



Ranging Patterns and Site Fidelity of Snubfin Dolphins in Yawuru Nagulagun/Roebuck Bay, Western Australia

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For long-lived species such as marine mammals, having sufficient data on ranging patterns and space use in a timescale suitable for population management and conservation can be difficult. Yawuru Nagulagun/Roebuck Bay in the northwest of Western Australia supports one of the largest known populations of Australian snubfin dolphins (*Orcaella heinsohni*)—a species with a limited distribution, vulnerable conservation status, and high cultural value. Understanding the species' use of this area will inform management for the long-term conservation of this species. We combined 11 years of data collected from a variety of sources between 2007 and 2020 to assess the ranging patterns and site fidelity of this population. Ranging patterns were estimated using minimum convex polygons (MCPs) and fixed kernel densities (weighted to account for survey effort) to estimate core and representative areas of use for both the population and for individuals. We estimated the population to range over a small area within the bay (103.05 km²). The Mean individual representative area of use (95% Kernel density contour) was estimated as 39.88 km² (± 32.65 SD) and the Mean individual core area of use (50% Kernel density contour) was estimated as 21.66 km² (±18.85 SD) with the majority of sightings located in the northern part of the bay less than 10 km from the coastline. Most individuals (56%) showed moderate to high levels of site fidelity (i.e., part-time or long-term residency) when individual re-sight rates were classified using agglomerative hierarchical clustering (AHC). These results emphasize the importance of the area to this vulnerable species, particularly the area within the Port of Broome that has been identified within the population's core range. The pressures associated with coastal development and exposure to vessel traffic, noise, and humans will need to be considered in ongoing management efforts. Analyzing datasets from multiple studies and across time could be beneficial for threatened species where little is known on their ranging patterns and site fidelity. Combined datasets can provide larger sample sizes over an extended period of time, fill knowledge gaps, highlight data limitations, and identify future research needs to be considered with dedicated studies.

Keywords: ranging patterns, site fidelity, snubfin dolphin, *Orcaella heinsohni*, Yawuru Nagulagun, Roebuck Bay

INTRODUCTION

As top predators, marine mammals play important ecological roles in marine ecosystems (Bowen, 1997; Heithaus et al., 2008) and are often considered indicators of ecosystem health (Bossart, 2011; Nelms et al., 2021). Many species and populations, including coastal dolphins, are experiencing cumulative anthropogenic pressures such as habitat degradation and modification (Parra et al., 2017; Krebs et al., 2020), increasing vessel traffic and noise (Bejder et al., 2006; Jensen et al., 2009a; Marley et al., 2017a; Erbe et al., 2019), and pollution (Cagnazzi et al., 2013a; Parra et al., 2017). Direct impacts may come from incidental entanglement in fishing gear (Laist, 1997; Jensen et al., 2009b; Reeves et al., 2013) and vessel strike (Wells and Scott, 1997; Thiele, 2010; Peel et al., 2018; Schoeman et al., 2020), whilst habitat loss, reduced prey from fishing (recreational, commercial and aquaculture activities) and increasing tourism have indirect impacts often resulting in disturbance, avoidance, and displacement from critical habitats (Paiva et al., 2015; Strickland-Munro et al., 2016; Karczmarski et al., 2017; Wang et al., 2017; Clarkson et al., 2020; Kassamali-Fox et al., 2020; Lin et al., 2021). Managers rely on science to better understand these impacts to wildlife populations and, in particular, how to mitigate these. This includes understanding how animals use space and resources over time to identify areas of overlap or conflict with human activity (Lotze et al., 2017), which can then be applied through environmental impact assessments, species conservation assessments, protected area design, and marine spatial planning.

Animal movement can influence the dynamics of a population, including abundance, distribution, habitat selection, species interactions, and social and population structure, all of which, in turn, can affect the fitness of an individual and population (Nathan et al., 2008; Börger, 2016). Ranging patterns, (i.e., the size of the area used by each individual and population within the confines of a study area), and site fidelity, as defined by Switzer (1993), are components of animal movement that are thought to be driven by changes in an individual's needs and the distribution of its conspecifics, predators, and resources (Switzer, 1993, 1997; Nathan et al., 2008). Areas of high-quality habitat, for example, areas with abundant resources and shelter from predators, are likely to be associated with individuals that exhibit high site fidelity and a small range (Knip et al., 2012; Habel et al., 2016; Passadore et al., 2018). However, populations with high site fidelity and limited ranges can potentially be more vulnerable to anthropogenic impacts, stochastic events, and population declines, particularly where there is limited connectivity with other populations as they may have limited resilience or adaptability to local impacts. Information on ranging and residency patterns can contribute to existing knowledge of the species' ecology and lead to a better understanding of overlap with pressures which, in turn, can inform management (Worton, 1989; Flores and Bazzalo, 2004; Sprogis et al., 2016).

For long-lived species such as marine mammals, having sufficient data that can identify population dynamics and needs in a timescale suitable for population management and conservation can be difficult. In some cases, particularly for vulnerable and data deficient species, sightings from multiple

sources can be pooled together to increase the sample size and ability to estimate ranging patterns and detect site fidelity over a broader range and timescale (Maes et al., 2015; Molinari-Jobin et al., 2018). A similar approach could be used for cryptic species to study population ranging patterns, where individual range estimation is not possible, and tagging is not an ethical or feasible option due to the technology available or inability to capture the animals, however, where it is possible to identify individuals through natural marks (Andrews et al., 2019).

