

Movement patterns of juvenile Atlantic tarpon (*Megalops atlanticus*) in Brewers Bay, St. Thomas US Virgin Islands

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Abstract

Background Atlantic tarpon (*Megalops atlanticus*) are a highly migratory species ranging along continental and insular coastlines of the Atlantic Ocean. Due to their importance to regional recreational and sport fisheries, research has been focused on large-scale movement patterns of reproductively active adults in areas where they are of high economic value. As a consequence, geographically restricted focus on adults has left significant gaps in our understanding of tarpon biology and their movements, especially for juveniles in remote locations where they are common. Our study focused on small-scale patterns of movement and habitat use of juvenile and subadult tarpon using acoustic telemetry in a small bay in St. Thomas, U. S. Virgin Islands.

Results Four juvenile tarpon (80 – 95 cm FL) were tracked from September 2015 to February 2018, while an additional eight juveniles (61 – 94 cm FL) left the study area shortly after tagging and were not included in analysis. The four resident tarpon had >78% residency and average activity space of 0.76 km² (range = 0.08-1.17 km²) within Brewers Bay (1.8km²). Their vertical distribution was <18 m depth with occasional movements to deeper water. Activity was greater during day compared to night, with peaks during crepuscular periods. During the day tarpon used different parts of the bay with consistent overlap around the St. Thomas airport runway and at night tarpon typically remained in a small shallow lagoon. However, when temperatures in the lagoon exceeded 30 °C, tarpon moved to cooler, deeper waters outside the lagoon.

Conclusion Our results, although limited to only four resident fish, provides new baseline data on the movement ecology of juvenile Atlantic tarpon. We showed that juvenile tarpon had high residency within a small bay and relatively stable non-overlapping daytime home ranges, except when seasonally abundant food sources were present. Fine-scale acoustic tracking for over a year showed the effects of extreme environmental conditions on tarpon movement and habitat use. These observations highlight the need for more extensive studies of juvenile and subadult tarpon across a broader range of their distribution, and compare the similarities and differences in behavior among various size classes of individuals from small juveniles to reproductively mature adults.

Background

Tracking the movements and migrations of animals in the aquatic environment provides insight into spatial and temporal patterns of habitat use, trophic interactions, reproductive behavior, and behavioral responses to environmental change [1–7]. Recent studies have shown that some highly migratory species can exhibit high site fidelity to discrete nearshore areas between migratory events, whereas relatively site-attached species can undergo repeated large-scale migrations for reproduction [1,8–10]. Integrating these variable patterns of large-scale movements and small-scale activity spaces are becoming increasingly important for implementing ecosystem-based fisheries management, understanding connectivity, and designing ecologically relevant marine managed areas [5,11,12].

Atlantic tarpon (*Megalops atlanticus*) is a highly mobile pelagic species that supports important recreational and sport fisheries. Tarpon range across coastal areas, estuaries, and rivers of the western and eastern Atlantic Ocean, the Caribbean Islands, and the Gulf of Mexico [6,13,14]. Tarpon spend their larval stage drifting as leptocephali in open ocean, and as juveniles settle nearshore in tropical and subtropical estuarine, mangrove and lagoon habitats, where food resources are high and predator pressures are low [15–18]. Adult tarpon range in size from 90-250 cm FL. Males reach sexual maturity at about 90 cm and females at 128 cm FL [13,19–21]. Much of our knowledge of tarpon movements and behaviors come from satellite tracking and conventional anchor tag studies conducted in Florida, southeast Atlantic, Gulf of Mexico, and the northwestern Caribbean (e.g., Mexico, Belize, Cuba) [6,7,13,14,22,23]. These studies have focused on large-scale movements (>500 km) of large adult tarpon (>130 cm FL) that support a valuable sport fishery. The focus on adult tarpon over a limited geographic range leaves large gaps in our understanding of tarpon biology and movement ecology, especially in insular areas throughout the Eastern Caribbean, where they are common [13]. We applied acoustic telemetry to quantify activity space, rates of movement, vertical distribution and habitat use of juvenile tarpon during diel and seasonal time scales and examined how environmental conditions (i.e., water temperature, dissolved oxygen) influenced their behavior.

Materials And Methods

Study site

Brewers Bay is located on the western end of St. Thomas, U.S. Virgin Islands (18° 20' 28" N, 64°58'40" W) and is bounded by a commercial airport runway and small lagoon on the south, a sandy beach on the north-eastern shore, and a rocky headland and smaller bay (Perseverance Bay) to the northwest (Fig. 1). Brewers Bay is 1.8 km² in area, ranges in depth between 0- 33.1 m (Fig. 1), and has steep vertical slopes along the airport runway and around the rocky headland. The bay is composed of a variety of habitat types including sand, seagrass, patch reefs, fringing coral reefs, rocky reefs, and rubble and reinforced concrete blocks (dolosse) around the seaward slopes of the airport runway. The lagoon is mostly soft muddy bottom with scattered rocks and dead corals. It is partly enclosed by the airport runway with the remaining shoreline composed of rocky reef or soft sediments, and red mangroves (*Rhizophora mangle*).

