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Investigations into the winter habitat of juvenile sandbar sharks, *Carcharhinus plumbeus,* using pop-up archival satellite transmitters (PSATs).

Abstract

Defining areas of aggregation of Atlantic shark species is important for current and future management efforts. Recent studies have found that the principal summer nursery areas for the North Atlantic population of sandbar sharks occur in shallow coastal bays from New Jersey to South Carolina. The principal overwintering areas for this population are likely found off the North and South Carolina coasts. The primary objective of this project was to use a fishery independent method to examine the overwintering location and habitat preferences of large juvenile sandbar sharks. During the summer of 2003, 21 sandbar sharks captured in the Eastern Shore of Virginia bays and lagoons were outfitted with satellite transmitters that were programmed to detach during the winter of 2003/2004. Of the 21 transmitters: four transmitters did not report, 12 released prematurely, and five reported on time. Nine of the transmitters reported during the targeted overwintering period (November 2004 through February 2005). The data from these nine transmitters, was used to examine winter habitat preferences and the overwintering localities of large juvenile sandbar sharks. Satellite pop-off locations during the overwintering period were concentrated in central North Carolina coastal waters. The sharks predominantly remained in waters ranging from 18 to 22° C and in depths ranging from 0 to 50 m and there was a shift into deeper and slightly colder waters during this period.

Introduction

Sharks are harvested in significant numbers by commercial and recreational fisheries on the Atlantic and Gulf Coasts of the United States. The recreational fishery for Atlantic sharks expanded considerably during the 1970s reaching a maximum in 1974-75, with 1,588,000 sharks caught in the Atlantic Ocean, Gulf of Mexico, and Caribbean Sea. Directed commercial fisheries for sharks in the North Atlantic have been present intermittently since the 1930s but expanded rapidly during the 1980s with landings reaching a maximum value in 1989 (Stone et al. 1998). The sandbar shark is the most abundant large coastal shark found in the waters off the East Coast of the United States and is the principal species caught by the commercial shark fishery. Atlantic sandbar sharks have been federally managed as a member of the large coastal species group since 1993 and are currently managed under the 1999 Final Management Plan for Atlantic Tunas, Swordfish, and Sharks and the 2003 Amendment 1 to this plan. Current management measures include regional commercial quotas split into trimester fishing seasons, a recreational bag limit, a list of prohibited species, and a time area closure off North Carolina (NMFS 2003).

Sandbar sharks are found globally in warm temperate and tropical waters. The North Atlantic population of sandbar sharks ranges from Cape Cod to the western Gulf of Mexico. This population migrates seasonally and segregates by sex during much of the year. In the summer, sandbar sharks are common from Long Island to West Palm Beach, Florida. In the winter months, sandbar sharks are common from the Carolinas around the tip of Florida to the western coast of Florida (Springer 1960). Springer (1960) reported the winter distribution of the juveniles of this population to be waters off of both Carolina coasts out to 75 fathoms. Recent studies indicate that while juveniles may range in the waters off of both Carolina coasts in the winter months, the shallow waters off the central coast of North Carolina (Cape Hatteras to Cape Lookout) may be particularly important as an overwintering area for these sharks (Grubbs et al. in press, Mersen 1998, Jensen and Hopkins 2001). Neonate and juvenile sharks have been found to remain in this area from the middle of October through the month of May (Jensen and Hopkins 2001). The principal objectives of this study were to use a fishery independent method to determine the overwintering locations of large juvenile sandbar sharks and to determine the depth and temperature habitat preferences of these animals throughout the overwintering period.

Methods

To determine the location of the overwintering grounds of large juvenile sandbar sharks in North Atlantic Ocean, 21 pop-up archival satellite transmitters were attached to sandbar sharks captured within the Eastern Shore of Virginia summer nursery area during 2003 (Figure 1). The satellite transmitters used were Pop-up Archival Transmitters (PAT) manufactured by Wildlife Computers (8345 154th Avenue NE, Redmond, WA 98052), 13 were PAT version 2, seven of the transmitters were PAT version 3. Juvenile sandbar sharks ranging in size from 121 to 144 cm total length caught by bottom set longline were brought on board the boat, measured, and a transmitter was attached. The transmitter was attached by drilling four holes into the first dorsal fin of the shark and attaching a plastic plate to the dorsal fin using cable ties, the transmitter was then attached to the fin through the plate using 250-pound monofilament line and stainless steel crimps. The transmitters were set to detach from the sharks during the period between December 2003 and February 2004. The transmitter pop-off locations were compared with data from conventional tag returns in a previous study by Grubbs et al. (in press) to determine if the pop-off locations occurred within the same geographical area.

While attached to the animal the transmitters were programmed to take hourly temperature and depth readings binned into histograms of the following temperature and depth ranges: a. depth: 0 - 4, 4.5 - 6, 6.5 - 8, 8.5 - 10, 10.5 - 12, 12.5 -14, 14.5 - 16, 16.5-18. 18.5 - 20, 20.5 - 50, 50.5 - 1000 meters, b1. temperature: 0 - 5, 5.05 - 10, 10.05 - 12.5, 12.55 - 15, 15.05 - 17.5, 17.55 - 20, 20.05 - 22.5, 22.55 - 25, 25.05 - 27.5, 27.55 - 30, 30.05 - 32.5, 32.55 - 60° C or b2. temperature: 0 - 5, 5.05 - 10, 10.05 - 15.0, 15.05 - 18, 18.05 - 20.00, 20.05 - 22, 22.05 - 24, 24.05 - 26, 26.05 - 28, 28.05 - 30, 30.05 - 32, 32.05 - 60 ° C. In addition the transmitters recorded the minimum and maximum temperatures associated with the minimum and maximum depths per day as well as up to six depths in between the minimum and maximum to create depth temperature profiles. The data from the winter months, November through February were used to determine what the depth and temperature preferences of these sharks were during their overwintering period. In addition the data from the depth temperature profiles will be used to determine the maximum and minimum depth and temperatures these sharks occurred at during the overwintering period. Lastly this data was compared with the data from the pre-migratory summer months, July through August 15 to determine if there is a shift in temperature and depth regimes as the sharks move into the overwintering area.