The Australian snubfin dolphin (*Orcaella heinsohni*, hereafter, snubfin dolphin) was described as a separate species in 2005 and is endemic to the tropical waters of northern Australia and southern New Guinea (Beasley et al., 2005). Snubfin dolphins are typically found in shallow coastal waters (<20 m) and usually in proximity (<15 km) to freshwater inputs (Parra et al., 2002, 2006b; Parra, 2006; Bouchet et al., 2021). Due to small population sizes and ongoing cumulative impacts across their coastal habitat, snubfin dolphins were assigned a conservation status of Vulnerable to extinction by the International Union for Conservation of Nature (IUCN) (Parra et al., 2017). Previous research suggests they are discontinuously distributed across their range as small local populations of 50–200 individuals (Parra et al., 2006a; Palmer et al., 2014b; Brown et al., 2016; Brooks et al., 2017; Bouchet et al., 2021) that exhibit site fidelity (Parra, 2006; Brown et al., 2016), and limited gene flow between populations (Brown et al., 2014b, 2017). A recent study by Bouchet et al. (2021) found that snubfin dolphins occupy a relatively small area within their distribution in the Kimberley, further highlighting the limited range and vulnerability of the species. Due to their low numbers, limited resilience, and apparent reliance upon shallow waters (Parra et al., 2006b; Bejder et al., 2012; Brown et al., 2016; Bouchet et al., 2021), combined with their geographic isolation and long-lived characteristics (e.g., late maturation and low reproductive rates), snubfin dolphins are increasingly vulnerable to anthropogenic impacts, as reflected by their IUCN status. Furthermore, the importance of conserving snubfin dolphins has not only been identified at the global level but is also a priority at local, state, and national levels (DoE, 2015; Department of Parks and Wildlife, 2016a; Parra et al., 2017; Waples and Raudino, 2018).

Yawuru Nagulagun, also known as Roebuck Bay (hereafter, Yawuru Nagulagun, meaning sea country of the Yawuru people), in the northwest of Western Australia is part of Yawuru Country — the land and sea cared for by Yawuru people for thousands of years (Department of Parks and Wildlife, 2016a). In recognition of the unique and rich habitat known for its biodiversity and cultural values, Yawuru Nagulagun was partially gazetted as a marine park in 2016 under the *Conservation and Land Management Act 1984* (CALM Act) and is jointly managed by the Yawuru Registered Native Title Prescribed Body Corporate (Yawuru P.B.C) and the Department of Biodiversity, Conservation and Attractions (DBCA). The northern half of Yawuru Nagulagun represents the highest density of snubfin dolphins among any population yet studied (~130 individuals in a 100 km² study area) (Brown et al., 2016; Raudino et al., 2020). Consequently, snubfin dolphins are considered a key biodiversity asset of the marine park and are the focal point for a small tourism

industry in the area. While this population has been the subject of several studies on population abundance and connectivity across the region (Brown et al., 2014b, 2016; Raudino et al., 2020), there is still limited understanding of how the population uses the bay both spatially and temporally.

On a global scale, the northern waters of Australia are relatively undisturbed (Halpern et al., 2008) partly due to their remoteness. However, usage of the region is predicted to increase (Palmer et al., 2014b; Department of Parks and Wildlife, 2016a), raising concerns about increasing pressures within Yawuru Nagulagun from population growth and development (Boschetti et al., 2020) and associated increases in recreational use and tourism (Allen et al., 2012; Bejder et al., 2012; Department of Parks and Wildlife, 2016a). More specifically, current pressures include development associated with the Port of Broome (Bejder et al., 2012), shipping traffic (Beckley, 2015), interactions with commercial tour vessels and interactions with recreational vessels including recreational fishing (Thiele, 2010; Department of Parks and Wildlife, 2016a). These pressures, along with effects of climate change, are predicted to impact the conservation of snubfin and other dolphin populations in the region (Boschetti et al., 2020).

Our study aimed to improve current knowledge on snubfin dolphin ranging patterns and site fidelity to Yawuru Nagulagun with a focus on identifying areas of high use and importance. To fulfill these aims, our study: (1) estimated range size and locations at the individual and population levels and (2) classified site fidelity at the individual and population levels. Data collected over 11 years by a variety of sources (i.e., researchers, rangers, managers, and citizen scientists) were used to allow the exploration of space use and site fidelity over an extended timeframe (2007–2019). Collating data from different programs is becoming increasingly common in ecological research (Fletcher et al., 2019; Isaac et al., 2020) as it offers a cost-effective means of increasing sample size over space and time for long-lived and wide-ranging species. The approach taken in this study allowed for the first assessment of individual ranging patterns for snubfin dolphins, and one of very few on site fidelity for this species to be produced and published.

MATERIALS AND METHODS

Study Area

Yawuru Nagulagun is a large tropical embayment (~500 km²) near the township of Broome in north-western Australia (Figure 1). The area is subject to a large tidal range of up to 10 m during peak spring tides (Cresswell et al., 2011), resulting in 200 km² of exposed mud flats at low tide that become unavailable to dolphins (Brown et al., 2014a; Raudino et al., 2020). The benthic substrate consists of mud and silt with seagrass and mangroves lining the coastal edge of the bay. The waters are commonly turbid, due to the predominantly shallow bathymetry of the bay, strong tidal flow, wind action, fine sediments, and organic matter in the water column from fringing mangrove systems. Water movement and mixing patterns in the nearshore zone are thought to be