Acoustic Array

The acoustic monitoring system consisted of 45 omnidirectional receivers (VR2W, 69kHz, Vemco Inc, Halifax, NS, Canada), moored, and spaced equally across Brewers Bay, in the adjoining Perseverance Bay, and along the seaward side of the airport runway. (Fig. 1). Range testing of receivers [24] across the study site was conducted over four days in June 2015, by placing receivers in depths ranging from 5 to 19 m over different substrate types including shallow and deep coral/rock and seagrass/sand [25]. Probabilities of transmission were tested using three A69-1601 Innovasea (previously Vemco) transmitters V9-2H (151dB), V13-1H (153dB) and V16-4H (158dB) that transmitted every 60 seconds. Transmitters were attached to mooring lines, connected to cinder blocks, and suspended 1 m above the bottom. A detection probability of 70% for V13-1H transmitters was selected providing high coverage throughout the study area with estimated detection ranges of 101 m in seagrass/sand and 120 m in coral/rock substrates (Fig. 1). Water temperature and dissolved oxygen (DO) were collected at several stations in Brewers Bay using Hobo temperature loggers (Onset Computer Corporation, Bourne, Massachusetts) and miniDot DO loggers (Precision Measurement Engineering Inc, Vista, California) that were attached to acoustic receiver moorings. Temperature loggers were deployed in August 2015 and O2 loggers were deployed in February 2016 and both recorded at 15-minute intervals (Fig. 1).

Fish capture

All capture and tagging methodology on all fish in Brewers Bay was approved by the University of the Virgin Islands Institutional Animal Care and Use Committee (IRB #747807-1). Juvenile Atlantic tarpon were caught using hook and line from a boat or dock between September 2015 and November 2016. As each fish was reeled in, it was guided alongside the boat or dock and into a floating cradle constructed of PVC pipe, plastic mesh and foam noodles for buoyancy. Once in the cradle, the fish was turned upside-down to induce tonic-immobility and hook was removed from mouth. Fish remained immersed in open seawater the entire time, so no general or local anesthetic was administered, which also allowed us to release fish shortly after completion of data collection and tagging. Each fish (n=14) was measured for fork length (FL) and total length (TL) to the nearest millimeter (mm). Acoustic transmitters (either V13 (13 mm x 36 mm; n=8) or V13P (13 mm x 46 mm; n=6) 69kHz, Innovasea Inc, Halifax, NS, Canada) were surgically implanted into the body cavity on the ventral side of the fish [26]. The V13P transmitters provided depth data of fish. The incision was closed with surgical staples and treated with antibacterial ointment. Fish was turned back over, faced into the current to increase ventilation, and after a few minutes of recovery, fish was released at its capture location (Fig 1).

Data processing

Detections were downloaded from receivers every three months and analyzed using R Version 3.4.3[27]. Detections for each individual tarpon by receiver were plotted through time to investigate the presence of dropped tags, dead individuals, and short-term residency. Of the 14 juvenile tarpon that were tagged, this exploratory method was used to identify four (n=4) individuals with adequate data to conduct spatial home range analysis, eight (n=8) tarpon that were in array two days or less and had insufficient detections for analyses, and two (n=2) tarpon that either died or shed their tags (Table 1). Thus, four juvenile tarpon were considered resident and included in most analyses, whereas the remaining ten juvenile tarpon, whose fate was unknown, were excluded. Three of four resident tarpon had detections for 344 d to 472 d and also had pressure transmitters, thus were used to analyze monthly and seasonal trends in rates of movement, activity space, and vertical distribution (Table 1).

Temporal data were examined for seasonal and diel patterns. Seasons were defined as Spring (March, April, May), Summer (June, July, August), Fall (September, October, November) and Winter (December, January, February). Crepuscular periods were calculated using astronomical twilight based on daily sunrise/sunset time charts for Charlotte Amalie, St. Thomas, USVI [28]. Specifically, dawn was defined as -1 hr before Astronomical morning and +1 hr after sunrise to account for seasonal changes in day length. Likewise, dusk was defined as -1 hr before astronomical twilight to +1 hr after sunset. Day and night periods were the remaining hours between bracketed dawn and dusk, respectively.

Data Analysis and Statistics

Residency index - For each resident tarpon, the total number of detections, first/last day detected, number of days between first and last day, total days, and residency index within Brewers Bay array were calculated. Residency Index was defined as the percentage of time spent within Brewers Bay and was calculated by dividing total days detected within the array by number of days between the first and last detection.

Center of Activity - The center of activity (COA) location for juvenile tarpon (n=4) was calculated every 30 minutes using mean position (latitude and longitude) of all detections during that time step [29]. Distance between COA relocation points and difference in time between each relocation point were calculated for each fish using 'adehabitatLT' package of R environment [30]. COA values were used to calculate rate of movement (ROM) and activity space for individual fish, and included minimum convex polygons (100% MCP) and kernel utilization distributions (50% and 95% KUD).

Rate of movement - ROM (m/s) was calculated by dividing the distance between consecutive COA position values by the time difference between these consecutive points. Kruskal-Wallis and a Tukey *post hoc* test were used to test differences in ROM between diel periods and a two-way ANOVA tested differences in diel ROM across seasons.

Activity space - MCP, 50% KUD and 95% KUD were calculated using the 'move' and 'adehabitat' package in R environment [30,31]. MCPs provided information on the extent of an individual's range or area used and included all outlying points that might be the result of exploratory movement or periodic migration not part of their typical activity. KUDs highlight the density of positions of an individual within the activity space based on COAs (i.e. 50% KUD = high density, 95% KUD = low density), as well as estimated error around these positions [32,33]. When necessary, a 'land' barrier polygon was used to clip out the area of MCP and KUD polygons that fell on land (rgeos package, [34]). The calculated MCP and KUD (50% and 95%) activity spaces were plotted in ArcGIS 10.6 for annual, monthly, and diel periods. To calculate the degree of overlap in 50% and 95% KUD among individuals over diel and monthly time periods, a Home Range (HR) percent overlap analyses was applied using the 'kerneloverlaphr' function of the 'adehabitatHR' package [30,35,36]. The percent overlap HR method analyses of the kerneloverlaphr function calculates the proportion of animal a's home range that is overlapped by animal b's home range [30,35,36]. The data output matrix with value of indices of overlap of all pairs of animals [35,36]. Using the matrix output, average and ranges in fish overlap values were calculated. Repeated Measures Analyses of Variance (RM-ANOVA) was used to test for differences in KUD across monthly and diel periods. All monthly analyses used data from only three (n=3) tarpon that had average KUD activity space representing each month (Table 1). Individual tarpon were treated as random variables, and either monthly or diel periods were treated for autocorrelation effects (corAR1) using the 'lme' function of the nlme package for R [37,38]. To assess relationship between monthly ROM and 50% KUD size, a linear regression was applied.