Results

Transmitter performance

The 21 satellite transmitters were programmed to detach during the period between December 2003 and February 2004. Of the 21 transmitters, four did not report (19%), twelve popped off early (57%), and five popped off on the scheduled day (24%). The first ten transmitters deployed were programmed to detach if the animal remained at constant depth for more than eight days. We later determined the sharks were not changing depth enough to use the constant depth release function. Four of the twelve early release transmitters released early due to being at constant depth and eight released either due to pin failure or attachment failure. The later versions of the PAT transmitter performed much more consistently, with four of the eight later version transmitters releasing at the correct time (50%) and only one of the thirteen earlier version transmitters releasing at the correct time (8%). Data transmission for the transmitters was much poorer than expected with six (67%) of the popped-off transmitters reporting less than 100 usable data lines. The remaining three transmitters reported between 189 and 340 usable data lines. Three of the nine sharks had no usable habitat data during the overwintering period and only transmitted data from prior to this time period.

Transmitter results

The objective of this study was to determine winter habitat of these sharks and despite the high early pop off rate, nine (43%) of the transmitters released during the time period (November - February) we would expect these animals to occur in their overwintering area. Two satellite transmitters that released early during the winter months remained at the surface for eight days before transmitting and appear to have been transported by oceanic currents a considerable distance (over 500 nautical miles) before transmitting data. The location of these transmitters will not be used in examining overwintering areas for these sharks but environmental data from prior to the surfacing period will be included in the habitat analysis. The remaining seven transmitters that surfaced and transmitted data in the winter months all popped up off the North Carolina coast between Cape Hatteras and 50 nautical miles southeast of the Cape Fear River (Figure 2). The transmitters popped up in waters ranging from 7.8 - 49.8 nautical miles offshore and ranging in depths from 10 - 150 meters. These animals were found between 124 to 250 nautical miles from the transmitter attachment site within the summer nursery (Table 1).

In order to compare the winter habitat preferences with the summer habitat preferences from these sharks two time periods were defined. The time period from November 1st until tag release was defined as the overwintering period, and the time period from tag attachment until September 15th, 2003 was defined as the summer nursery period. September 15th was chosen because sharks leave this nursery area between late September and the middle of October. The sharks were found in a wide range of water depths from the surface down to over 50 m during the winter months with the most common depth of occurrence being between 20 to 50 m (Figure 3). Sharks during this period occurred in all depth bins, even occurring in waters greater than 50 m deep and appear to have occupied a variety of depths throughout the overwintering period. In contrast these sharks exhibited a marked preference for shallow waters during the summer months with greater than 80 percent of the depth readings occurring in waters less than 12 meters deep. There was a noticeable decline in proportional frequency of greater depths throughout the depth range during the summer period.

The depth temperature profiles for these sharks during the winter recorded depths ranging from 0 to 172 m, whereas during the summer period the depths ranged from 0 to 24 m also indicating these animals occupy a much larger range of depths during the overwintering period. The depth profiles further reveal a decrease in the mean depth of occurrence of these large juvenile sandbar sharks from the beginning of the tag deployment (July through September) to the time of pop-off (during November – February). Several of these sharks mean depths were still decreasing when the transmitters popped-off potentially indicating these animals may increase the depth of their habitat well into the late winter and early spring months (Figure 4).

Two different temperature binnings were used to study the temperature preference of these sharks, therefore data on each of these bins will be provided separately. These sharks were found in water temperatures that range from 10 to 26 ° C during the winter months with sharks tending to prefer water temperatures ranging between 18 to 22 ° C (Figures 5a and 5b). Both data sets show a peak in the proportional frequency of depth occurrence in 17.5 to 22 ° C temperature waters with over 60% of the depth readings falling within these temperature bins during the overwintering period. There is clearly a shift into colder waters during the overwintering period. During the summer months the animals show a preference for waters with temperatures ranging from 20 to 28 ° C.

The temperature depth profiles took temperature readings ranging from 15.6 to 25.4 ° C during the overwintering period in contrast to temperature readings from 9.2 to 29.4 ° C during the summer months. The temperature profiles also show a decrease in the mean temperature of occurrence during the southern migration. A few of the sharks, however, were present in some low mean temperature waters during the end of July and the beginning of August. A cold water event took place around this time period and we measured temperatures less than 20 d° C egrees in the surface waters of three out of twenty of our regular sampling sites during the time period between July 29th to August

8th (these sampling areas had temperatures ranging between 23.9 – 29.3° C in the sampling periods prior to and after the cold water event sampling) (Figure 6). This event appears to have been limited to cold waters coming in from the inlet and sites greater than a few kilometers from the inlet had near normal temperatures, possibly indicating these sharks were closer to the inlet and the other sharks were further up into the nursery areas.

