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"Solo datasets": Unexpected behavioral patterns uncovered by acoustic monitoring of single individuals

Joffrey BAEYAERT[a-b*], David ABECASIS[a*], Pedro AFONSO[b], Gonçalo GRAÇA[b], Karim ERZINI[a] & Jorge FONTES[b-c]

[*] Both authors contributed equally to this work.

[a] CCMAR - Centro de Ciencias do Mar, Universidade do Algarve, Campus de Gambelas, 8005-139 Faro, Portugal

[b] MARE – Marine and Environmental Sciences Centre, University of the Azores, Portugal

[c] Okeanos Research Centre of the University of the Azores, Horta, Azores, Portugal

davidbecas@gmail.com, pafonsopim@gmail.com, goncalograca@gmail.com, kerzini@ualg.pt, fontes04@gmail.com

corresponding author: Joffrey BAEYAERT: jhbaeyaert@ualg.pt

+33.6.78.75.39.87

Centro de Ciencias do Mar (CCMAR), Universidade do Algarve, Campus de Gambelas, 8005-139 Faro, Portugal

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Introduction.

A holistic understanding of the life-history strategies of marine populations is often hindered by complex population dynamics, exacerbated by an intricate movement ecology across their life-history (Jeltsch et al. 2013; Nathan et al. 2008; Parsons et al. 2008). Movement patterns and spatial ecology can vary spatially and temporally for different reasons, mainly related to the organism’s life-history and environmental variability (Abecasis et al. 2009; Abecasis et al. 2013; Afonso et al. 2009). Changes in spatial use and movement can occur daily when visiting feeding grounds or avoiding predators, or seasonally, when sexually mature individuals migrate to spawning/breeding grounds (Kozakiewicz 1995; Sundström et al. 2001). However, observed shifts in spatial use and movement patterns; as a result of behavioural plasticity, may also vary greatly from one individual to another of the same species and/or population (Afonso et al. 2009). Further, ontogeny can also play an important role and explain a possible change in individual spatial variation. Noticeable differences in the behavior and movements of mature and immature individuals have been documented in various marine organisms (Lecchini and Galzin 2005; Lowe et al. 1996). Permanent habitat shifts have been associated with ontogenesis in pigeye sharks (*Carcharhinus amboinensis*), moving from inshore to offshore areas after reaching maturity (Knip et al. 2011).

Hence, a relevant debate lies in the implications of “solo datasets” and the potential pertinence of the patterns an individual dataset could uncover. Data deficiency can be the primary barrier to efficient marine conservation and management, and while long-term species-specific data are often lacking (Broderick 2015), it appears worthwhile to investigate patterns exhibited by single individuals as a baseline to address further research projects more thoroughly. Relatively long-term monitoring of a unique specimen can reveal extraordinary, previously unexpected behaviors. For instance, using a “solo dataset” from a Scalloped hammerhead shark, *Sphyrna lewini*, Spaet et al. (2017) provided relevant insights into the movement dynamics of the species, identifying deep-diving behaviour and unreported habitat use, therefore contributing to guiding future research (Spaet et al. 2017). Likewise, Chateau and Wantiez (2007), after examination of a single dataset of 25 days of acoustic monitoring of a humphead wrasse (*Cheilinus undulates*), presented spatial use and movements extent previously underestimated for the species. The results, from one individual, suggested the humphead wrasse uses a larger home range, that the species undergo small spawning migration movements as well as more dynamic activity patterns than already observed. Thus, there are many gaps in knowledge of movement ecology of marine species, such as many reef-associated pelagic fish of high commercial and ecological importance in tropical and warm temperate regions.

This is noticeable for the three case study species involved in this investigation, namely the greater amberjack, *Seriola dumerili* (Risso, 1810), the school shark, *Galeorhinus galeus* (Linnaeus, 1758) and the salema, *Sarpa salpa* (Linnaeus, 1758). The greater amberjack is a circumglobal top predator Carangid (up to 190cm and over 80kg) (Manooch and Potts 1997), for which no telemetric studies have yet been conducted. Little is still known concerning the oceanodromous behaviour of this iconic fish, which may involve large seasonal migrations towards warmer waters, possibly related to reproduction (Ingram Jr and Patterson 2001; Marino et al. 1995; McClellan and Cummings 1997; Thompson et al. 1999). Information on its habitat preferences and fine scale movements is almost absent from the literature.