Vertical distribution - For resident tarpon with depth-enabled transmitters (n=3), depth measurements were binned into hourly and monthly periods and boxplots applied to elucidate their vertical movement patterns. ANOVA and Tukey *post hoc* tested for differences in vertical movement across both diel and monthly periods.

Environmental conditions - To assess relationship between daily average number of detections of tarpon and average temperature and dissolved oxygen within the lagoon and waters along the airport runway, a linear regression was applied for study period (September 2015-February 2018).

Results

We captured and acoustically tagged 14 juvenile and subadult tarpon in Brewers Bay (average FL 83.7 cm, range 61-95cm; Table 1). Only four (n=4) individuals provided a sufficient number of detections over a sufficient duration (32 to 472 days), and a residency index of 78% - 100%, to be included in our spatial analysis (Table 1). Eight (n=8) fish were detected for less than a week and had fewer than 1000 detections. Since their fate was unknown after leaving the bay, we therefore excluded them from analysis (Table 1). Based on acoustic data assessment, it was determined that the two remaining fish detected within the bay had died or shed their tags within one day following release.

Activity space

The activity space of juvenile tarpon varied among individuals and through time. The average MCP for resident tarpon (n=4) was 0.97 km² (range 0.77-1.17 km²), while the average 95% and 50% KUD was 0.76 km² (range 0.49-0.99 km²) and 0.13 km² (range 0.08-0.20 km²), respectively (Table 2, Fig. 2). Comparison of mean day, night and crepuscular activity spaces among juvenile tarpon for both 50% and 95% KUDs were not significantly different across diel and crepuscular periods (50% KUD: $p = 0.07$; 95% KUD: $p = 0.44$) and across months (50% KUD: $p = 0.78$; 95% KUD: $p = 0.29$).

Analysis of daytime activity space overlap averaged 12% for 50% KUD and 42% for 95% KUD during the year (Table 3), with each tarpon showing distinct 50% KUD core areas centered around northwest corner of runway (36032), around Black Point and deeper part of Brewers Bay (2966), in and around the lagoon and Range Cay extending to shallow and deep parts of Brewers Bay (10979), and around the tip of runway (10980) (Fig. 2 day). In April, however, overlap for 50% and 95% KUD during daytime showed an increase to 20% and 63%, respectively (Table 3). Excluding the month of April, daytime 50% and 95% KUD overlap values declined from 12% to 2% and 42% to 23%, respectively (Table 3). At nighttime, 50% KUD areas were centered in shallow Brewers Bay, around the airport runway and particularly inside the shallow lagoon, where all resident tarpon went at night (Fig. 2 night). Consistent use of these areas at night tended to increase nighttime 50% and 95% KUD overlap relative to daytime, except for April, when space overlap decreased at night (Table 3).

Rate of Movement

Average ROM of juvenile tarpon was 0.07 m/s (± 0.02 SD) and was significantly different among diel periods ($H=12.4$, $P<0.006$). Post-hoc comparisons between day (mean = 0.06 m/s ± 0.004 SD), night (mean = 0.05 m/s ± 0.008 SD), dawn (mean = 0.09 m/s ± 0.01 SD) and dusk (mean = 0.10 m/s ± 0.013 SD) showed a significant difference between dusk and night time periods only (Tukey HSD: $P<0.01$). Diel ROM also varied across seasons (2-Way ANOVA: $F_{1,15} = 253.2$, $P<0.0001$). Most notable, daytime ROM was significantly lower in winter compared to other seasons (Tukey HSD: $P<0.001$). During all seasons, crepuscular ROM peaked between 04:00 to 05:00 and at 18:00 (Fig. 3a). ROM was not significantly different across months (mean = 0.07 m/s ± 0.013 SD), but there was a strong relationship between monthly ROM and 50% KUD ($F = 34.07$, $P = 0.0001$, $R^2 = 0.77$) with the highest rates for both metrics during the months of April, June and September (Fig. 3b).

Vertical movement

Vertical movement of juvenile tarpon with pressure transmitters (n=3) varied among time of the day (ANOVA: $F_{1,3} = 36526$, $P<0.0001$) (Fig. 4). Tarpon used more of the water column during the day with average depths between -2 to -13 m and maximum depth range between -16 to -37 m (Fig. 4). At night, tarpon stayed in shallower waters with depths ranging from 0 to -5 m, while maximum depth ranged between -8 to -14 m (Fig. 4, Suppl. Table 1). Nighttime vertical movements were partly constrained when tarpon were in lagoon (maximum depth -4 m, Fig. 2). During dawn and dusk, average depth of tarpon ranged between 0 to -8 m (Fig. 4, Suppl. Table 1). Vertical distribution across months showed no consistent patterns among the three tarpon with depth transmitters.