Discussion

Sandbar shark wintering areas in the North Atlantic are less well studied than summer nursery areas but tag return data from Mersen and Pratt (2001), and Grubbs et al. (in press) indicate sandbar shark wintering areas occur in shallow waters off the Carolina coasts, with higher concentrations of animals potentially occurring off the central North Carolina coast. Jensen and Hopkins (2001) studied the shark bycatch from October and November 1996-1998 and 2000, during Spanish mackerel and king mackerel sinknet fishing at Cape Hatteras, North Carolina. They found that the Cape Hatteras region was an important overwintering area for sandbar sharks as well as dusky sharks. Neonate and juvenile sandbar sharks began to arrive in this area during the last two weeks in October and remained in the region from Cape Hatteras to Cape Lookout in large numbers through the month of May. During the course of the study they had 77 tag recaptures, 73 of which were recaptured within the sampling period in the same region they were tagged in, 3 returns were animals tagged in the Delaware Bay summer nursery, and 1 return was an animal tagged in the Chesapeake Bay summer nursery. These three studies however relied upon fishery dependent fish capture or tag recoveries and reporting by observers or commercial fishermen and there is the potential for apparent patterns to reflect fishing activity and not fish abundance. Our fishery independent data support the results of these studies.

Larger juvenile sandbar sharks are thought to have a more expanded range of occurrence with animals ranging further south and more offshore than their smaller juvenile counterparts. However our study found those large juveniles with successful satellite transmitter pop offs during the course of the winter months occurred in the same general area off of North Carolina, concentrated in the region from Cape Hatteras to Cape Lookout. These animals were found to occur relatively close to shore, within 50 km of the shore and in relatively shallow waters from 10 - 100 m. When compared to Grubbs et al (2005) conventional tag-recapture study, we find that these animals occur within the same locations as those animals that were recaptured at a size greater than 100 cm total length (TL) and further offshore from those animals recaptured at a size less than 100 cm TL (Figure2). We estimated size at recapture when not known or questionable by applying the growth equation for sandbar sharks determined by Sminkey and Musick (1995). We then determined the age at tagging, added the time at liberty to determine the age at recapture, and then used the same equation to calculate the estimated size at recapture. These results indicate there is some spatial delineation between large and small juveniles with larger juveniles occurring in deeper slightly more offshore waters than small juveniles.

Large juvenile sandbar sharks of this population do appear to occupy a deeper and colder environment during the winter months than during the summer months. We saw a shift in temperatures from 20 to 28 ° C to predominantly 17 to 22 ° C . We further saw a shift in the depth regime from predominantly less than 10 meters to predominantly over

20 meters. This presumably in combination with potentially less resources available results in slower productivity during the winter months. This pattern is likely prevalent in many temporal species that migrate large distances between their summer and wintering habitats. Grusha (2005) applied satellite transmitters to cownose rays that were programmed to detach in the spring months. She found that cownose rays captured in Chesapeake Bay, Virginia overwintered in the Florida area. With animals occurring in colder and deeper waters in the winter months than during the summer months and a gradual shift in the climatic regime experienced by these rays.

The 2003 Amendment 1 to the 1999 Final Fishery Management plan for Atlantic Tunas Swordfish and Sharks includes a time area closure that encompasses the area between Cape Hatteras to the north and Cape Fear to the south, out to the sixty fathom line off the coast of North Carolina (Figure 2). This area is closed to directed shark bottom longline fishing during the months of January to July. Six of the seven pop-off locations for these sharks occurred within the area encompassed by the closed area. In addition all of the conventional tag returns with the exception of one age-10 animal occurred within the closed area during the overwintering period. There has been a significant emphasis on the delineation and protection of summer nursery areas for this species. While sharks may experience increased productivity during the nursery period, their summer distribution is quite spread out in comparison to their overwintering grounds. The concentration of both small and large juvenile sharks within this coastal area may make the population more vulnerable to overfishing within the overwintering area. This study reconfirms the importance of shallow North Carolina coastal waters as an overwintering area for juvenile sandbar and supports the size and scope of the winter closed area enacted by the 2003 management amendment.

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Table 1: Release locations and data from nine target time period releases.

No.	Distance Offshore (nm)	Nearest Land Point	Depth (fathoms)	Distance from attachment (nm)	Date of Pop-Off *scheduled	# depth data	# temp data	PDT depth range (m)	PDT temp range C
2	7.8	E of Drum Inlet, NC	10 to 20	159	12/13/03*	0	0	*	*
11	drifter	*	*	*	12/20/2003	0	0	*	*
13	27.8	S of Cape Lookout, NC	20 to 30	198	11/27/2003	0	0	*	*
16	18.0	E of Cape Hatteras, NC	20 to 30	137	01/07/04*	80	67	0-48	16.0-25.4
18	49.8	SE of Cape Fear, NC	60 to 100	250	01/24/04*	57	39	0-172	15.6-25.4
19	17.7	E of Cape Lookout, NC	20 to 30	156	02/04/04*	20	14	0-168	17.2-23.6
20	26.7	E of Cape Lookout, NC	20 to 30	168	12/04/03	25	23	0-50	17.8-24.6
21	14.1	E of Cape Hatteras, NC	30 to 40	124	01/01/04*	84	66	0-36	17.0-23.8
22	drifter	*	*	*	12/05/03	14	10	0-40	16.8-22.6

Figure 1. The locations of transmitter attachment in the Eastern Shore of Virginia's coastal bays and lagoons.

Figure 2. The locations of winter transmitter pop-off s off the North Carolina coast.

