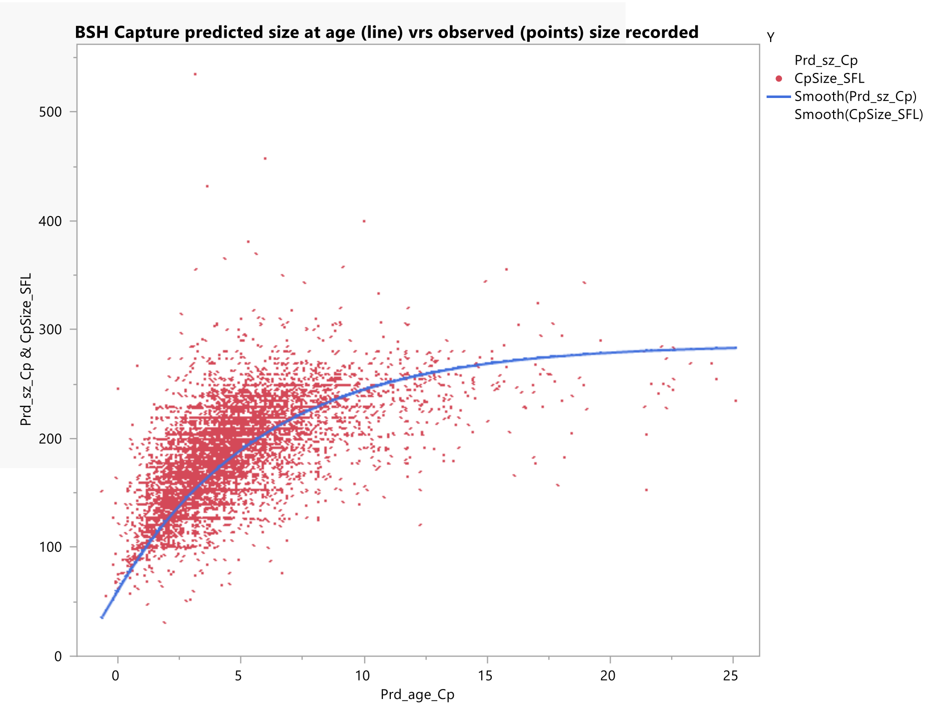


Figure 15. North Atlantic blue shark scatter plot of size (SFL cm) at age (years) as predicted by SCRS growth model (Ref) combined sex (blue solid line) and the observed size at recapture (red dots) assuming that at size and age at release were known and followed the growth model.