Movement and environmental variability

Water temperature in Brewers Bay ranged from 25-28°C in winter to 29-32°C in late summer and early fall. Inside the lagoon water temperature showed greater fluctuations on a daily basis and had a greater range (mean=28.3°C ± 1.27 SD, range = 24.8 – 32.0°C) than in the bay (mean=28.1°C ± 1.15 SD, range = 25.6 – 30.6°C) (Fig. S1). Water temperature had a strong effect on tarpon movement and habitat use. We found a significant negative relationship between number of tarpon detections and

temperature in the lagoon at night (adjusted $R^2 = 0.31$, $P < 0.001$), but no relationship between frequency of detections in the lagoon or around the runway at other times of day (Fig. 5). Juvenile tarpon were present in the lagoon at night when temperature ranged between 26-28°C; however, once temperature reached 29°C frequency of tarpon detections decreased rapidly and stopped at about 30.5°C (Fig. 5), indicating tarpon left the lagoon. Water temperatures in the lagoon reached or exceeded 30.5°C on 59 d of the study period compared to only 4 d at the airport runway. Likewise, water temperatures 26°C colder were recorded on 61 d in the lagoon but only on 16 d along runway. At times of high lagoon temperatures, juvenile tarpon left the lagoon and had higher frequency of detections at night along the tip and south side of the airport runway (i.e. stations 248, 249, 285, 251, 282; Fig. 1), where night-time maximum water temperatures were cooler (Fig. 5A, Fig. S1). When water temperatures in lagoon cooled to below 30.5°C juvenile tarpon returned to resting in lagoon at night (Fig. S1).

Similar to water temperature, dissolved oxygen concentrations in lagoon varied widely from 0.9 -7.1 mg/L (mean = 4.7 ± 1.89 SD) but were more stable along the airport runway (mean = 6.1 ± 1.89 SD, range 5.3 – 6.6 mg/L) (Fig. S1). Based on detection frequencies, there was no significant relationship in number of detections of tarpon at different levels of dissolved oxygen within the lagoon or the runway (Fig. 5B), indicating that tarpon seemed to tolerate the low oxygen levels in the lagoon, especially at night.

Discussion

This was the first study to use passive acoustic telemetry to illustrate small-scale three-dimensional movement patterns of juvenile Atlantic tarpon ($n=4$) and provides a useful baseline data for comparison to adult movements [6,22]. Although most juvenile tarpon ($n=8$) left the bay shortly after tagging and their fate remained unknown, and two fish died or shed their tags, the remaining four fish provided useful baseline data on juvenile tarpon behavior. Juvenile tarpon were resident within the bay 78% to 99% of time but some transient behavior was observed for two of the larger individuals (i.e. both were 95 cm FL). One tarpon (ID 10979) left the bay for nearly two months (October and November) before returning to its home range for another seven months. The second tarpon (ID 36032) was resident within Brewers Bay for one month before departing mid-October, but it was then detected at an acoustic array 12 km offshore in January. Interestingly, both tarpon departed in October when water temperature was high. Seasonal movements, such as these, by Atlantic tarpon and other coastal species have been attributed to food availability, reproductive maturity (spawning aggregations) and changes in environmental conditions (i.e., temperature, dissolved oxygen) [6,13,15,16,39–41].

We found that juvenile tarpon had distinct daytime 50% KUDs, core areas (0.07 to 0.20 km²) within Brewers Bay that overlapped very little with the other individuals for most of the year (<2%). At night, all resident tarpon tended to move into or near a small, shallow lagoon in Brewers Bay, which resulted in an increase in overlap of 50% KUDs during most months. The spatial patterns displayed by juvenile tarpon suggest habitat partitioning during daytime and sheltering and protection from predation in a common area at night [6,13,17,18,42]. During April, however, daytime overlap in 50% KUD area showed a ten-fold increase, as they shifted their activity space to similar areas within Brewers Bay. These changes in behavior and activity space coincided with the arrival of schools of bait fish as well as nesting seabirds that also feed on bait fish in the spring [43,44]. Tarpon can increase their foraging success in the presence of seabirds feeding on bait fish at the water surface [15,43,45]. When seabirds were present, we observed groups of tarpon foraging on bait fish near the surface during the spring months primarily in the middle of Brewers Bay and near Black Point reef (Duffing Romero, M. and Nemeth, R.S., *pers. observations*). The areas of Brewers Bay where this feeding behavior was observed corresponded to April daytime activity space of tagged tarpon.

Adult tarpon tend to feed at sunset and continue feeding into the night if there is enough food and available light for foraging [15,46]. If ROM is used as a proxy for feeding [47] then juvenile tarpon may display similar patterns as adults. Juvenile tarpon had the highest rates of movement during dawn and dusk, but ROM was significantly slower at night, which suggests that juvenile tarpon were not feeding at this time. High ROM during crepuscular periods, may also indicate consistent use of migration pathways between nighttime and daytime activity spaces [18,48–54]. Further research with improved experimental design will help to distinguish between multiple behavioral states such as resting, searching, foraging or traveling [55].

Juvenile tarpon generally stayed less than 10 m depth, but occasionally went to 25 m or deeper, which is also typical for adult tarpon [6,13]. Many coastal and pelagic fish, such as barracuda (*Sphyraena barracuda*), white marlin (*Kajikia albida*), dolphinfish

(*Coryphaena hippurus*) and many species of tuna (*Thunnus* spp) show similar vertical movement patterns, where they spend the majority of time at shallow depths or close to the surface and then make diel/seasonal deep water movements [56–58]. Adult tarpon show a variety of vertical distributions that fall into four typical patterns: (1) clear diel pattern shallow in day and deep at night, (2) deep in day and shallow at night, (3) deep and shallow at irregular intervals throughout diel period, and (4) random vertical movements throughout diel period [6]. Juvenile tarpon in Brewers Bay showed a consistent diel vertical movement pattern that matched pattern (2) where fish stayed shallow at night and deeper during the day.