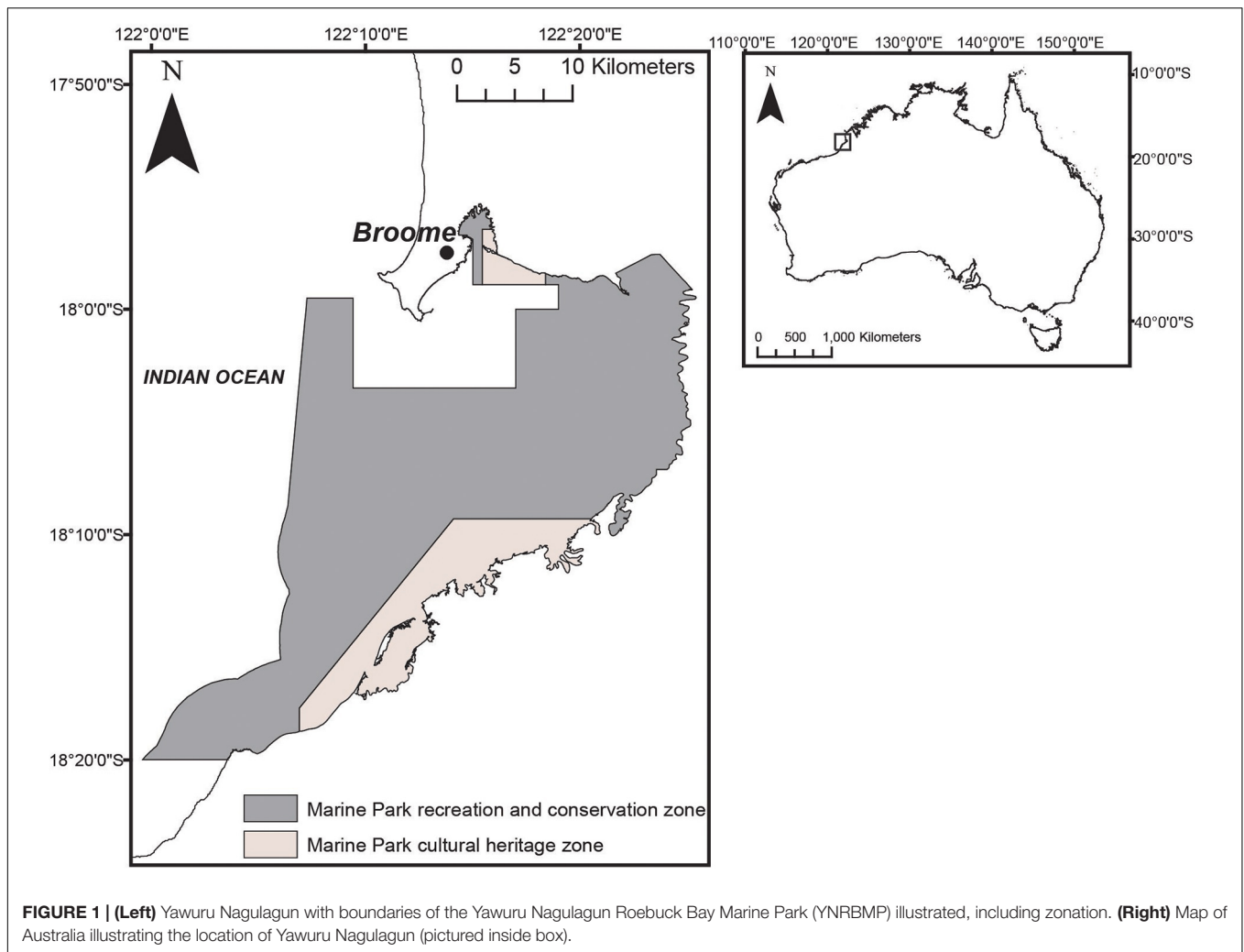
driven by large tidal ranges, seabed topography, and local winds (Department of Parks and Wildlife, 2016b).

Data Collection

Data used in this project were collected through a range of research and citizen science projects, including dolphin surveys using standard survey techniques, as well as opportunistic sightings (see **Supplementary Table 1**). The majority of surveys were designed to cover the northern part of the Bay (~100 km²). A full description of methods for individual surveys are available from the references listed in **Supplementary Table 1** and a brief description is provided here. Each data source defined a dolphin group as “individuals within 100 m of each other engaging in the same or similar behavioral activity” (Irvine et al., 1981; Wells et al., 1987; Parra et al., 2006a). Age class was defined by comparing size and position in relation to an assumed adult: Adults appear fully grown relative to others in the group and are ~2 m long; juveniles are around 2/3 the length of an adult and appear to be independent of an adult and calves are around 1/2 the length of an adult or smaller and swim in close association with an adult (Parra et al., 2006a; Jefferson et al., 2015). During systematic surveys, when a dolphin group was sighted, information collected on dolphin sightings included species present, number of individuals, behavior, and location. Photographs of individual snubfin dolphins were taken for identification. Sighting information included identification of individual dolphins, allowing for the compilation of individual sighting histories, including when, where and with whom they were sighted. The same information was recorded during opportunistic sightings, though photographs were not always available for all individuals.

Photo-Identification and Image Analysis

Individuals were identified in photographs based on the natural marks present on their body and dorsal fins (Würsig and Jefferson, 1990). Adults and juveniles were included in analysis where they could be reliably identified through photo-identification (photo-ID). Calves were excluded from analysis. Evaluating images according to photographic quality and distinctiveness in a consistent manner is a critical step for all photo-ID studies, as this helps minimize bias and prevent misidentification of individuals (Urian et al., 1999, 2015; Rosel et al., 2011). Previous studies have successfully photo-identified individual snubfin dolphins in northern Australia and used protocols described by Urian et al. (1999) to study these populations (Parra et al., 2006a; Cagnazzi et al., 2013b; Palmer et al., 2014a; Brooks and Pollock, 2015; Brown et al., 2016; Raudino et al., 2020). In Yawuru Nagulagun, studies using photo-ID of individual snubfin dolphins have been conducted over many years (see **Supplementary Table 1**) to develop information on the population. To ensure consistency across datasets, the protocol developed by Urian et al. (1999, 2014) was applied to all photo-ID images used in this study to ensure the photo quality and distinctiveness of individual dolphins was standardized for all data (see **Supplementary Appendix 1**). An assumption of this study is accurate identification of individuals across time and space (Stolar and Nielsen, 2015), and the methods



described here used to standardize image analysis from each data source minimizes potential mis-identification that could introduce such bias.

Ranging Patterns

We used two methods to improve our understanding of the animals' use of space: (i) minimum convex polygons (MCPs), which contain all points where an individual has been recorded (Mohr, 1947); and (ii) kernel density estimation (KDE) to measure the utilization distribution, which examines the intensity of space use to describe an animal's range (Jennrich and Turner, 1969; Worton, 1989; Kie et al., 2010). While the MCP method can provide a representation of the overall range, it is known to be biased and can introduce intraspecific variation when small sample sizes are used (Nilsen et al., 2008). Therefore, we also used KDE to estimate the use of space within the species' range. Individuals with a minimum of 10 sightings were used for this analysis as per Bräger et al. (2002) and Rayment et al. (2009). To minimize temporal and spatial autocorrelation, when an individual was sighted more than once within a day, only one randomly chosen sighting of an individual on that day was used.

Methods for individual range analysis were repeated to estimate the population range using one randomly chosen dolphin group sighting per day.

Ranging Patterns Estimation Using Minimum Convex Polygons

The MCP is widely recognized and commonly used in the estimation of ranging patterns due to its validity for comparison to previous studies and simple calculation methods (Seaman et al., 1999; Flores and Bazzalo, 2004). MCPs provide a maximum representation of a species' range based on the data available which can provide useful information for spatial risk assessments (Rayment et al., 2009; Sprogis et al., 2016). To estimate range on an individual level, MCPs were used to delineate the boundaries of the ranging patterns of individual snubfin dolphins by connecting the outermost sighting points (White and Garrott, 2012). For every individual, cumulative polygonal areas for each new sighting were calculated using R v 1.2.5042 (R Core Team, 2020) to determine if any individuals reached a maximum range size (Cobarrubia-Russo et al., 2020). The tool set Home Range Tools

(MacLeod, 2013) in ArcMap v 10.7 (ESRI, 2019) was used to calculate MCPs.