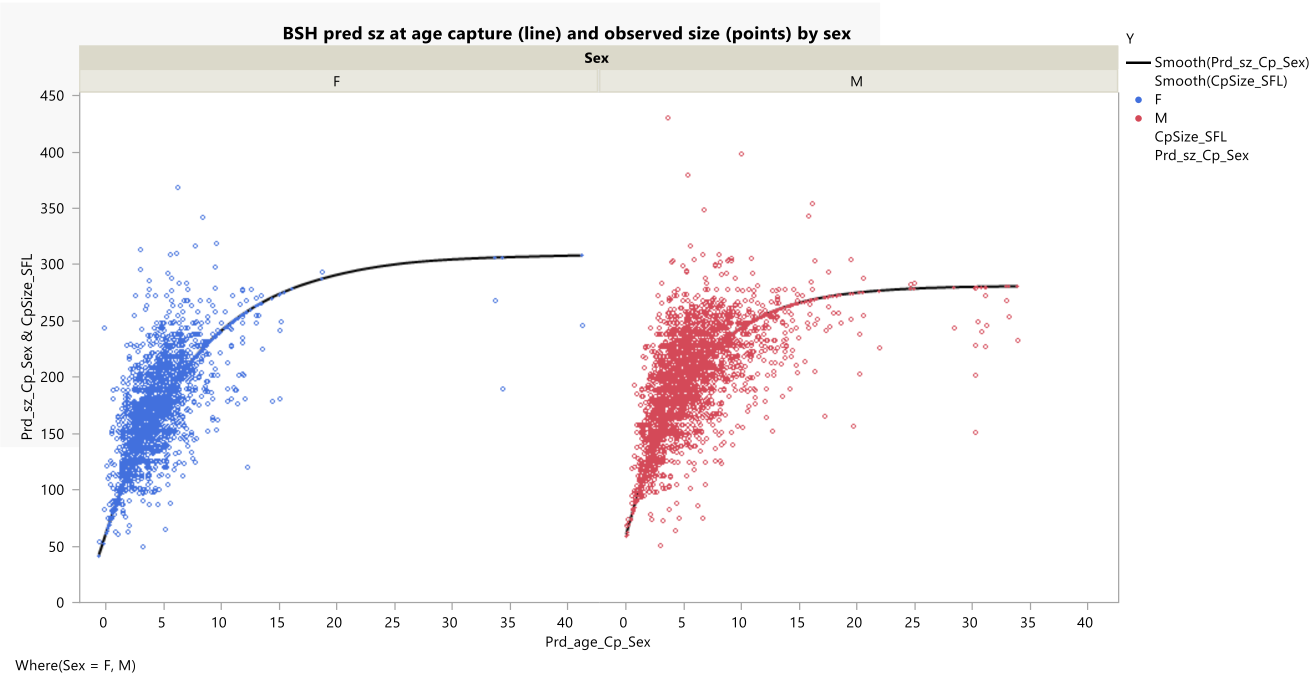


Figure 16. North Atlantic blue shark scatter plot of size (SFL cm) at age (years) as predicted by SCRS growth model (Ref) form females (F) and males (M) (solid line) and the observed size at recapture (dots) assuming that at size and age at release were known and followed the growth model by sex.

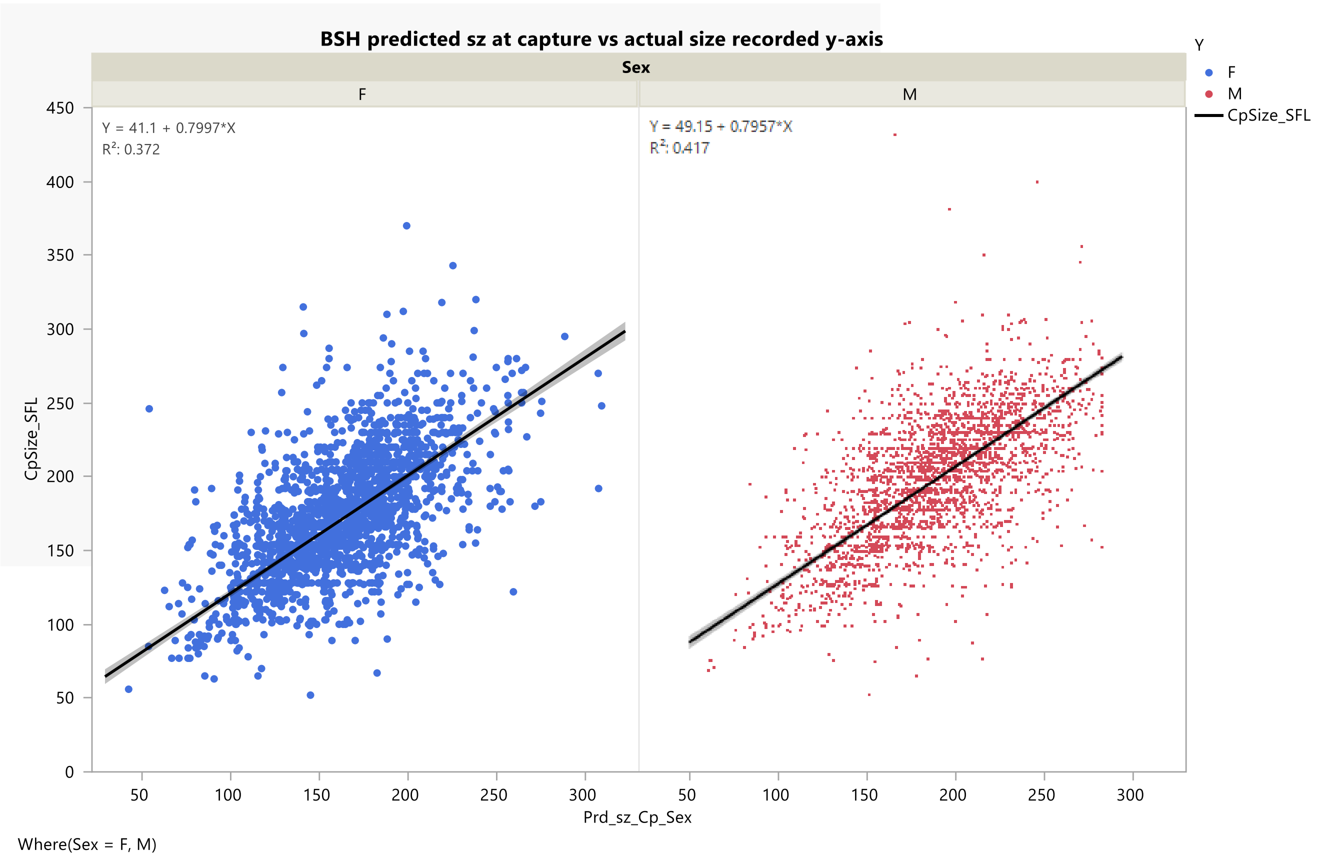
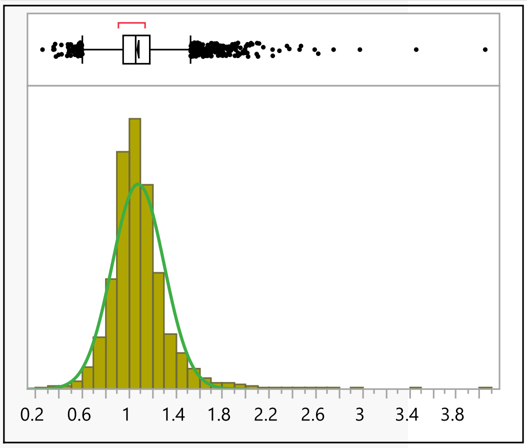