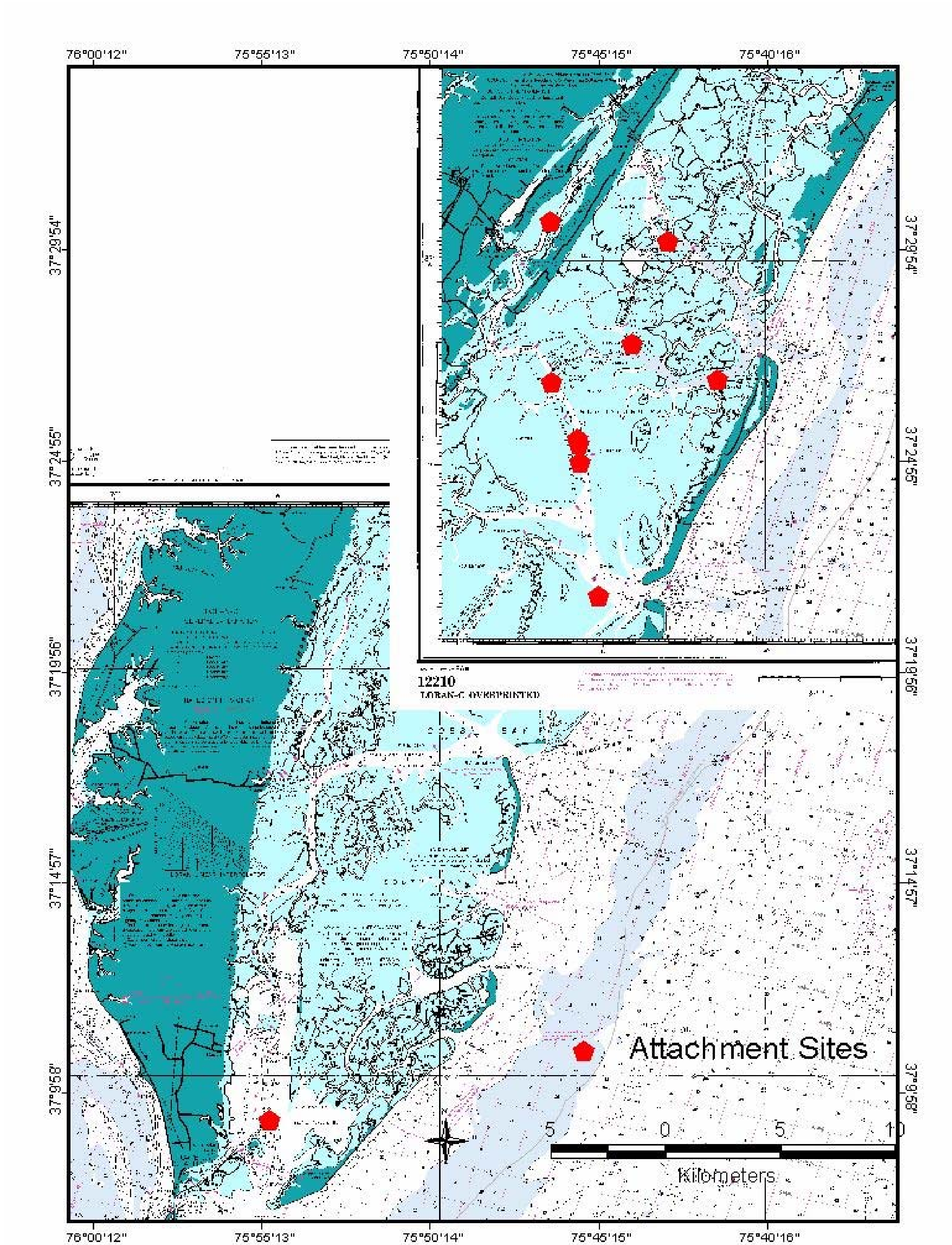
Figure 3. Cumulative depth histogram of the satellite transmitters during the winter overwintering period and the summer nursery period.

Figure 4. Mean depths from the depth profiles from the onset of transmitter attachment until transmitter release.

Figure 5. Cumulative temperature histograms of the satellite transmiiters during the overwintering period and the summer nursery period a) depth binning #1 and b) depth binning #2.

Figure 6. Mean temperatures from the temperature profiles from the onset of transmitter attachment until transmitter release.

Figure 1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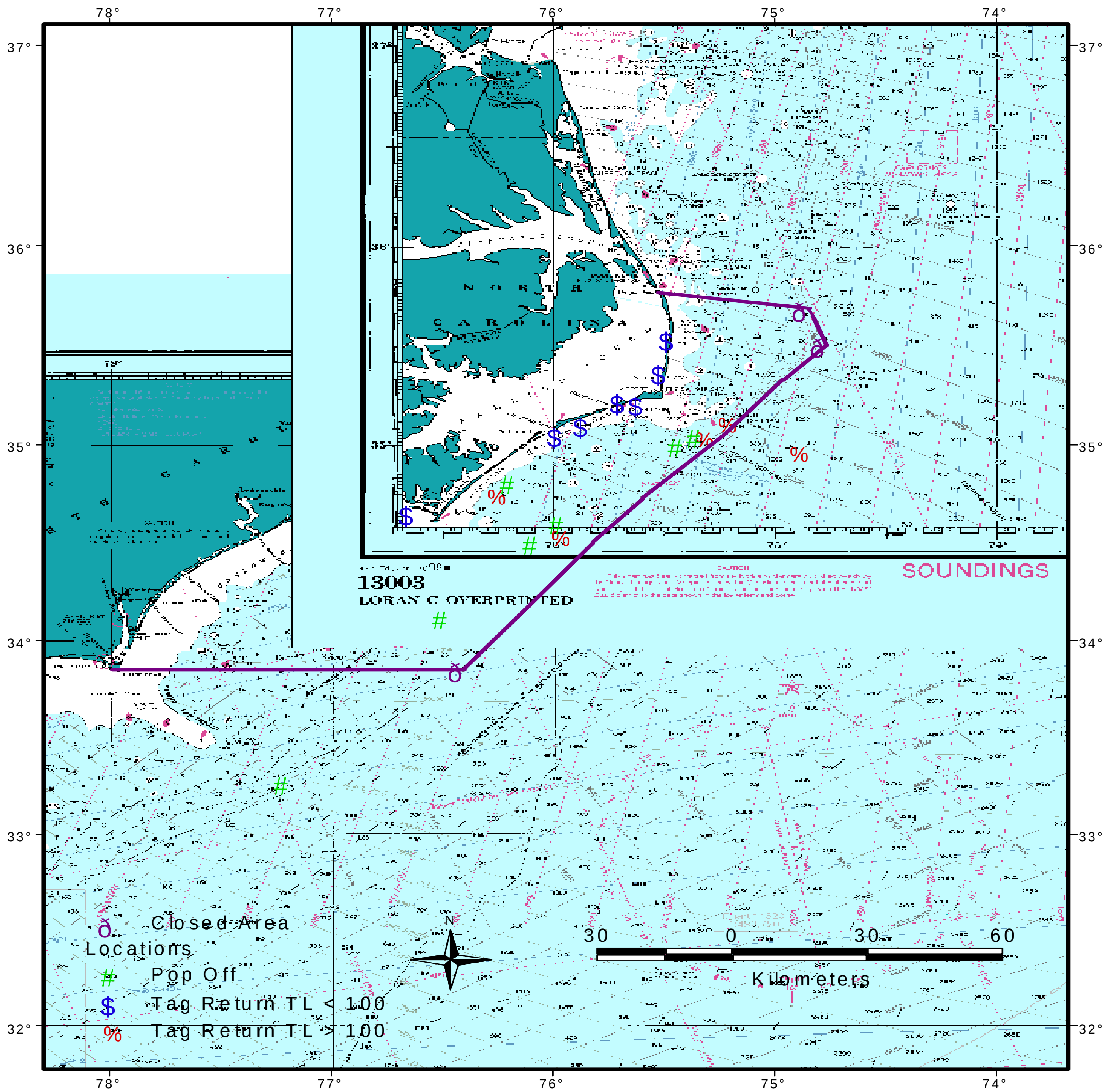
12210
Attachment Sites
5
0
5
10
Kilometers