Ranging Patterns Estimation Using Kernel Densities

One of the most common methods used to measure utilization distribution is KDE, which estimates the intensity of use throughout the spatial range using a density based statistical approach (Silverman, 1986). KDE is a non-parametric method and has the potential to accurately estimate densities of any shape when the most appropriate level of smoothing is selected (Seaman and Powell, 1996). The width of the kernel, also known as “bandwidth” or “smoothing parameter,” determines the relationship between the distance of a location from which a species has been sighted and the contribution of the location to the density estimate at that point (Gitzen et al., 2006). For this study, several methods were considered (see **Supplementary Table 2**) and trialed for the individual and population home range estimates. The likelihood cross-validation (CVh) method was chosen as it produced relatively consistent density estimates and density contours that were the least fragmented, despite the relatively small number of sightings. Smoothing parameters using the CVh method were calculated *via* Animal Space Use v 1.3 (Horne and Garton, 2009).

The tool set Home Range Tools (MacLeod, 2013) in ArcMap v 10.7 (ESRI, 2019) was used to estimate the utilization distribution using fixed kernel densities. Fixed kernels (i.e., where the bandwidth remains constant) were used rather than adaptive kernels (i.e., where the bandwidth varies depending on nearby observations) as they generally have lower bias at outer contours of the home range (Seaman et al., 1999; Gitzen et al., 2006). The “Kernel Density Estimate with Barriers” tool was chosen to ensure that land was excluded and would not bias the density estimates. Using the Spatial Analyst and Data Management toolbox, the kernel density values were extracted and then used to produce percentage density contours (PDC) at 50% and 95% levels to indicate core and representative areas for individual dolphins, respectively (Gill et al., 2011; Brough et al., 2019).

Accounting for Spatial Survey Effort

A consequence of using data from multiple sources (including opportunistic data) in this study was the lack of equal survey coverage across the study area. To account for non-uniform survey effort, each dolphin sighting was assigned a weight based on the probability of obtaining that sighting (Fieberg, 2007; Rayment et al., 2009; Brough et al., 2019). Survey tracks were extracted from each dataset where available (see **Supplementary Table 1**) and imported into ArcMap v 10.7 (ESRI, 2019). Using data from 2014 (the year with the highest survey intensity), the maximum detection distance (distance from the survey vessel where dolphins were detected) was estimated as 450 m. A buffer of 450 m was added to both sides of each survey track to include the estimated detection range in the surveyed area. As this study aimed to obtain minimum ranging estimates, a uniform key function was applied using the maximum distance that groups were sighted within. This approach aimed to reduce large spatial scale biases caused by survey effort varying significantly over the broad study area, and not detection bias. The potential bias of

reduced detection range from the vessel over several hundred meters from the transect was considered to be smaller in scale, and relatively small in its impact on gaining insight into broader scale ranging patterns, which was the main aim of the study. A grid with a cell size of 0.01 km² was applied to the survey area and the number of times a grid cell was surveyed and the number of sightings per grid cell were calculated. Different grid cell sizes ranging from 0.01 to 1 km² were trialed to determine the most suitable size for the analysis. A cell size of 0.01 km² was used as it produced density estimates at a high resolution with the least amount of fragmentation and over-smoothing (Powell, 2000; Gregory, 2016). Grid cells were then weighted using the following equation modified from Rayment et al. (2009):

$$W_i = 1 / \frac{(A_i \times V_i)}{\sum_{i=1}^T (A_i \times V_i)}$$

where, A_i = the area of cell i covered by a survey, V_i = the number of visits to cell i during the time the dolphin was known to be alive, and T = the total number of cells surveyed. The scaled weight for each sighting (W_i^S), such that all the scaled weights for an individual would sum to one and the resulting distribution would be a true probability density function, was calculated using the following equation from Rayment et al. (2009):

$$W_i^S = \frac{W_i}{\sum_{i=1}^T W_i}$$

This weighting process assigns greater weight to sightings in areas that received less survey effort. Some assumptions for this study that were not validated included: (1) detection within the buffer area (450 m) was uniform and (2) that the individuals were in the study area and therefore available for detection. Weighting for survey effort with the assumptions given above reduced spatial bias in the kernel density estimates toward areas that received more survey effort.

Site Fidelity

Site Fidelity Analysis of Individual Snubfin Dolphins

To investigate the tendency of individual snubfin dolphins to return to or remain in the study area, three measures of site fidelity using re-sighting rates were calculated for individual dolphins: (1) monthly sighting rate (number of months a dolphin was identified in as a proportion of the total number of months over which surveys took place), (2) yearly sighting rate (the number of calendar years a dolphin was identified in as a proportion of the total number of calendar years surveyed) and (3) site fidelity indices (SFIs) (Parra et al., 2006a; Zanardo et al., 2016; Hunt et al., 2017; Passadore et al., 2018; Haughey et al., 2020). SFIs were calculated as the ratio between the number of re-sightings for each individual and the number of survey days (defined as the number of survey days from an individual's first sighting to its last re-sighting) (Simpfendorfer et al., 2011; Daly et al., 2014). Individuals that were first sighted in the last survey period (2019) were excluded from the analysis. To reduce temporal autocorrelation, only one randomly chosen sighting per day of an individual was included.

Due to variation in sampling effort over the study period (2007–2019), minimum sampling times were implemented for the site fidelity measures to ensure that the months and years included had sufficient survey effort to reliably identify all snubfin dolphins present at that time. Months with a minimum of two survey days were included for the monthly sighting rate calculation. Years with surveys in at least 2 months were included for the yearly sighting rate calculation. These minimum sampling periods were chosen to eliminate months and years with potentially insufficient sampling coverage whilst aiming to maximize the ability to detect site fidelity (Vermeulen et al., 2017).