Figure 17. Comparison of the predicted (solid lines) size at capture (SFL cm) based on the current growth models for N-BSH by sex and the observed size at recapture (points).

Distributions

Rat_SzCp



Compare Distributions

Show	Distribution		AICc	BIC	-2*LogLikelihood
☑	Normal		-1137.823	-1124.146	-1141.825

Quantiles

100.0%	maximum	4.0483139905
99.5%		1.9617386507
97.5%		1.5861965494
90.0%		1.3278542716
75.0%	quartile	1.1798680393
50.0%	median	1.0538845657
25.0%	quartile	0.9490306656
10.0%		0.836506791
2.5%		0.7002522951
0.5%		0.5827262817
0.0%	minimum	0.2583691755

Summary Statistics

Mean	1.0771729
Std Dev	0.2227772
Std Err Mean	0.0026815
Upper 95% Mean	1.0824295
Lower 95% Mean	1.0719163
N	6902
N Missing	2299
Minimum	0.2583692
Maximum	4.048314

Fitted Normal Distribution

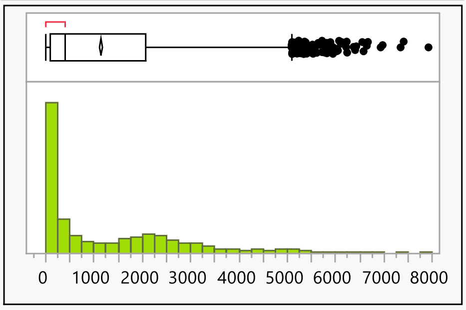
Parameter		Estimate	Std Error	Lower 95%	Upper 95%
Location	μ	1.0771729	0.0026815	1.0719172	1.0824286
Dispersion	σ	0.2227772	0.0040177	0.2150402	0.2228392

Measures	
-2*LogLikelihood	-1141.825
AICc	-1137.823
BIC	-1124.146

Figure 18. Histogram distribution of the ratio of observed size at recapture over the predicted size at recapture for Atlantic blue shark conventional tag recaptures. The predicted size at recapture assumes the N-ATL BSH growth model (see text for details).

Distributions

DistMov_km



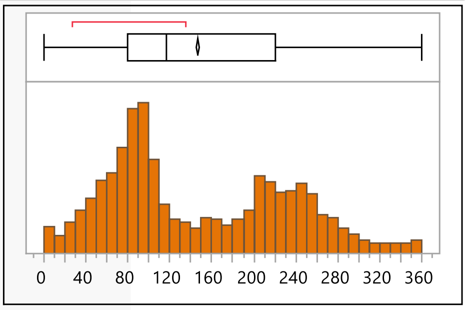
Quantiles

100.0%	maximum	7921.3901638
99.5%		5568.6875763
97.5%		4717.6129811
90.0%		3050.6253028
75.0%	quartile	2082.5249772
50.0%	median	417.58874894
25.0%	quartile	83.444469585
10.0%		30.27310103
2.5%		9.2787532707
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	1146.5194
Std Dev	1344.2672
Std Err Mean	14.064728
Upper 95% Mean	1174.0894
Lower 95% Mean	1118.9494
N	9135
N Missing	1055
Minimum	0
Maximum	7921.3902