Extreme environmental conditions influenced tarpon behavior in Brewers Bay. Tarpon prefer water temperatures from 24 - 26°C in spring and fall and 28 - 30°C in summer [6,13,23]. We found that juvenile tarpon avoided water temperatures greater than 30°C. For instance, tarpon detection frequencies within the lagoon decreased at temperatures above 29°C and they did not enter nor rest in the lagoon at night when water temperature was higher than 30.5°C, but instead moved to deeper water on the south side of airport runway (Fig. S1). At this threshold temperature, tarpon faced a trade-off of remaining in higher temperatures within the protected lagoon or leaving the lagoon for cooler, less protected waters around the airport runway at night. Previous studies on barracuda (*S. barracuda*) and bonefish (*Albula vulpes*) have shown that both species move to deeper waters away from their home range to avoid seasonal weather patterns and associated temperature fluctuations [15,39,59]. Adult tarpon in Florida migrated farther northward on a daily basis as sea surface temperatures increased and seemed to track the 26°C isotherm from the Florida Keys to the southern coast of Virginia from May to July, respectively [6]. Despite the effect of high water temperatures on tarpon behavior, tarpon tolerated low dissolved oxygen concentrations in the lagoon, which is attributed to being facultative air-breathers [13,60].

Conclusion

Our acoustic telemetry study provided some of the first information on juvenile tarpon movement ecology including home range size, rates of movement, vertical distribution, and habitat partitioning. Although limited to only four fish, our results showed high residency within a small bay and relatively stable non-overlapping daytime home ranges, except when seasonally abundant food sources were present. Fine-scale acoustic tracking over multiple years showed the effects of extreme environmental conditions on juvenile tarpon movement and habitat use. These baseline observations highlight the need for more extensive studies of juvenile and subadult tarpon across a broader range of their distribution. In addition to a larger sample size, we suggest including a wider range of tarpon size classes, from small juveniles to large reproductive adults, in future studies. Since tarpon are highly mobile but also show resident behavior [6,7,13,40] (Ault 08, PopDyn, Luo, Griffin), it is difficult to assess their movement patterns using an acoustic array limited to one bay. A better approach, to facilitate tracking tarpon movements over a broader geographic range, would be to tag tarpon with both acoustic and satellite tags and place additional receivers along the coastlines or use a regional network within and among neighboring islands [9,40,61,62](Farmer et al. 2014, Abecasis, Griffin).

List Of Abbreviations

COA: Center of Activity; MCP: Minimum Convex Polygon; KUD: Kernel Utilization Distribution; ROM: rate of movement; HR: home range

Declarations

Ethics and consent to participate

All capture and tagging methodology on all fish in Brewers Bay was approved by the University of the Virgin Islands Institutional Animal Care and Use Committee (IRB #747807-1).

Consent for publication

Not applicable.

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interest

The authors declare that they have no competing interests.

Authors contributions

MDDR conducted most of the field work, data analyses/interpretation and writing; JKM contributed to data management/analyses; RSN secured funding for project and contributed to field work; JL, SJP, JKM, JSA and RSN contributed to data interpretation and writing of manuscript.

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Tables

Table 1. Summary data for Atlantic tarpon (*M. atlanticus*) caught and tracked in Brewers Bay acoustic array, including date caught, total length (TL), fork length (FL), total number of detections and total residency time detected in Brewers Bay. Symbols indicate: \diamond = fish used for Brewers Bay spatial analyses, * transient fish not used in spatial analyses, † fish died or shed tag, and P = acoustic pressure transmitter measured depth.

Fish ID	Tag Date	TL (cm)	FL (cm)	Total Detections	First day detected	Last day detected	Days between first and last detection	Total days detected	Residence Percentage
2966P♂	10/25/2016	96	85	395606	10/26/2016	2/10/2018	472	464	99
10979P♂	6/26/2016	112	95	106564	6/26/2016	7/1/2017	370	287	78
10980P♂	6/17/2016	96	80	54564	6/18/2016	5/28/2017	344	330	96
36032♂	9/17/2015	109	95	12231	9/17/2015	10/19/2015	32	28	88
24976*	10/29/2016	96	83	212	11/8/2016	11/8/2016	1	1	100
36039*	8/16/2016	100	94	10	8/16/2016	8/16/2016	1	1	100
36044*	5/24/2016	70	61	5	5/24/2016	5/24/2016	1	1	100
36045*	6/1/2016	130	91.2	14	6/1/2016	6/1/2016	1	1	100
59272*	1/12/2016	86.4	76.1	10	1/12/2016	1/13/2016	1	1	100
2963P*	9/15/2016	92	77	660	9/16/2016	9/17/2016	2	2	100
2964P*	8/14/2016	100	80	11	8/14/2016	8/14/2016	1	1	100
2965P*	8/8/2016	96	85	70	8/9/2016	8/9/2016	1	1	100
36034†	10/16/2015	90	78	326110	10/16/2015	7/11/2016	269	271	100
36036†	10/21/2015	130	91.2	2017	10/22/2015	1/25/2016	95	74	78

Table 2. Calculated home range size (km²) for each tarpon based on 50% and 95% KUD and 100% MCP; number of COA points that fell on land and total percentage of COA points on land removed out of total COA points used for home range analyses.