The school shark has a long history of exploitation (Morato et al. 2003; Punt et al. 2000) and is often landed as a by-catch of bottom long-line fisheries in the Azores (Morato et al. 2003). The species is currently facing a global population decline and is registered as Data Deficient in Northeast Atlantic by The International Union for Conservation of Nature (IUCN) Red List due to a lack of biological data (Walker et al. 2006). Except for a recent short-term study reporting a possible large scale migration-related movement in southern Australia (Rogers et al. 2017), information is largely deficient regarding the species' movement ecology. Although nursery areas are believed to occur in Portugal and the Canaries (Walker et al. 2006), a proper assessment remains unavailable. Further research, monitoring and status assessment is required for this species in the Northeast Atlantic (Walker et al. 2006).

The salema is a seabream typically found in seagrass areas and coastal rocky bottoms of the Mediterranean Sea and Eastern Atlantic Ocean (Bauchot and Hureau 1986). Given its ecological importance as one of the main herbivores, especially in seagrass meadows, its movement and activity patterns have already been the focus of few studies using acoustic telemetry (Abecasis et al. 2012; Jadot et al. 2006; Jadot et al. 2002; Pagès et al. 2013). Yet, the results obtained in the present study relating the moon phase with movement patterns are unique and unexplored. Besides foraging oriented movements (Afonso et al. 2014a), moon phase has been related to migrations, spawning aggregations and gonadal development synchronization in teleost species (Bolden 2000; Hasegawa 2012; Meyer et al. 2007; Rahman et al. 2004; Takemura et al. 2004).

Therefore, by exploring three case studies of single individuals, the main purpose of this paper is to expand our current knowledge on poorly investigated species but also to provide a modest contribution to the debate on the prominence of "solo dataset" in uncovering extraordinary behavioural patterns in wild ranging individuals.

Methods

The monitoring area of the greater amberjack and the school shark is part of a broader monitored region in the Azores archipelago, located on the north mid-Atlantic ridge (Fig. 1), approximately 1360 km west from continental Europe.

The area of interest included the central group of islands, comprising Faial, Pico and São Jorge Islands (Afonso et al. 2009), as well as a reef located offshore of Santa Maria Island, part of the Eastern group (Fig. 1). Parts of the Faial-Pico channel are internationally designated as Marine Protected Areas (OSPAR, Natura 2000) and encompass various habitats, including the shallow coastal reefs around the “Monte da Guia” (MG) and three offshore shallow reefs previously described as aggregation sites for pelagic predators (i.e. “Baixa do Sul”, BDS) (Fig. 1) (Afonso et al. 2009; Afonso et al. 2008b; Fontes et al. 2014). Santa Maria Island has also been identified as an important spot for whale sharks (Afonso et al. 2014b) and mobula rays (Sobral and Afonso 2014; Thorrold et al. 2014) (Fig. 1).

The greater amberjack (90 cm total length) was captured in September 2007 in the south of the Faial-Pico Channel, at BDS station (Fig. 1B), using a hand-line with live bait. This spot was selected based on preliminary SCUBA visual census reporting seasonal greater amberjack aggregations during warm water months (Pedro Afonso - personal observation).

The female school shark (157cm total length) was caught in November 2012 on the north shore of Faial Island (Fig. 1C), during experimental longlining using 15 circle hooks on a 1000 m line. Due to the evident lack of knowledge about the species in the North Atlantic, we decided to acoustically tag this individual, resulting in a 4-years dataset, exposing unsuspected movement patterns. The maturity state of this individual was extrapolated from the length at sexual maturity documented in Francis and Mulligan (1998) and Lucifora et al. (2004).

Both animals were implanted with a VEMCO ultrasonic transmitter (V16-4H, 68mm in length, 16mm of diameter, and a weight in air of 26g) in the peritoneal cavity during an onboard surgery. The transmitters emitted random coded signals every 60 to 180 seconds at 69kHz and 158-dB. Individuals were kept in tonic immobility with seawater flowing through during the whole procedure (for details see Afonso et al. 2008a). An external T-type dart tag was also implanted for recognition upon recapture. Animals were released at the same location after a short observation period (~10 min).