Figure 2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76°
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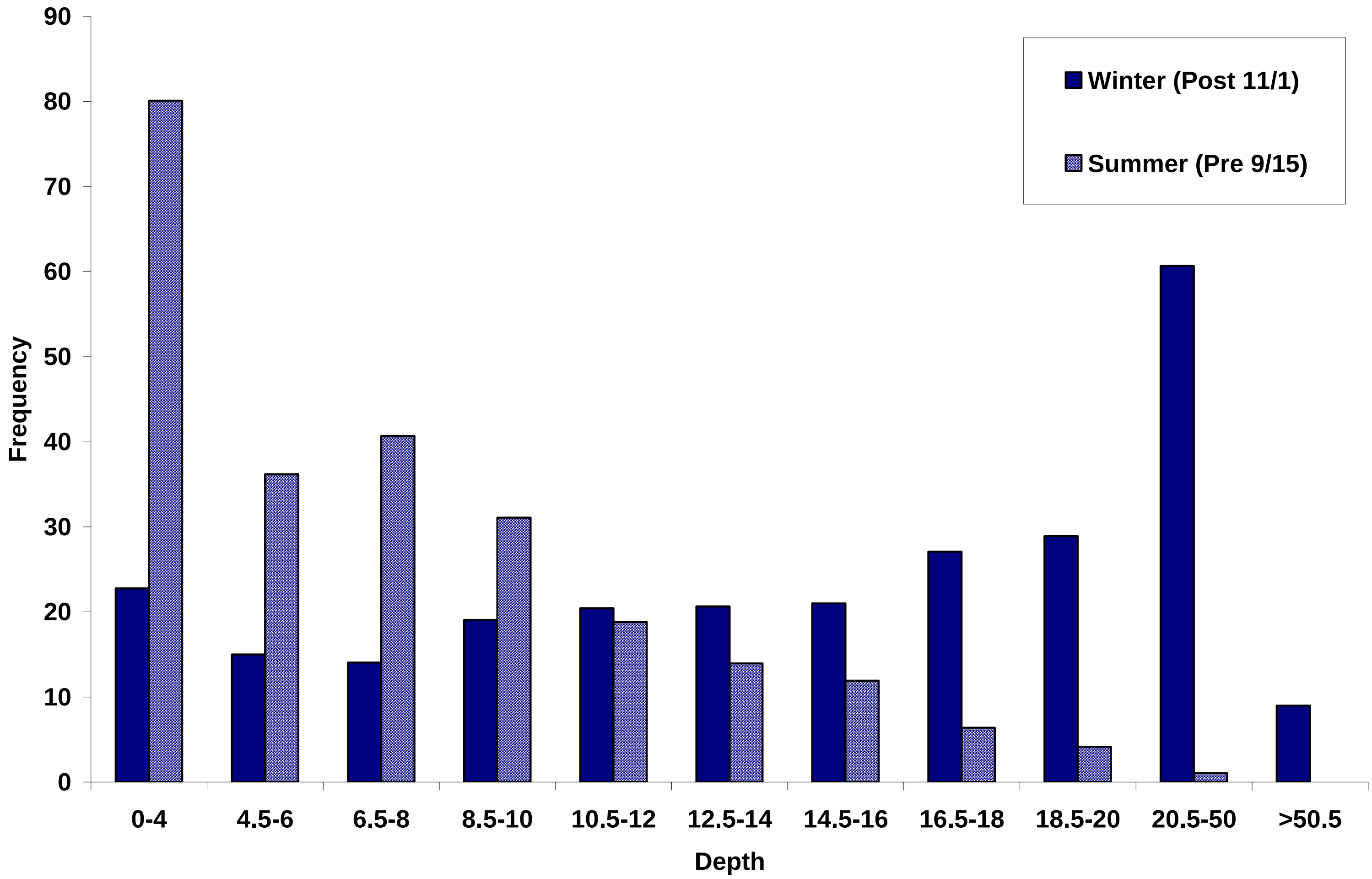
74°
37°
36°
35°
34°
33°
32°
NORTH
CAROLINA
13003
LORAN-C OVERPRINTED
SOUNDINGS
N
30
0
30
60
Kilometers
Closed Area
Locations
Pop Off
Tag Return TL < 100
Tag Return TL > 100