Fish ID	Total number of COA points	MCP 100% area (km ²)	KUD 95% area (km ²)	KUD 50% area (km ²)	Number of COA points on land	Percentage of COA points removed
2966	19367	1.174	0.988	0.200	123	0.64
10979	11888	1.055	0.619	0.075	163	1.37
10980	10425	0.864	0.492	0.090	166	1.59
36032	887	0.767 ^a	0.938	0.149	7	0.79

^a In this case 100% MCP is smaller than 95% KUD based on how they are calculated (see Methods).

Table 3. Summary of 50% and 95% KUD overlap for juvenile tarpon (n=3) during day and night for full year, May to March (April excluded) and only April.

Month(s)	Diel period	KUD 50% area \pm se (km ²)	KUD 50% area range (km ²)	KUD 95% area \pm se (km ²)	KUD 95% area range (km ²)
All year	Day	12% \pm 6%	0 – 27%	42% \pm 12%	11 – 72%
All year	Night	20% \pm 18%	0 – 99%	51% \pm 8%	28 – 99%
May - March	Day	2% \pm 2%	0 – 6%	23% \pm 14%	8 – 55%
May - March	Night	19% \pm 18%	0 – 99%	44% \pm 10%	14 – 99%
April	Day	20% \pm 16%	1 – 55%	63% \pm 4%	42 – 74%
April	Night	10% \pm 9%	0 – 32%	33% \pm 19%	11 – 81%

Figures

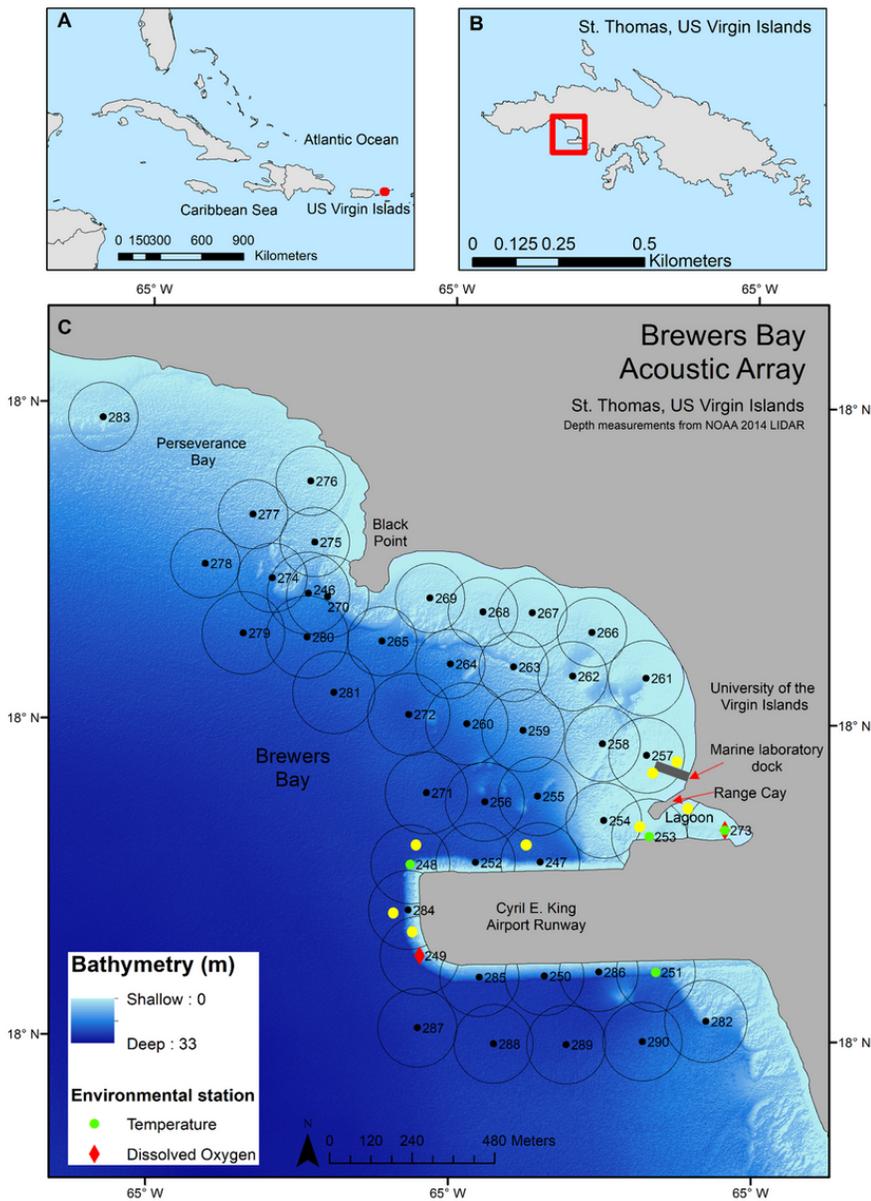


Figure 1

Map of the Caribbean (A) and the island of St. Thomas in the U.S Virgin Islands (B) and study site in Brewers Bay (C) depicting bathymetry and the acoustic array with station number and approximate range of 70% detection probability (circles). The detections ranges vary by habitat (deep hard bottom=115m, deep soft bottom=120 m, shallow soft and hard bottom= 101 m) based on range testing [25]. Location of environmental data logger stations shown as green dots (temperature) and red diamonds (dissolved oxygen). Yellow dots represent approximate location where juvenile Atlantic tarpon were caught and released.