To determine if there were groups or “clusters” of individuals with similar levels of site fidelity, an agglomerative hierarchical clustering (AHC) analysis was run using the monthly and yearly sighting rates (Zanardo et al., 2016; Hunt et al., 2017; Passadore et al., 2018; Haughey et al., 2020). AHC is a clustering method that builds a dendrogram beginning with each observation as an individual cluster. These clusters are then successively combined based on similarity until all clusters have been combined into one (Legendre and Legendre, 2012). While several methods were considered, the Euclidean distance and Ward's method (minimum variance) were used as the dissimilarity measure and the clustering algorithm, respectively, as these are considered suitable approaches (Ward, 1963; Singh et al., 2011) and comparable to past research (Zanardo et al., 2016; Hunt et al., 2017; Passadore et al., 2018; Haughey et al., 2020).

To assess the strength of each cluster identified, approximately unbiased (AU) probability values (i.e., p -values) were calculated by generating 1,000 bootstrap resampling replications per cluster (Suzuki and Shimodaira, 2006; Singh et al., 2011; Zanardo et al., 2016). The AU— p -values were also used to define a dissimilarity threshold to determine the most suitable number of clusters. The validity of dissimilarities among observations was assessed using the cophenetic correlation coefficient (CCC). The CCC measures the relationship between the original dissimilarity matrix and the cophenetic matrix, which is obtained after the dissimilarities are recalculated by the clustering algorithm (Sokal and Rohlf, 1962; Passadore et al., 2018). A CCC-value greater than 0.8 can be considered a reliable representation of the data (Bridge and Fry, 1993). The AHC analysis was performed using the “pvclust” package (Suzuki and Shimodaira, 2006) in R v 1.2.5042 (R Core Team, 2020).

Site Fidelity Analysis of the Snubfin Dolphin Population

To investigate site fidelity at the population level, indicators such as permanence and periodicity as defined by Tschopp et al. (2018) were calculated as part of a standardized site fidelity index (SSFI) using the following equations:

$$IT = \frac{IT \text{ individual 1} + IT \text{ individual 2} \dots}{\text{Total number of individuals}}$$

and

$$It = \frac{It \text{ individual 1} + It \text{ individual 2} \dots}{\text{Total number of individuals}}$$

followed by:

$$SSFI = \frac{2}{\frac{1}{IT} + \frac{1}{It}}$$

where IT (Permanence) is the average amount of time spent in the study area expressed as the number of days between the first and final sighting of each individual as a proportion of the total number of days from the beginning to the end of sampling (non-constant effort). It (Periodicity) is the average recurrence of an individual, expressed as the number of days between an individual's first, and final sighting as a proportion of the individual's total number of sightings minus one.

RESULTS

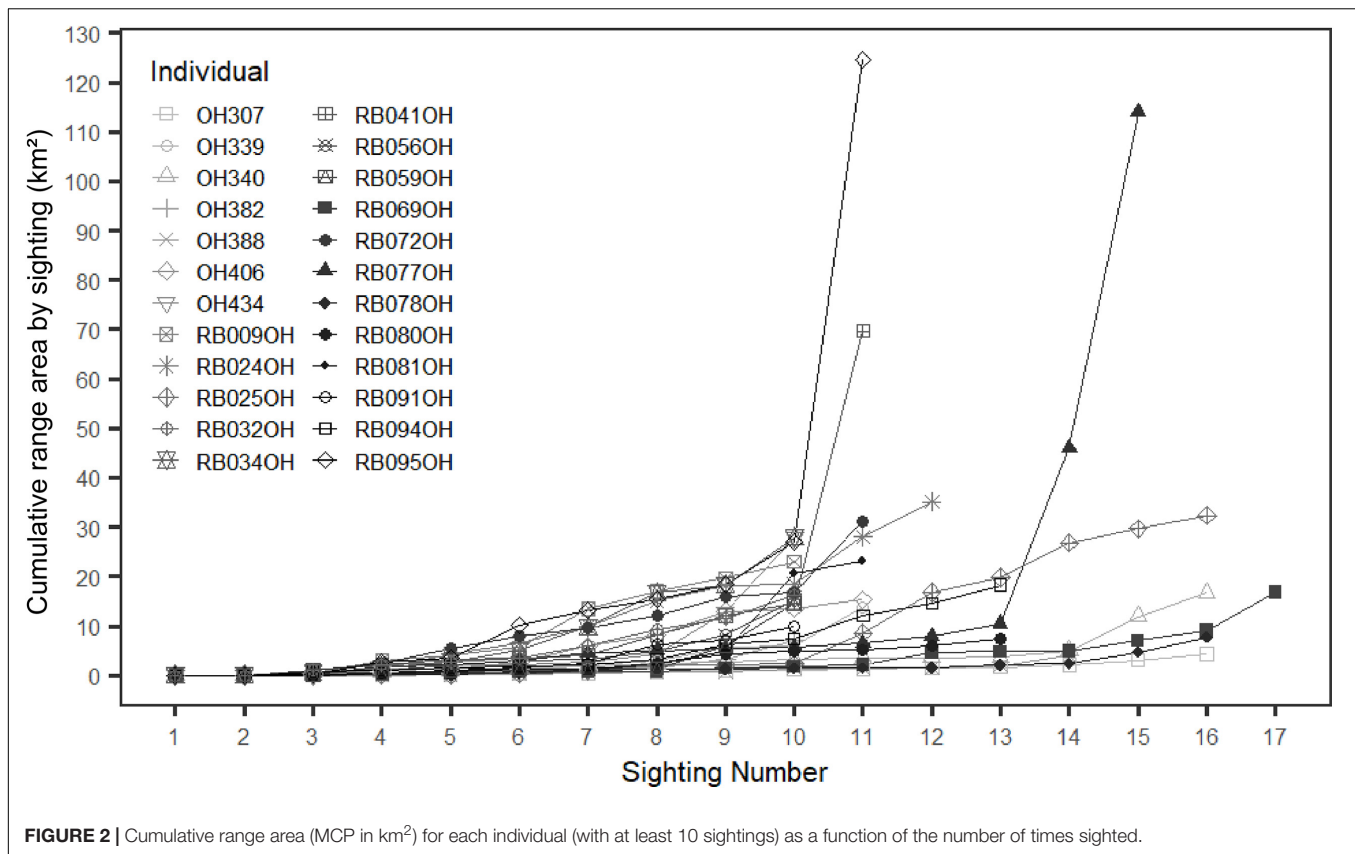
Sightings and Survey Effort

A total of 147 surveys were conducted between 2007 and 2019 (see **Supplementary Figure 1**). Surveys were usually conducted in the dry season (April–October) with few surveys conducted in the wet season (November–March). The most intensive survey periods included October/November in 2013, April/May in 2014 and July 2014 (see **Supplementary Figure 1**). During the study period, there were 688 group sightings of snubfin dolphins in Yawuru Nagulagun (see **Supplementary Figure 2 Left**). Effort was unevenly distributed throughout the bay, with the northern area of the bay (~100 km²) receiving notably more effort in comparison to the southern end of the bay (see **Supplementary Figure 2 Right**). There were 2,306 images processed, with 1,390 (60.28%) classified as excellent/good quality of a distinctive individual (D1 or D2) of a total of 268 unique individuals.