The manufacturer projects a battery life of 1470 days for the transmitter, during which the receivers would continuously record the exact time, date and code of the tag if within the listening range. The total detection period of the greater amberjack, from September 2007 until July 2011 corresponds to 1410 days of monitoring, while the monitoring period of the school shark, from November 2012 to March 2016, comprises 1188 days. The period of detection was well within the expected battery life of the tag.

A network of underwater anchored VEMCO receivers (VR2, VR2W and VR3) was deployed in the Archipelago, around Faial and Pico Islands, within the Channel as well as around Santa Maria Island, prior to the beginning of the present research (Fig. 1). The monitored sites included what were thought to be the most important habitats for a variety of reef-fishes. The passive acoustic monitoring relied on and benefited from the experimental design of studies on several other reef fishes conducted in the same area and time, and was therefore not specifically designed to investigate the movements of either of these studied animals (e.g. Afonso et al. 2009; Afonso et al. 2008b; Fontes et al. 2014) (Fig. 1B & C). The number of available receivers was not constant throughout the study, yet, these changes did not affect our ability to analyse the data and interpret the results.

A maximum listening range of 800 meters was expected according to previous telemetry studies conducted in the area (Afonso et al. 2009; Afonso et al. 2008b; Fontes et al. 2014).

The Salema study took place in the Luiz Saldanha Marine Park (LSMP), a marine protected area (MPA) established in 1998 and fully implemented in 2009. Located off the Portuguese western coast, this MPA covers an area of approximately 53 km^2 of which 4.3 km^2 are no-take (Supplementary material). The remaining area includes 21 km^2 of partially protected zones, where only octopus traps and jigs are allowed, and 28 km^2 of buffer areas where commercial fishing vessels smaller than 7m are allowed to use traditional fishing gears and recreational angling is permitted (Abecasis et al. 2014b). This MPA is largely composed of soft bottom habitats (sand and mud) but also harbours rocky reefs and some patches of seagrass meadows in shallower areas (Henriques et al. 2015).

Salema proved to be a very difficult fish to capture in the study area and for this reason only one fish was captured (35.5 cm total length). Several methods were tested: nets while scuba diving, trammel nets operated by professional fishermen, rod and reel and fish traps. The fish was captured by a trammel net, next to the Anicha islet (Supplementary material).

For tagging purposes, the fish was placed in V shaped support and a small incision was made between the anus and the insertion of the pelvic fins following the procedures described by Abecasis et al. (2012). For recovery, the individual was placed in a small container with fresh seawater next to the boat and released approximately 15 minutes after capture in the same location. The transmitter emitted an acoustic signal with a random delay between 30 and 90 seconds (V9-2L, Vemco) and had an estimated lifetime of 191 days.

An array of 14 VR2 and VR2W VEMCO acoustic receivers was deployed in the LSMP (Supplementary material), located throughout the protected area in different habitats. The monitoring period lasted from April 2010 to January 2012, thus exceeding the expected lifetime of the transmitters. Range tests, using fixed tags, indicated a 300m radius range for the tag, and no significant differences between day and night time detections.

The data series were first inspected for spurious detections, likely to be misinterpreted as authentic evidence of presence of the fish. We considered any detection spurious if it occurred isolated within a 24h period (i.e. only one detection over 24h) and/or if the distance and elapsed time between consecutive detections suggested an unreasonable movement by the fish. This procedure ensures that the fish was actually present in the area.

To better depict temporal shifts in movements of both the greater amberjack and the school shark, all detections were filtered by ecological seasons in the mid-Atlantic as characterized in Vandeperre et al. (2014). All data analyses were performed in R (Team 2017).

For the analysis of the residency patterns of the greater amberjack, detections from all three stations deployed around the coastal area of MG were pooled together (Fig. 1B & 2).