Figure 2

Activity space of juvenile tarpon (n=4) based on yearlong 100 % MCP (left), day (yellow/orange), night (blue/green), crepuscular (dawn = red, dusk = blue purple) time intervals using 50% and 95% KUD. Arrow represents an example of a corridor between day and night activity space. See Fig. 1 for labels.

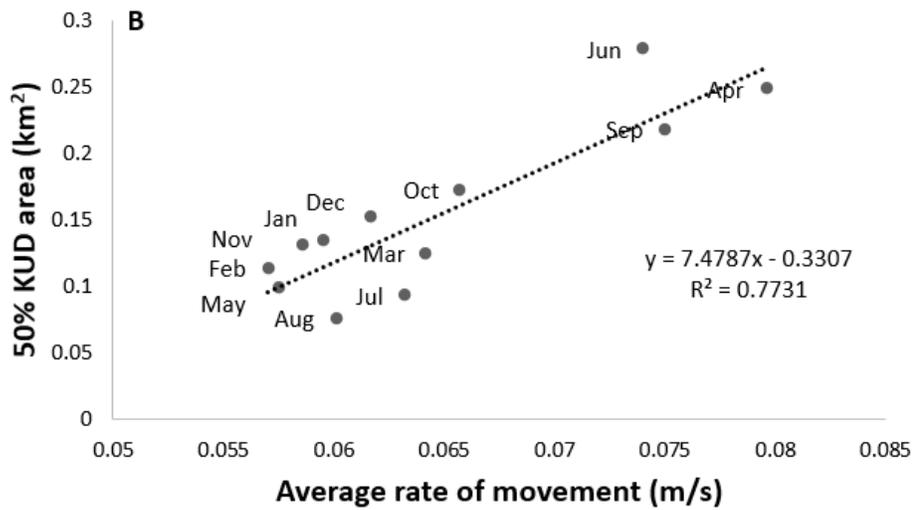
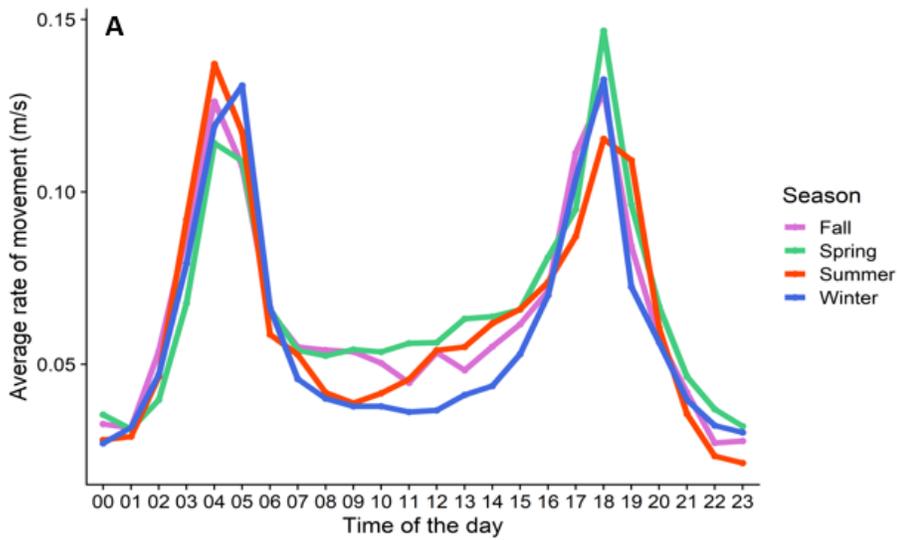


Figure 3

A) Diel ROM of juvenile tarpon by season of the year: Spring (March, April, May), Summer (June, July, August), Fall (September, October, November) and Winter (December, January, February). B) Relationship between average ROM and core activity space 50% KUD for four juvenile tarpon during each month.