Ranging Patterns

For ranging pattern analyses of individuals, there were 24 individuals with 10 or more sightings that qualified for range analysis and the number of sightings per individual ranged from 10–17 (see **Supplementary Table 3** and **Supplementary Figures 3.1–3.6**). The cumulative range area curve (**Figure 2**) indicated only four individuals (oh307, oh340, rb069oh and rb078oh) reached a stable asymptote at 14 sightings; however, the area for these individuals began to increase slightly after 14 sightings. The majority of individuals did not reach a stable asymptote, indicating that their full range size is likely underestimated.

The core and representative areas for the 24 individuals were located in the northern part of the bay where the majority of survey effort occurred (see **Supplementary Figures 3.1–3.6**). Three individuals (rb077oh, rb041oh and rb095oh) also had core areas located in the southern part of the bay (~20 km between areas) (see **Supplementary Figure 3.2**; rb077oh, **Supplementary Figure 3.3**; rb041oh and **Supplementary Figure 3.5**; rb095oh). The MCP for the 24 individuals ranged from 4.3 to 124.57 km² with a mean of 29.30 km² (± 31.73 SD) (see **Supplementary Table 3** and **Supplementary Figures 3.1–3.6**). The 50% PDC ranged from 6.51 to 90.09 km² with a mean of 21.66 km² (± 18.85 SD) and the 95% PDC ranged from 12.27 to 157.52 km² with a mean of 39.88 km² (± 32.65 SD) (see **Supplementary Table 3** and **Supplementary Figures 3.1–3.6**).



For population level ranging pattern analyses, 134 sightings were used. The core and representative areas were in both the northern and southern areas in the bay and within 5–10 km of the coastline (Figure 3, Right). The population MCP area was 215.05 km² (Figure 3, Left). The 50% PDC was 54.15 km² and the 95% PDC was 103.05 km² (Figure 3, Right).

Site Fidelity

For the site fidelity analyses, 20 months (out of 30) and six years (out of 11) were included. Site fidelity analyses indicated that 24.10% of individuals ($n = 47$) were sighted only once, 23.59% ($n = 46$) were sighted two or three times, and 52.31% ($n = 102$) were sighted four or more times (based on 195 individuals that could be included in the analyses). The average monthly re-sighting rate was (\pm SD) 0.13 ± 0.09 (95% CI: 0.12–0.14) indicating individuals were usually sighted in two or three out of the 20 months surveyed. Site fidelity analyses indicated 34.36% of individuals ($n = 67$) were sighted during only one month, while three individuals (rb025oh, rb078oh and rb080oh) were seen in eight survey months and had the highest monthly re-sighting rate (0.40). The average yearly re-sighting rate was 0.31 ± 0.17 (95% CI: 0.30–0.32) indicating that individuals were typically sighted in one or two years out of the six included in the site fidelity measures. In total, 43.59% of individuals were sighted in one year ($n = 85$), 50.26% sighted in two or three years ($n = 98$), and 6.15% individuals ($n = 12$) sighted in four or more years. One individual was sighted in all six years

(rb107oh). The longest period between first and last re-sighting was 11 years ($n = 2$) followed by 10 years ($n = 3$). The average SFI was 0.10 ± 0.08 (95% CI: 0.09–0.11), however, this includes the 24.10% of individuals ($n = 47$) that were sighted only once (SFI = 0).

Individuals were separated into three clusters based on the AHC analysis (dissimilarity threshold = 12.5) (Figure 4) using monthly and yearly re-sighting rates. Clusters in the dendrogram were considered a reasonable representation [the cophenetic correlation coefficient (CCC) = 0.67 and the AU— p -values (0.91–0.95)]. Cluster 1 consisted of 43.59% of individuals ($n = 85$) that were sighted in one out of the six years and can be considered as “non-residents” with no site fidelity to the area. Cluster 2 consisted of 44.62% of individuals ($n = 87$) that were sighted in two or three years and can be considered as “part-time residents” with moderate site fidelity. Cluster 3 consisted of 11.79% of individuals ($n = 23$) that were sighted in either three or four of the six years and can be considered as “long-term residents” who displayed a high level of site fidelity (Table 1). This finding was further supported by the primary cluster for clusters 2 and 3 being derived from the same “root” in the dendrogram tree (AU p -value = 0.95; Figure 4).

The standardized site fidelity estimate for the population (SSFI) overall was low (0.19) in Yawuru Nagulagun, given that an SSFI of zero suggests low site fidelity for the population and one suggests high site fidelity for the population (Tschopp et al., 2018).