To quantify levels of residency within the monitored area, a seasonal residency index was calculated over time for each cluster of stations as well as for the whole array. This index was based on the ratio of the total numbers of days the individual was detected by a cluster of receivers (or whole array of receivers) per season to the total numbers of days of monitoring per season (Abecasis et al. 2013). The index can take on values from 0, which indicates no residency, to 1, which suggests an absolute residency within the monitored area. Only effective duty periods of each receiver were considered for calculation of each index, i.e. the period during which the station was actively listening for transmitters. We computed an additional site attachment index, the proportion of absence, as an indicator of movements away from the original core of site fidelity. Absence period was defined as the number of days between two consecutive detections at any station. Proportion of absence per season was then defined as the total number of days of absence during the entire season. As a proxy for movement within the array of receivers, we calculated the minimum linear distance traveled based on the distance between the stations consecutively visited over each season. Due to the changes in the overall design of the acoustic receiver array around the central group, driven by the needs of larger ongoing studies, the few detections occurring on receivers with reduced effective duty period and location shifts were discarded from further analyses.

Similarly to the greater amberjack, the four receivers deployed off the north shore of Faial that logged detections of the school shark were aggregated as one (Fig. 1C). An absolute seasonal residency index (A_{Ri}) was calculated following the above-mentioned equation. However, as the detection frequency indices were much lower, we also computed a relative seasonal residency index (R_{Ri}), based on the ratio between the total number of days the shark was detected and the number of days elapsed between first and last detection per season.

Detections of the Salema were first analyzed with the Eonfusion software (Myriax, Australia) to visualize the movement patterns of the fish inside the monitored area and assess possible influences of moon and/or sunlight on its activity. For this individual, an absolute residency index was calculated to evaluate site fidelity to the monitored area following the procedure previously described. Possible diel cyclical patterns were investigated by applying Fast Fourier transformations (FFT) to the hourly number of detections of each fish (Abecasis et al. 2013). Differences in the number of detections between day and night time were tested with a chi-square test. The fraction of illuminated moon was obtained from the astronomical applications department of the U.S. naval observatory (http://aa.usno.navy.mil/index.php) and plotted against the detections to investigate the lunar influence on Salema movements.

A Generalized Linear Model (GLM) with a Poisson family was used to test the moon illumination influence on the number of detections at stations #13 and #14.

Results

The receiver array logged 303 027 detections of the greater amberjack over 961 days, between September 2007 and July 2011 (Fig. 2). Detections were concentrated in the central group of Islands of the Azores (Fig. 1B & 2). The residency index calculated for the whole period and the entire network of receivers, indicates a relatively high residency (0.68) of the fish in the study area (Table 1).

The monitoring period of this individual depicts two phases over the 4 years of data. First, the greater amberjack exhibits a site attached phase, characterized by a high degree of residency at the south reef, BDS, from Summer 2007 to Winter 2010, manifesting residency indexes ranging from 0.50 to 1 (Table 1). This observation is corroborated by the relatively low absence of the individual from the array of receivers (Fig. 3). Noticeably, an exception occurred in Spring 2009, with the lowest residency index over this three-year period (0.33). During this same period of three years, the individual expressed a seasonal behaviour. The fish entered a more mobile state during Springs and Summers, covering distances up to 228 km (i.e. Summer 2009), periodically visiting coastal areas (MG; Fig. 2).

This pattern, corresponding to simultaneous lower residency index at BDS and higher residency index at MG, is relatively obvious for the year 2008, less apparent for the two subsequent years, during which the movement are consequently scaled-down (i.e. maximum of 68km during Summer 2010) (Table 1 & Fig. 4 & 3).

The second phase indicates a shift in the previously observed patterns, both in term of seasonality and residency. During Summer 2010 the results show recording of moderate residency (0.45, MG and BDS respectively representing 0.27 and 0.18) (Table 1). The subsequent seasons document a noteworthy decrease in distances covered, i.e. up to 5.6 km (Fig. 4). Autumn 2010 and Winter 2010 show no detections of the fish, while Spring and Summer 2011 mark a slight return to BDS, with rare visits to the MG (Table 1, Fig. 2 & 3). After Winter 2010, the fish residency at south reef underwent a decline (ranging from 0.23 to 0.02), which eventually led to a near absence in the fourth and last year of the study, when the seasonal behaviour was no longer reported (Table 1, Fig. 2, 3 & 4). Similarly, the frequency of visits to MG is considerably low and reveal an absence of seasonal pattern.

While almost no detections were recorded at either BDS or MG for Spring and Summer 2011, a newly deployed station (late 2010 - “CAP”, Fig. 1B) in the southwest part of the island, indicates a relative frequency of this area by the individual. For clarification purposes, this station was excluded from further analysis due to its discontinuous monitoring period. Yet, a preliminary analysis of the data showed a residency index over the effective monitoring period of the station of nearly 0.39.