BearingTD



Quantiles

100.0%	maximum	359.63840341
99.5%		353.5455215
97.5%		316.18662076
90.0%		261.33974998
75.0%	quartile	220.22150499
50.0%	median	116.52830145
25.0%	quartile	79.757008835
10.0%		50.109332273
2.5%		19.973252674
0.5%		0
0.0%	minimum	0

Summary Statistics

Mean	146.63079
Std Dev	84.827211
Std Err Mean	0.8875256
Upper 95% Mean	148.37054
Lower 95% Mean	144.89104
N	9135
N Missing	1055
Minimum	0
Maximum	359.6384

Figure 19. Blue shark conventional tag recaptures summary distributions of displacement distance (DistMov km) and bearing direction (degrees) between points of release and recapture.

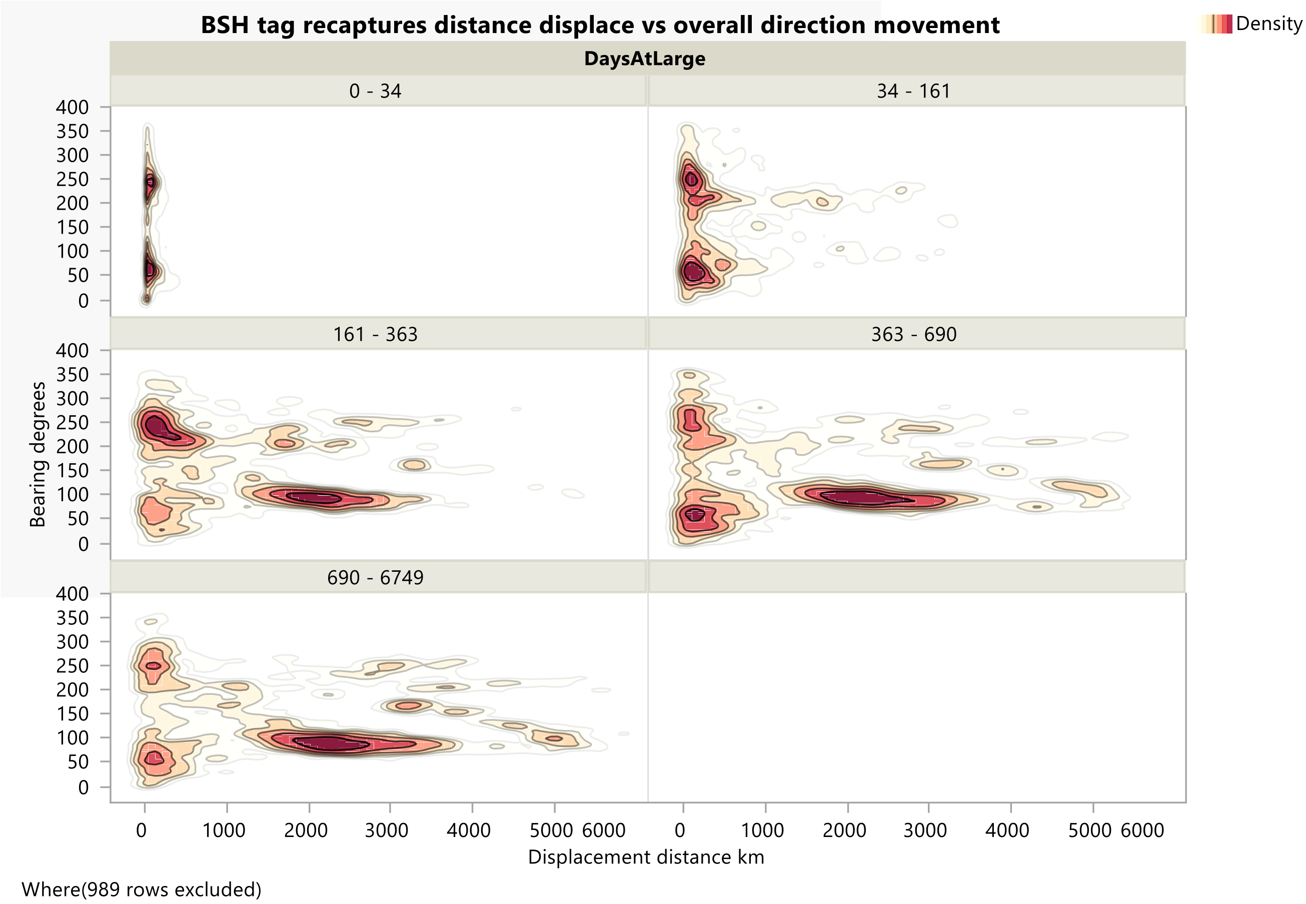


Figure 20. Blue shark tag recaptures non-parametric density distribution of displacement distance (km) and direction of movement (bearing degrees). Dark shades indicate a higher density of observations.

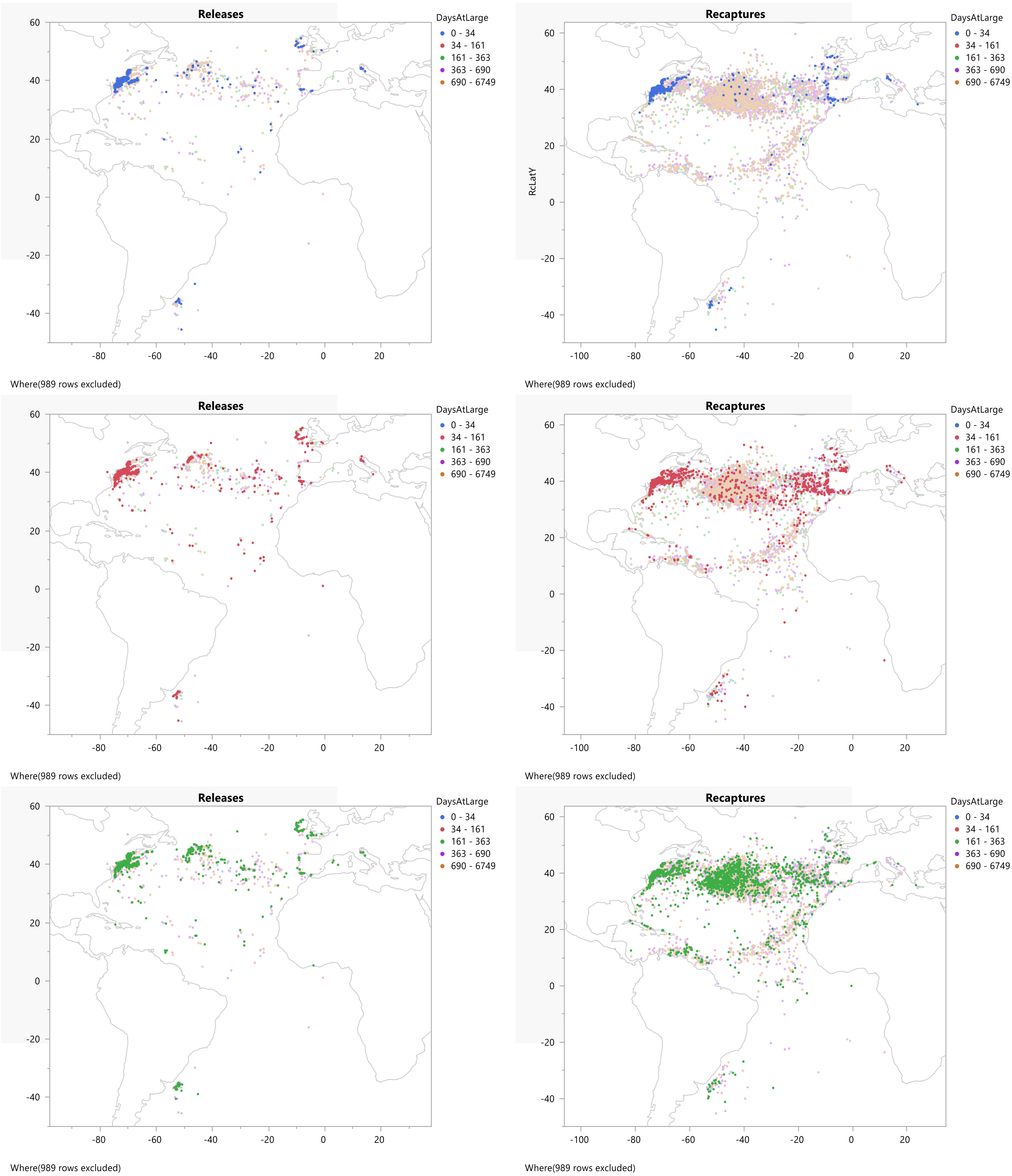


Figure 21. Blue shark conventional tag release (left column) and recaptures (right column) by days at large (rows).