Figure 3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80
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60
50
40
30
20
10
0
Frequency
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Summer (Pre 9/15)
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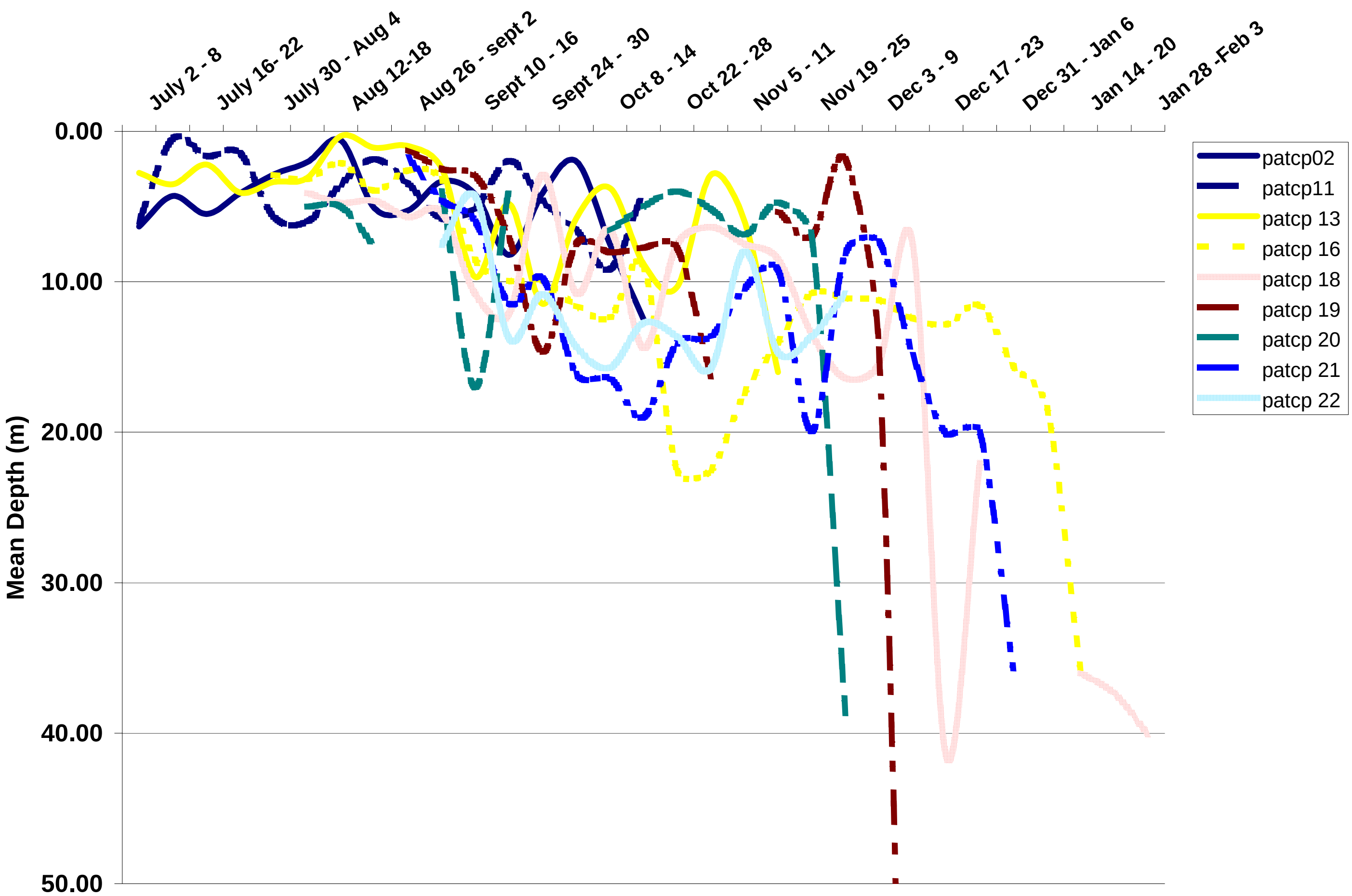
6.5-8
8.5-10
10.5-12
12.5-14
14.5-16
16.5-18
18.5-20
20.5-50
>50.5
Depth