Detections of the female school shark were reported at two distinct regions across the entire network of receivers deployed in the Azores, in the central group of islands (Faial & Pico Islands) as well as in the eastern group, particularly at a reef offshore of Santa Maria Island located 350 km away from the tagging site (“SMA”, Fig. 1C & 5, Table 2). The shark was detected by seven receivers (Fig. 1C & 5). Of these seven, three receivers on the north shore of Faial Island and receiver “SMA” accounted for 63% and 33% of the total number of detections respectively.

The shark switched between high residency at different groups of islands and large-scale movement patterns (Fig. 1C & Table 2). The long-term tracking of the movements of this shark revealed the repetition of these two main phases over four years.

During Autumn 2012 and Winter 2013, the individual appeared to be relatively site attached to the North shore of Faial Island as demonstrated by both the absolute and relative residency indexes (respectively 0.53 and 0.54 during Autumn 2012 & 0.24 and 0.88 during Winter 2013) (Table 2). From Spring 2013 to Winter 2014 mark a period of absence of the shark from the array of receivers; the residency indices revealing a possible departure early Winter 2013 (Table 2).

The following detections, in Spring 2014, were reported at a receiver deployed off of Santa Maria Island ("SMA") (Fig. 1 & 5). This observation suggests the shark entered a mobile phase, initiating a southward movement (bearing ~120º SSE), covering over 350 km (Fig. 1C). The first detection at "SMA" occurred late in the season, explaining the rather large difference between the two indices reported in Table 2. After this more mobile phase, between July and August 2014, the shark exhibited a high residency at this particular spot (Table 2). Afterwards, for the two consecutive seasons, no receiver in the array reported presence of the individual until it was finally detected again in May 2015. This detection occurred on a receiver deployed on the southwestern shore of Pico Island, at the mouth of the Faial-Pico Channel (Fig. 1C). This occurrence indicates that between August 2014 and May 2015, the shark initiated a return movement to its original residency site, i.e. crossing again the Archipelago (Fig. 1C). During the last monitoring period, between Spring and Winter 2016, the shark once again exhibits site attachment to the North shore of Faial Island, similar to that of Autumn and Winter 2012 (A_{Ri} from 0.32 to 0.93 and R_{Ri} from 0.67 to 0.77). The last detection of the shark occurred in March 2016, corresponding to the end of the expected battery life of the transmitter.

The receiver array in the LSMP logged a total of 13 084 detections of the Salema, over a 6 months period, between April and October 2010. The results of the residency index show high site attachment of the fish to the area where it was captured (Fig. 6).

Daily detections were frequent and only 3 periods of 4 days without a single detection were reported. The individual showed a significantly higher number of detections during the day (χ^2=6610.97, p<0.01) and a marked diel activity, as indicated by significant peaks at 24h, 48h and 72h on the FFT analysis.

This fish showed excursions to adjacent areas and was detected by a total of six receivers (Fig. 6 & Table 3). These excursions were often done towards receiver #10 almost daily and, only during the new moon periods to receivers #13 and #14 (Supplementary material). The GLM results show that moon illumination is correlated with the number of detections at these stations (Fig. 6 & Table S1). With very few exceptions, all such excursions occurred during the day, whereas night time detections always occurred in receivers #11 or #10. This fish also made a single larger excursion (ca. 10km) to the full protection area during the new moon phase (Supplementary material).

Discussion

These study cases reveal how single opportunistically tagged individuals may elucidate on peculiar patterns previously unexplored, but they also provide information useful for designing future proper scientific studies and should serve as a guidance for future hypothesis testing.

We are fully aware that meaningful conclusions or patterns that would apply to a wider context than the individual tagged would be unrealistic and cannot be drawn from these data. Although we are conscious of the level of uncertainty around the mechanisms underpinning the present patterns, we briefly present and discuss some potential interpretations of the current results.

In this paper we document, for the first time that a greater amberjack resided in a single reef for a period of multiple years, challenging the perception that reef predators are highly migratory. We found surprising that such an oceanodromous predator remained resident at a seamount for an extended period given the widely accepted notion that jacks are highly mobile fishes (Burch 1979; Ingram Jr and Patterson 2001; McClellan and Cummings 1997).