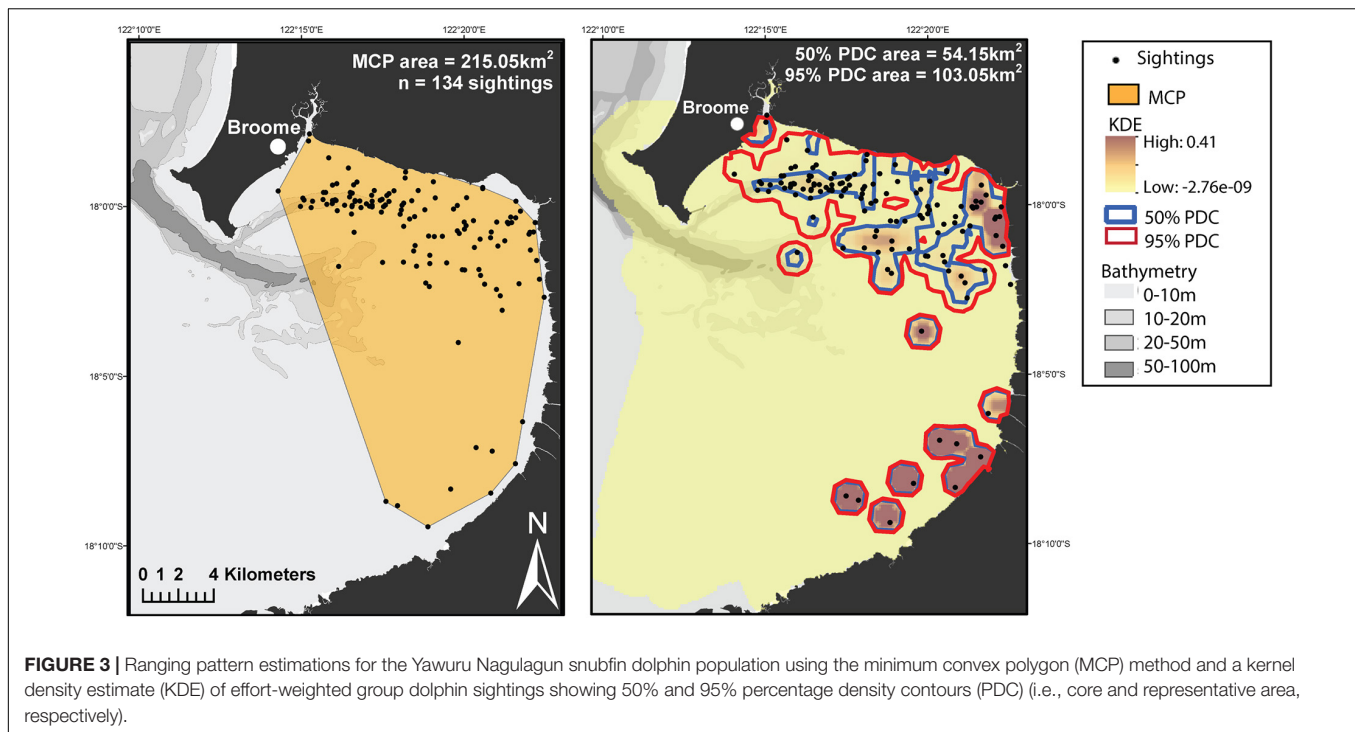


TABLE 1 | Average monthly and yearly resight rates and average site fidelity indices (SFI) of the three clusters of snubfin dolphins in Yawuru Nagulagun identified through an agglomerative hierarchical clustering analysis.

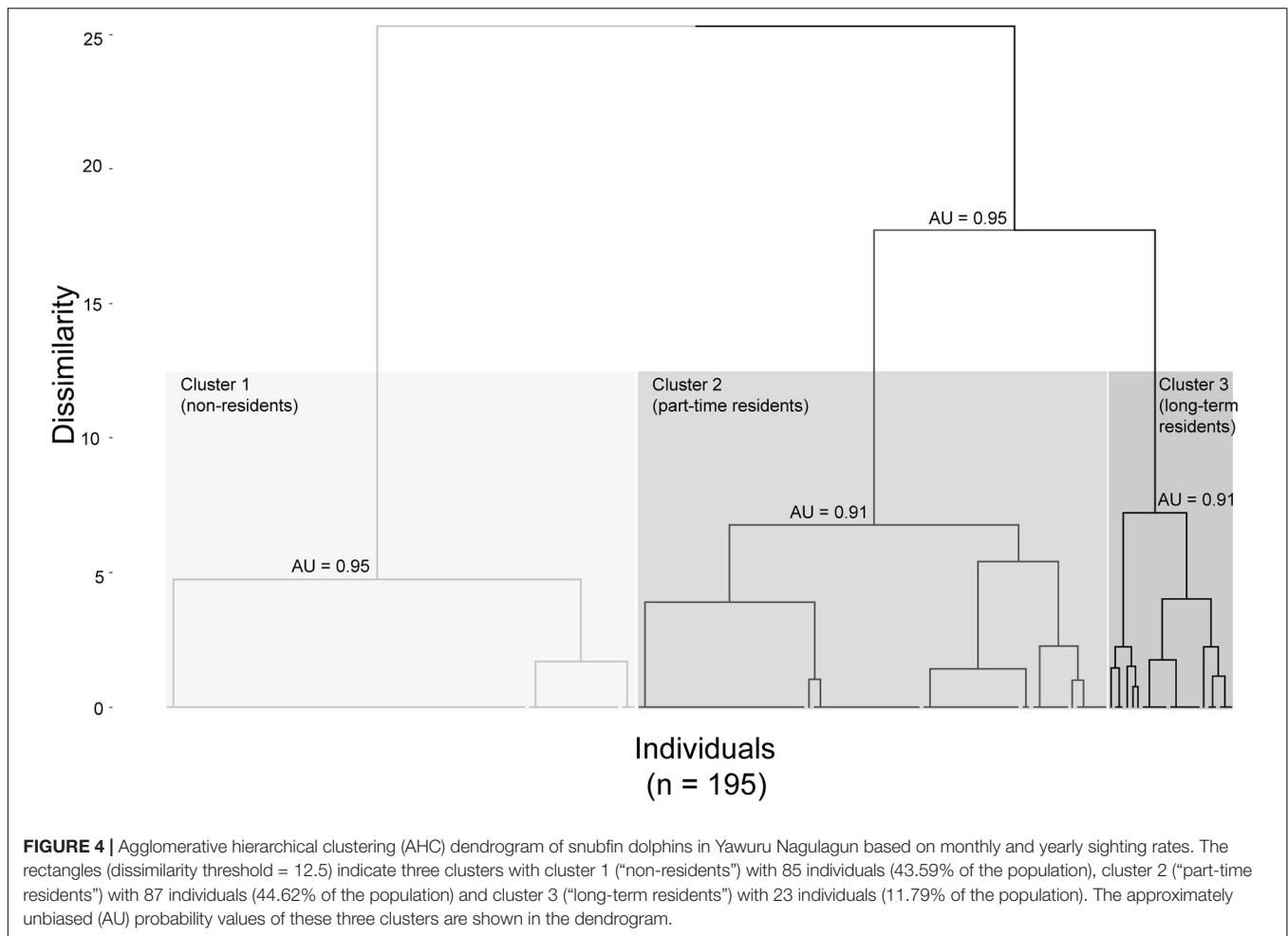
Cluster	No. individuals	Average monthly resight rate (SD)	Average yearly resight rate (SD)	Average SFI (SD)
1. "Non-residents"	85	0.06 (0.03)	0.16 (<0.00)	0.08 (0.11)
2. "Part-time residents"	87	0.15 (0.04)	0.36 (0.06)	0.12 (0.06)
3. "Long-term residents"	23	0.30 (0.05)	0.64 (0.15)	0.12 (0.03)