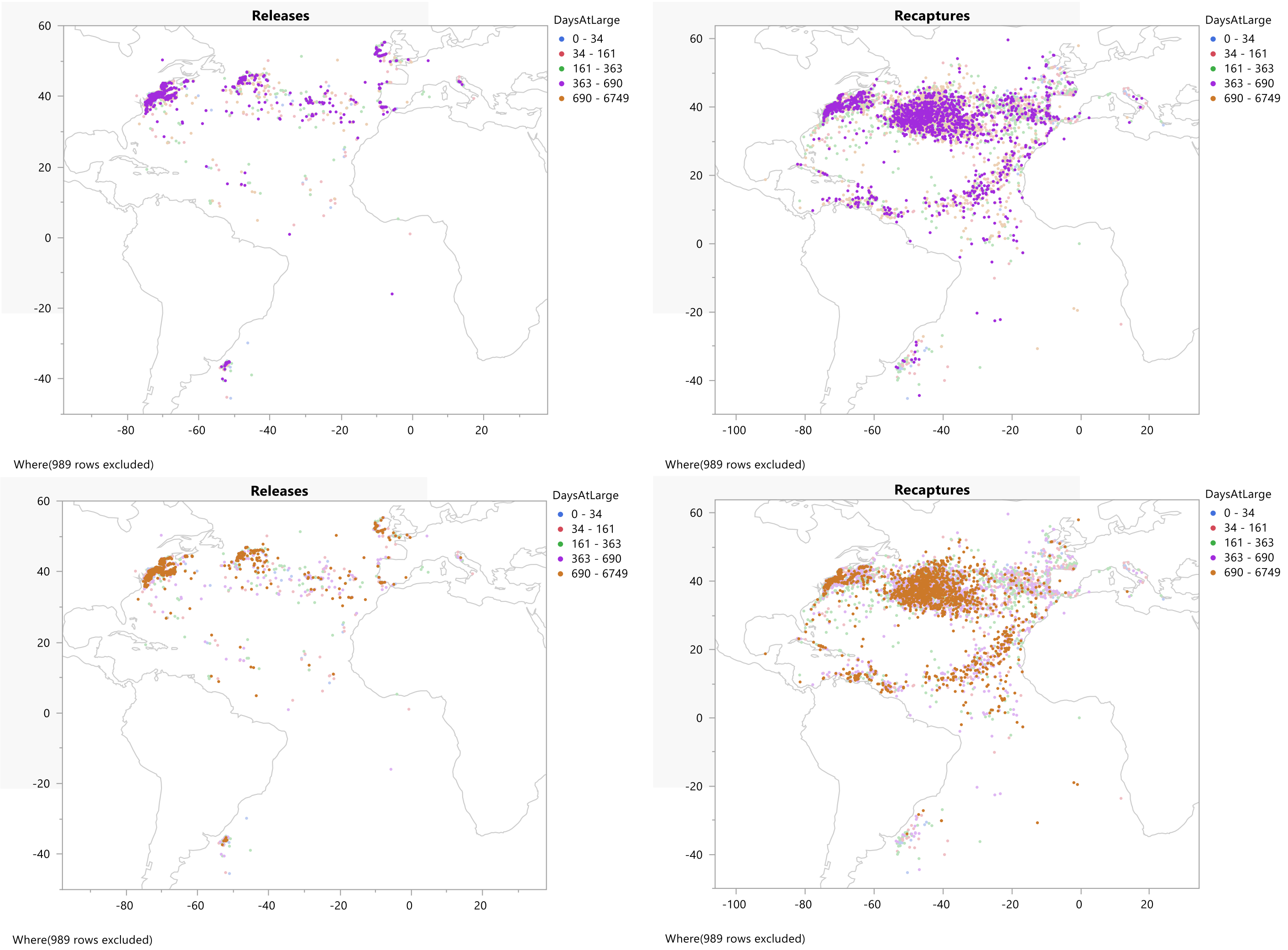


Figure 21 (continuation). Blue shark conventional tag release (left column) and recaptures (right column) by days at large (rows).