Despite an overall long-term residency, a seasonal movement pattern was evident over the duration of the study period, as shown by the lower residency at the southern reef and the frequent visits to coastal stations during warmer months. Although our results cannot be thoroughly explained based on our current data, two complementary hypotheses have emerged.

On one hand, this very same seasonal pattern of presumed higher mobility and spatial use expansion was reported in other investigations on the long-term (2 to 4 years) residency of closely related species, including white trevally (*Pseudocaranx dentex*), almaco jack (*Seriola rivoliana*) and yellowmouth barracuda (*Sphyraena viridensis*) in the same study area, at two Azorean offshore shallow seamounts (Fontes and Afonso 2017; Fontes et al. 2014) and giant trevally (*Caranx ignobilis*) in an isolated atoll in Hawai'i (Meyer et al. 2007). As in those studies, it can be argued that the seasonal patterns are associated with changes in biological requirements, such as reproduction. For instance, seasonal movements in greater amberjack have been previously hypothesized to be related to spawning behaviour (McClellan and Cummings 1997). Yet, other motivations, i.e. search for increased feeding opportunities, could also explain these patterns and therefore cannot be ruled out (Dempster 2005; McClellan and Cummings 1997; Tanaka 1984).

On the other hand, the results show that the site fidelity to an offshore reef, interspersed with seasonal visits to a coastal area, ceased from the Summer 2010 onward. This change in behaviour is interesting as our data suggest that it is a more definitive shift as opposed to the seasonal patterns previously observed. Moreover, the steep decrease in residency at BDS appears consistent with a definitive habitat shift hypothesis (i.e. a drastic shift in habitat use, unlikely to be reverted, due, either to the individual variability of the fish or to other changes in resource requirements) (Table 1), supported by the relatively higher residency index revealed by a newly deployed receiver (CAP, Fig. 1B). This shift can also be related to the fish´s ontogeny, thereby exhibiting the oceanodromous behaviour depicted in different works (Burch 1979; Ingram Jr and Patterson 2001; McClellan and Cummings 1997; Thompson et al. 1999). Ontogenic shifts in spatial use and movement patterns have been described for other reef fish species (e.g. Knip et al. 2011; Lecchini and Galzin 2005; Lowe et al. 1996). Similar shifts have been reported in reef species after reaching maturity and may explain a relocation of the more frequented habitat at a coastal inshore station (i.e. station CAP) (Lecchini and Galzin 2005). When caught and tagged, this animal was under the estimated size at first maturity (between 109 cm and 113 cm, Marino et al. 1995). Being a fast-growing species, the fish could have transitioned from immature to sexually active during the study period. Such assumption could well explain the long-term shift in behaviour but somewhat contradicts the previous suggestion that earlier seasonal patterns could be spawning related.

It could also be that this sudden shift is linked to physiological limitations linked to environmental conditions (e.g. water temperature) (Dempster 2005; Wells and Rooker 2004), as a shift from pelagic to demersal habitat by the end of the early life stages of the greater amberjack has been previously documented (Wells and Rooker 2004).

Further investigation on the biology of the species in the mid-Atlantic would produce important knowledge to study either hypotheses.

Our observations on the movements of the school shark are coherent with previous investigations, which mostly relied on archival or dart tagging methods. In these studies, results indicated frequent deep excursions (i.e. below 200m), implying a movement off the continental shelf while a mark-recapture study reported extended horizontal movements (Hurst et al. 1999; West and Stevens 2001, Rogers et al. 2017). However, none of the previous studies focused on providing finer scale spatial ecology and long-term movement patterns of the species. To our knowledge, we document the first long-term acoustic telemetry dataset of a school shark, uncovering repeated switches between residency and large-scale movement patterns. The individual showed relative residency at two islands ca. 350 km apart, on the coastal shore of Faial Island and at an offshore reef off Santa Maria Island, interrupted by a round-trip between both Islands. Based on the size of the individual and the reproductive biology of the species, suggesting an ovulation season during Spring in the Northern Hemisphere (Lucifora et al. 2004), we suppose we witnessed a breeding-related migration pattern of a mature female.