Figure 4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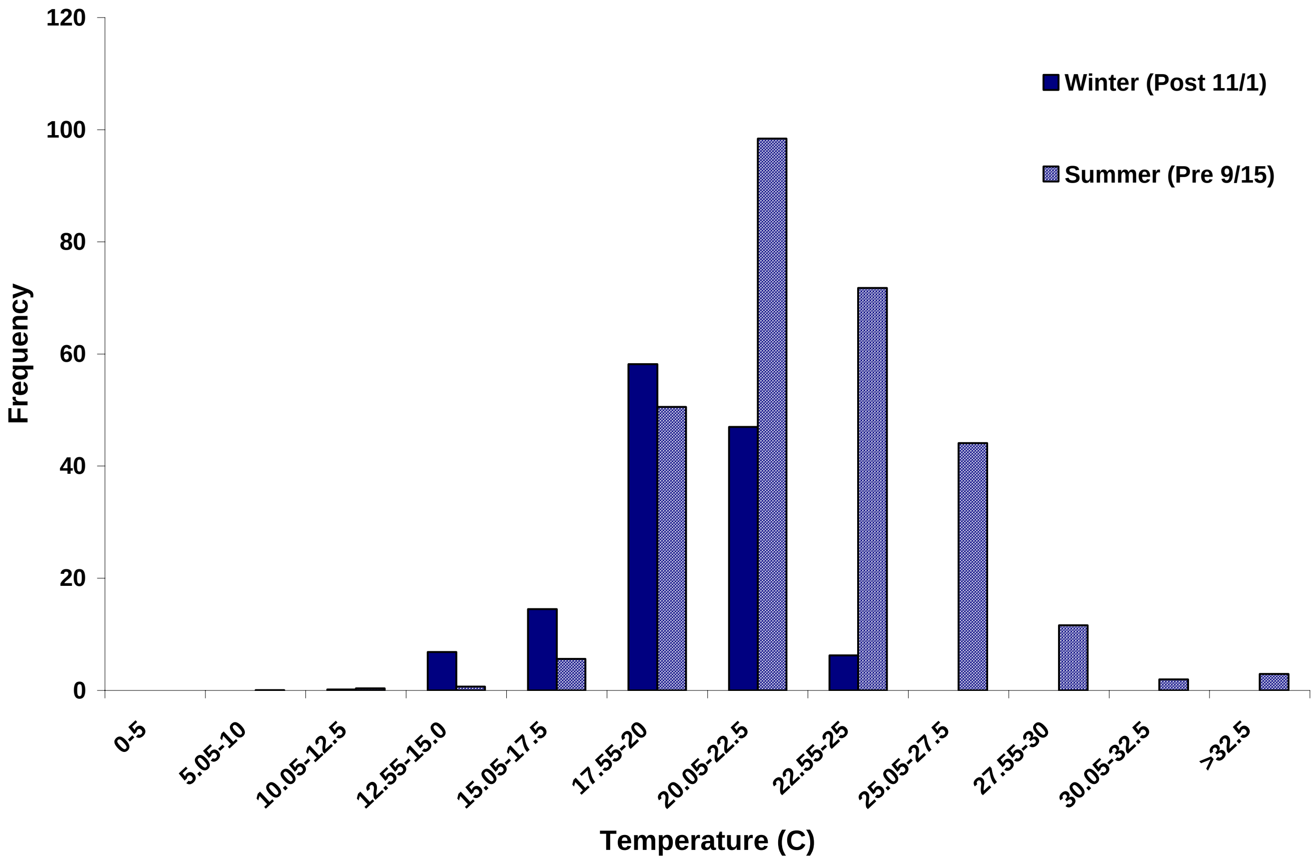
July 16- 22
July 30 - Aug 4
Aug 12-18
Aug 26 - sept 2
Sept 10 - 16
Sept 24 - 30
Oct 8 - 14
Oct 22 - 28
Nov 5 - 11
Nov 19 - 25
Dec 3 - 9
Dec 17 - 23
Dec 31 - Jan 6
Jan 14 - 20
Jan 28 -Feb 3
0.00
10.00
20.00
30.00
40.00
50.00
Mean Depth (m)
patcp02
patcp11
patcp 13
patcp 16
patcp 18
patcp 19
patcp 20
patcp 21
patcp 22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Summer (Pre 9/15)
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12.55-15.0
15.05-17.5
17.55-20
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22.55-25
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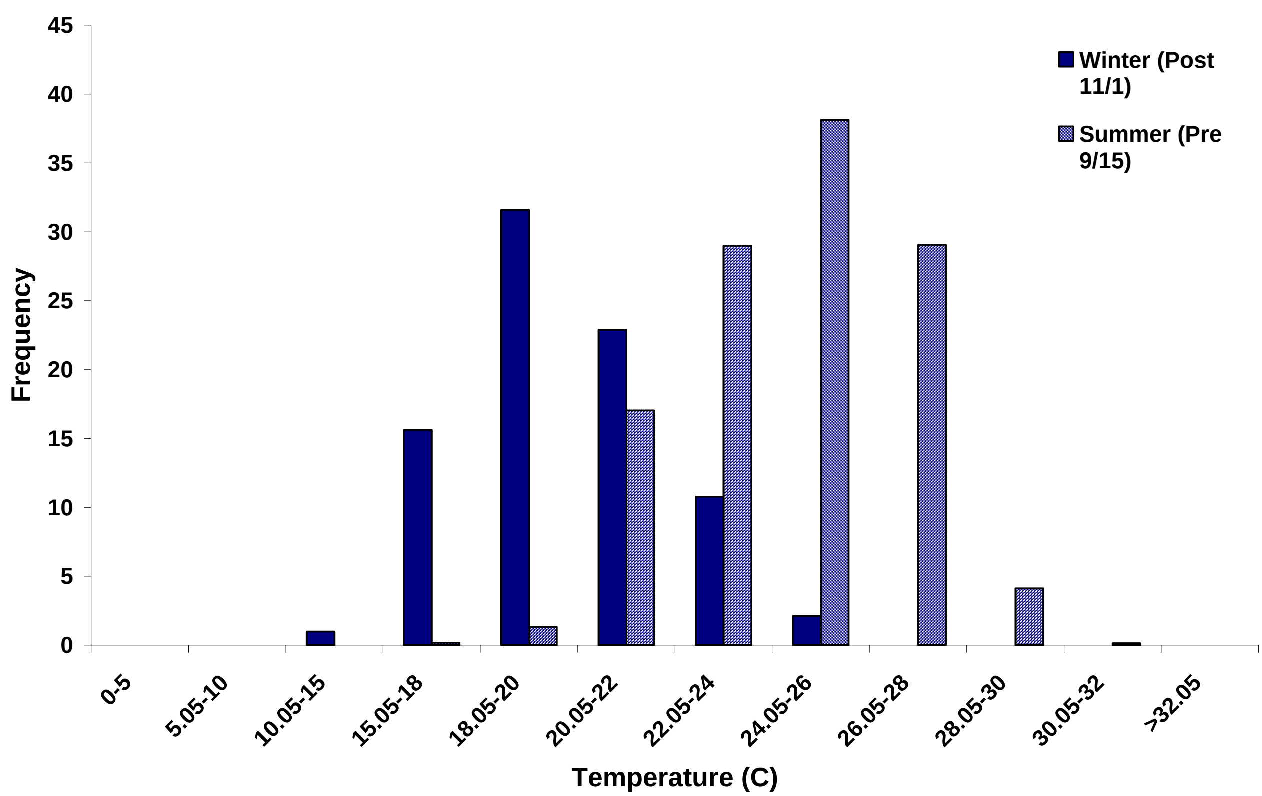