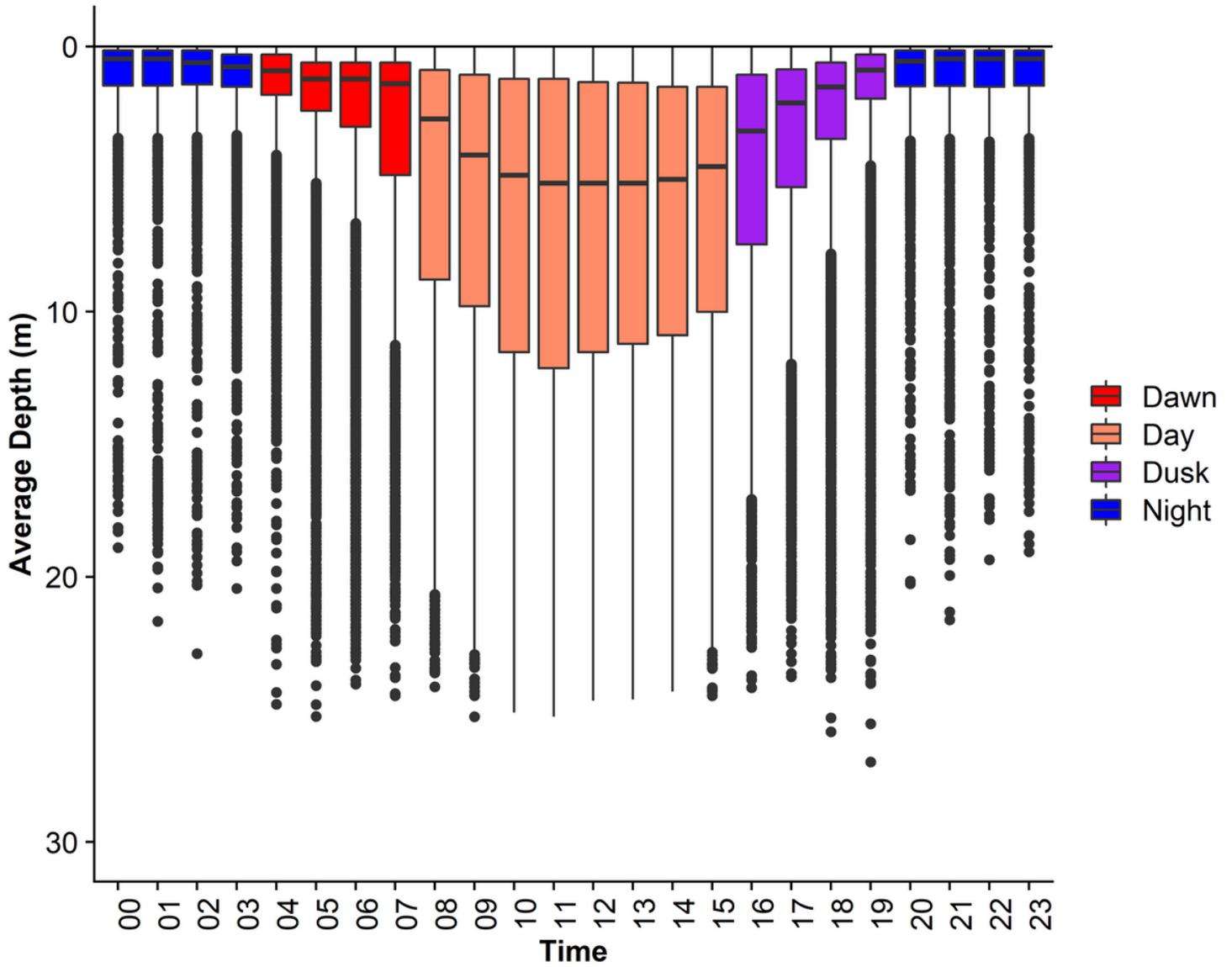


Figure 4

Boxplot of daily distributions by hour of vertical movement of three Atlantic tarpon during diel (day, night) and crepuscular (dawn, dusk) periods.

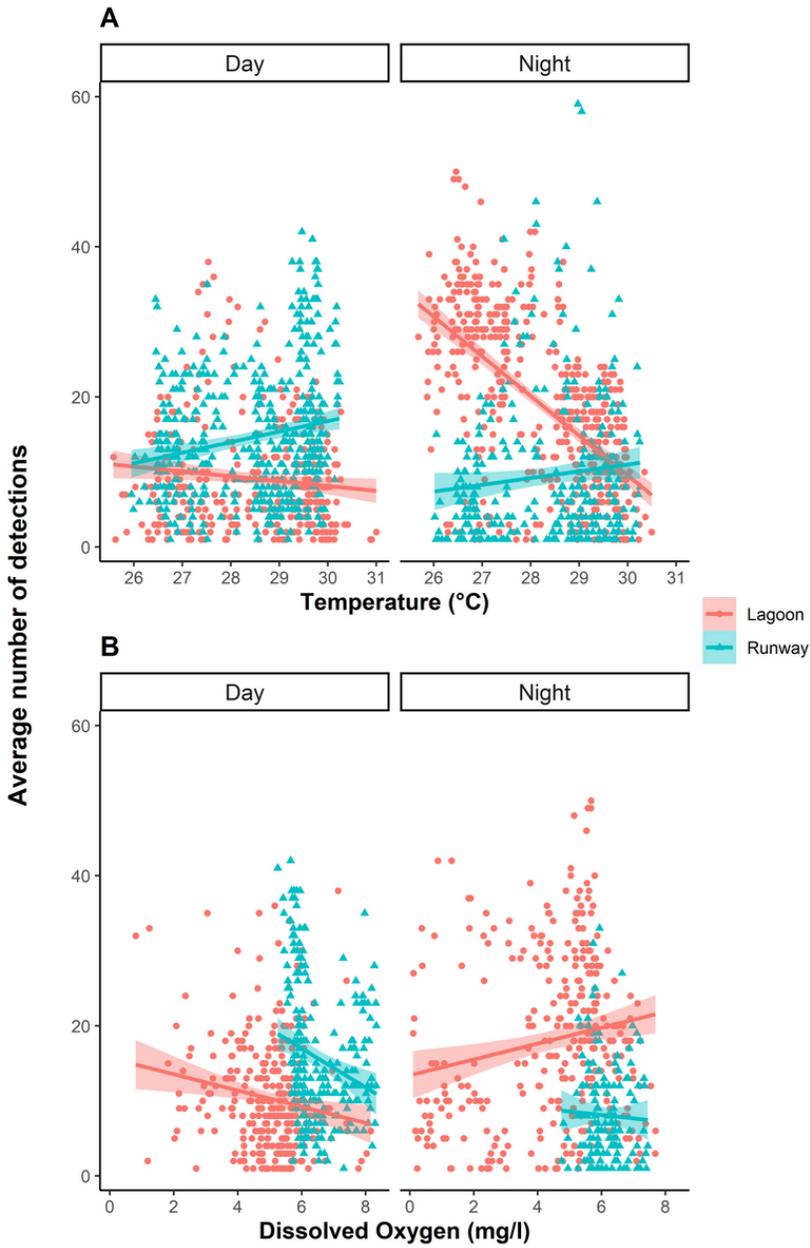


Figure 5

Day and night relationships between average number of tarpon detections and A) water temperature (°C) and B) dissolved oxygen (mg/l) within the lagoon and along the airport runway.

Supplementary Files

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