Despite the relative residency of the individual at the North shore of Faial Island, the individual was out of the detection range of the array for a long period of time (from Spring 2013 until Winter 2014), potentially suggesting a wider movement pattern than recorded, and this could imply visits to other islands of the Archipelago.

Results of this investigation corroborates the diurnal activity and small home range areas of salemas (Abecasis et al. 2012; Jadot et al. 2006; Jadot et al. 2002). The movements of this individual, such as the consecutive excursions to a specific area during daytime of new moons, are challenging to explain. Yet, our small study appears to produce interesting evidence for potential lunar influence in reef fish movements. We suggest that moon phase play a role *per se* in the species' behaviour, however, our current results preclude us from any conclusive statements. Further adequate investigation is required to better interpret these patterns.

Herbivorous fishes such as salemas are known to increase their activity with daylight, a behaviour thought to reflect the higher nutritive value of seagrass and algae along the day (Zemke-White et al. 2002). The area to where these excursions took place is characterized by small patches of seagrass. However, a feeding advantage seems unreasonable to explain such a punctual pattern. Alternatively, such movements could be related to spawning activities. Several other reef fishes are known to perform lunar related movements associated to spawning activities, mostly during the full moon (Bijoux et al. 2013; Bolden 2000; Danylchuk et al. 2011; Ledee et al. 2015; Meyer et al. 2007). It could be that this species spawns in a lunar related fashion, and that it uses seagrass meadows for such purpose. In the western Mediterranean, salemas spawns during two distinct periods (spring and autumn) whereas in the Canary Islands and Tunisian waters it occurs in a single period (winter) (Criscoli et al. 2006; Villamil et al. 2002). There is no information on the spawning period of salemas for the study area, but our study took place during the late spring and summer months suggesting that our study may not have occurred during the spawning period.

Another hypothesis could be that these more extensive movements during the new moon might be linked to stronger tidal currents. However, despite the proximity of the Sado estuary the tidal currents felt in the study area are not particularly strong (David Abecasis Personal Observation). In addition, if the observed displacements were due to tidal currents then these would be observed not only during the new moon but also during the full moon.

The main limitation of a "solo dataset" study is the reduced sample size, which ultimately hinders the ability to draw sound generalizations from these studies. A limited number of tagged individuals affects the ability of scientists to develop realistic generalizations for a given population or species. However, while scientists are facing a current lack of data to support adequate fisheries management measures, particularly obvious for predators (i.e. sharks and large pelagic fishes, e.g. Camhi et al. 2009), the investigation of "solo datasets" can not only provide crucial insight into unfamiliar behavior but also guide future research. For instance, the results from the greater amberjack allow us to advocate for further local spatial ecology analysis to uncover the importance of the Azores for such pelagic predators.

The results suggest high residency of a predator, potentially contributing to the growing notion that reef fishes have much higher behavioural plasticity than previously assumed (Fontes et al 2014; Fontes and Afonso, 2017). An adequate investigation would uncover the potential benefit of marine reserves for these species. Likewise, the migration pattern exhibited by the female school shark suggests further research into school shark spawning behaviour. If Santa Maria were revealed to harbor a nursery for this species, this might expose the importance of the Azores as an essential ecoregion for the species. Moreover, genetic studies would provide a crucial understanding of this behaviour, for instance aiming to characterize whether the species exhibits philopatry (Hueter et al. 2005).

Finally, further studies are needed in order to better understand the relationship between moon phase and salemas wide-ranging movements and to investigate some of the hypotheses raised by this preliminary study, such as an investigation of the reproductive biology and behaviour of the Salema.

However, we understand the importance of inter-individual variation, which often explains large proportions of animal movement variation (Spiegel et al. 2017) and should therefore mitigate the interpretation of the current results. Individual variation has been documented in dispersal, migration (partial migration is ubiquitous; Chapman et al. 2012), home range and many other movement patterns (e.g. Abecasis et al. 2014a; Vaudo et al. 2014). We are aware that the pervasive nature of individual variation means that studies based on a single fish such as those presented here, can never be expected to capture the spatial patterns of populations. Yet, they appear important for guidance of future experiments and hypothesis testing. We believe that “solo datasets” will provide important preliminary knowledge for conservation and management purposes and will be of great support for future initiatives.