27.55-30
30.05-32.5
>32.5
Temperature (C)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10.05-15
15.05-18
18.05-20
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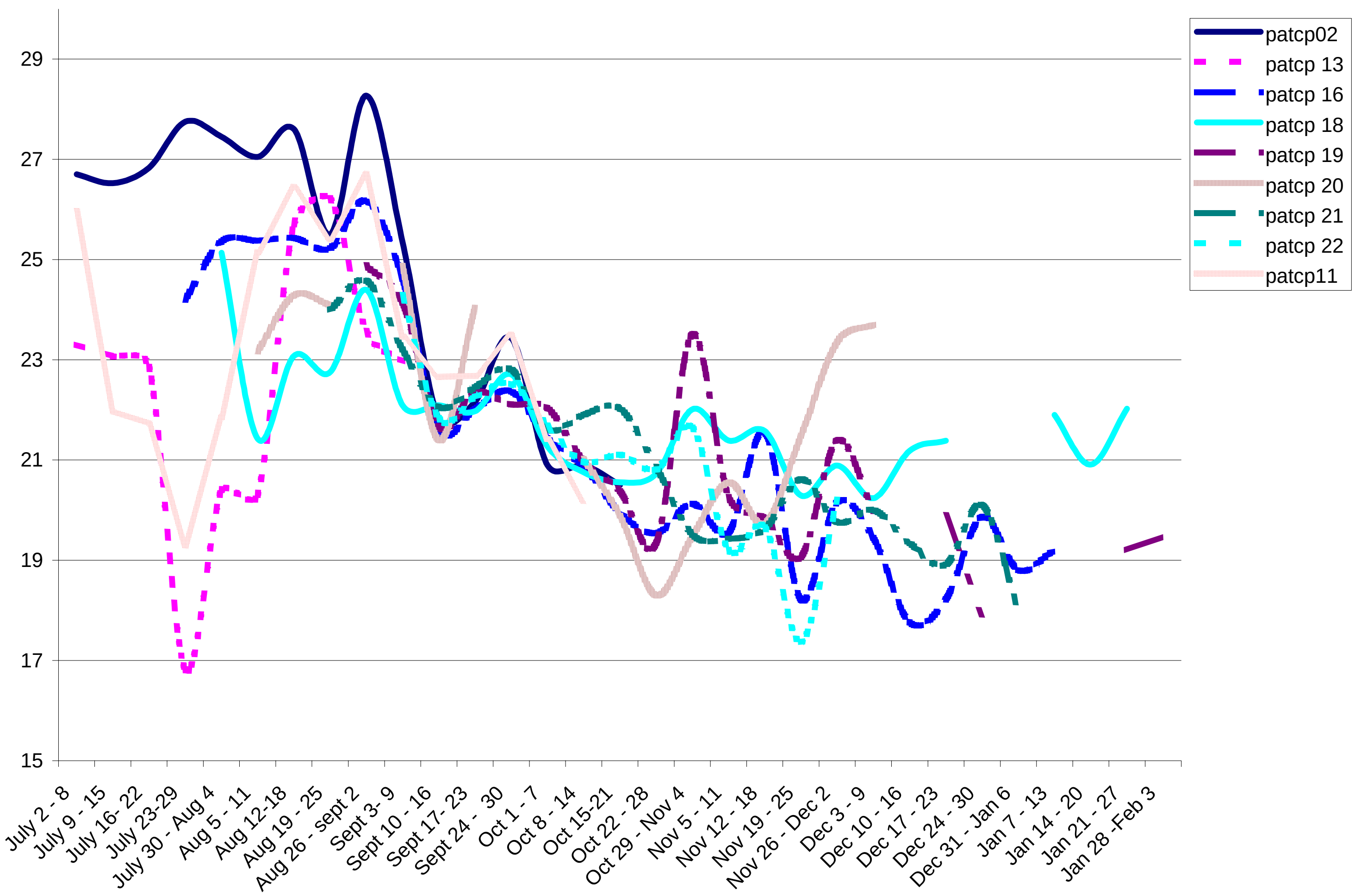
26.05-28
28.05-30
30.05-32
>32.05
Temperature (C)

Figure 6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patcp11
July 2 - 8
July 9 - 15
July 16- 22
July 23-29
July 30 - Aug 4
Aug 5 - 11
Aug 12-18
Aug 19 - 25
Aug 26 - sept 2
Sept 3- 9
Sept 10 - 16
Sept 17- 23
Sept 24 - 30
Oct 1 - 7
Oct 8 - 14
Oct 15-21
Oct 22 - 28
Oct 29 - Nov 4
Nov 5 - 11
Nov 12 - 18
Nov 19 - 25
Nov 26 - Dec 2
Dec 3 - 9
Dec 10 - 16
Dec 17 - 23
Dec 24 - 30
Dec 31 - Jan 6
Jan 7 - 13
Jan 14 - 20
Jan 21 - 27
Jan 28 -Feb 3