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Tables

Seasons	**Array**	**BDS**	**MG**
Summer 2007	1	1	0
Autumn 2007	1	1	0
Winter 2008	1	1	0
Spring 2008	0.62	0.59	0.62
Summer 2008	0.91	0.94	0.5
Autumn 2008	1	1	0
Winter 2009	1	1	0
Spring 2009	0.45	0.33	0.12
Summer 2009	0.54	0.5	0.15
Autumn 2009	1	1	0
Winter 2010	0.95	0.92	0.03
Spring 2010	0.27	0.23	0.04
Summer 2010	0.45	0.18	0.27
Autumn 2010	0	0	0
Winter 2011	0	0	0
Spring 2011	0.03	0.02	0.01
Summer 2011	0.07	0.03	0.07

Table 1. Seasonal residency indices for the individual greater amberjack, *Seriola dumerili*, tagged at “Baixa do Sul” offshore reef in September 2007 in the Azores, mid-Atlantic. BDS: “Baixa do Sul”, MG: “Monte da Guia”.

	Santa Maria Island		Faial Island	
Seasons	A_{Ri}	R_{Ri}	A_{Ri}	R_{Ri}
Autumn 2012	-	-	0.53	0.54
Winter 2013	-	-	0.24	0.87
Spring 2013	-	-	0	0
Summer 2013	0	0	0	0
Autumn 2013	0	0	0	0
Winter 2014	0	0	0	0
Spring 2014	0.05	1	0	0
Summer 2014	0.39	0.90	0	0
Autumn 2014	0	0	0	0
Winter 2015	0	0	0	0
Spring 2015	0	0	0.32	0.67
Summer 2015	0	0	0.40	0.42
Autumn 2015	-	-	0.93	0.94
Winter 2016	-	-	0.38	0.76
Spring 2016	-	-	0	0

Table 2. Seasonal residency indices for the individual school shark, *Galeorhinus galeus*, tagged at the North of Faial Island in November 2012 in the Azores, mid-Atlantic. – indicates periods off duty of the station. A_{Ri}: absolute seasonal residency index, R_{Ri}: relative seasonal residency index

Station ID #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Total
Ri	-	0.01	-	-	-	-	-	-	-	0.10	0.94	0.03	0.03	0.04	0.94

Table 3. Residency index (Ri) for the individual Salema (*Sarpa salpa*), tagged in the Luiz Saldanha Marine Park, per station and for the entire array (total). – indicates no detections.

Figure captions

Fig. 1. Map of the study areas in the Azores Archipelago. A) Azores Archipelago. B) Location of the study site of the *Seriola dumerili*, in the Faial-Pico channel and around Monte da Guia (MG). Black circles: acoustic receivers with constant duty period during the monitoring of the individual from September 2007 to July 2011. Black star indicates receiver CAP, with an intermittent duty period from late 2010 onward. BDS: Baixa do Sul. C) Movements of the female school shark, *Galeorhinus galeus*, monitored between Autumn 2012 and Winter 2016. Black circles: acoustic receivers without detections. Black stars: acoustic receivers with detections.

Fig. 2. Calendar plot of daily detections by receivers of monitored greater amberjack, *Seriola dumerili*, tagged at "Baixa do Sul" offshore reef in September 2007 in the Azores, mid-Atlantic. BDS: "Baixa do Sul", MG: "Monte da Guia".

Fig. 3. Proportion of absence from the whole array of receivers per season of the greater amberjack, *Seriola dumerili*, tagged at "Baixa do Sul" offshore reef in September 2007 in the Azores, mid-Atlantic.

Fig. 4. Minimum seasonal linear distance (km) travelled between stations by the greater amberjack, *Seriola dumerili*, tagged at "Baixa do Sul" offshore reef in September 2007 in the Azores, mid-Atlantic.

Fig. 5. Calendar plot of daily detections by receivers of the monitored school shark, *Galeorhinus galeus*, tagged in Faial in November 2012 in the Azores, mid-Atlantic.

Fig. 6. Calendar plots of the Salema (*Sarpa salpa*) tagged in April 2010 in the Luiz Saldanha Marine Park, continental Portugal. Circles indicate detections by stations located inside the Luiz Saldanha Marine Park. Grey line shows the fraction of the moon illuminated (0 – new moon and 1 – full moon).