DISCUSSION

Our approach of analyzing datasets from multiple sources collected over an 11-year period has contributed to our current understanding of the ranging patterns and site fidelity of snubfin dolphins and have provided further evidence of the importance of Yawuru Nagulagun to this species. The importance of the nearby un-surveyed areas remains unknown and will be a priority for future research to compare with Yawuru Nagulagun. In terms of sightings, our combined dataset was over four and a half times larger than the single largest component study (Brown et al., 2016). This study collated data from multiple sources and produced results that could not have been obtained with the data from any single study alone. However, as indicated here, using data opportunistically from multiple studies can present biases in spatial and temporal coverage and may be subject to other limitations (Isaac and Pocock, 2015). The results in this study have been interpreted taking these limitations into account and reducing biases where possible and have provided information that can be used by natural resource managers. As such, we recommend that consideration be given to the use of multiple data sources and datasets, particularly when evaluating long-lived and data deficient species. Strategic planning of

research should also be supported where possible to augment existing datasets. For example, a strategic research program should aim to produce comprehensive spatial and temporal data on populations, individuals and groups over decadal time frames that will support research questions relevant to long-lived animals such as snubfin dolphins. Often this is only possible through integration of data collected over multiple individual studies that collectively span time periods relevant to long-lived species. This approach will also help detect any shifts or patterns (e.g., in population size or distribution) over a finer resolution and will benefit on-going management planning and implementation.

The ranging patterns of individuals that could be evaluated (~20% of the estimated local population) demonstrated some variability; however, all included shallow (<20 m), inshore waters in the northern area of the bay (see **Supplementary Figures 3.1–3.6**), although this could be a result of the northern area receiving the most survey effort. Range estimates from this study illustrate the importance of relatively shallow waters for snubfin dolphins, as has been reported for the species elsewhere throughout their range (Parra et al., 2006b; Cagnazzi et al., 2013b; Palmer et al., 2014b; Bouchet et al., 2021), providing further evidence for their dependency on these habitats.



Notably, three individuals (rb077oh, rb041oh and rb095oh) sighted in the northern area were also recorded in the southern area of the bay (~20 km between areas), indicating that at least some dolphins in this population use a larger proportion of the bay (see **Supplementary Figure 3.2**; rb077oh, **Supplementary Figure 3.3**; rb041oh and **Supplementary Figure 3.5**; rb095oh). The weighted kernel densities for these sightings, however, are potentially over-inflated in the southern area of the bay due to relatively low survey effort (see areas with high kernel densities in **Supplementary Figure 3.2**; rb077oh, **Supplementary Figure 3.3**; rb041oh and **Supplementary Figure 3.5**; rb095oh); therefore, there is greater uncertainty in the estimated levels of use in the south of the bay which would also apply to the population home range estimate. Despite this uncertainty, the results confirm that the southern part of the bay is within the populations’ known range in Yawuru Nagulagun and may include important habitat. Full range sizes, as compared to the kernel densities, are expected to be larger for individuals and the population, which should be considered when comparing results with those from studies elsewhere, when applying these results to management decisions, and when designing future studies of ranging patterns (i.e., surveying a larger area than those covered by existing studies).

The range estimate for the snubfin dolphin population in Yawuru Nagulagun calculated using KDE (95% PDC = 103 km²) is considerably smaller than the estimates for two populations on the east coast of Australia (Parra, 2006; Cagnazzi et al., 2013b). Parra (2006) estimated the area (95% kernel range) for a population of 64–76 snubfin dolphins in Cleveland Bay (Queensland) as 197 km² using data collected from surveys over a 4-year period covering an approximate area of 310 km². Cagnazzi et al. (2013b) estimated the area (95% kernel range) for a population of approximately 100 snubfin dolphins in Keppel Bay on the Queensland coast as 349 km² over a 6-year period within a study area of 4,000 km². Whilst there may be true differences in the ranges between these populations, it is likely that differences in the size of area surveyed between the studies is a key influence, with most effort in the current study focusing on 100 km². Further, our estimate of the representative area of use with MCP was similar to the 95% kernel range estimates of Parra (2006) (215.05 km²; **Figure 3**). MCPs are considered less conservative than KDEs and are thought to be a measure of maximum range, while 95% kernel range is considered a representative range. The estimates from this study reflect minimum range size; we suggest that the larger MCP estimate is likely closer to the true range than that estimated by KDE, albeit still an under-estimate

due to survey effort not encompassing the entire range of the population. The relatively smaller population ranging pattern, coupled with the high density for this population, may also be a reflection of the rich and productive habitat of Yawuru Nagulagun (Department of Parks and Wildlife, 2016a).

In this study, range sizes represent minimum estimates, with a greater number of sightings (>10) than available here required to estimate the full ranges for these dolphins (Figure 2; Owen et al., 2002). Future studies should aim for a larger sample size of individuals and more sightings per individual to estimate the representative range of the population (Börger et al., 2006). Due to the limited sample size, it was not possible to investigate seasonal or age and sex differences in dolphin ranging patterns (e.g., Sprogis et al., 2016). Future dedicated studies are needed to assess if the ranging patterns presented here are representative across seasons and age/sex classes. This would require increasing survey effort across the entire bay and throughout the year and would yield a larger sample size with more even spatial coverage that could be used to investigate these questions as well as how ranging patterns change over time.

Yawuru Nagulagun is a large embayment covering ~500 km², and much of the survey effort was concentrated in the northern part of the bay (~100 km²). To reduce the uncertainty around range estimates and to optimize management, greater effort over the entire embayment and beyond the extent of existing sightings is required. An additional approach that may be more accessible in future studies, is to optimize results from analyses of existing datasets by accounting for autocorrelation in analyses rather than removing autocorrelated temporally proximal observations (as done here), which reduces the overall available sample size. Using a subset of data with reduced autocorrelation is statistically sound (Noonan et al., 2019); however, the resulting estimate could be considered a conservative home range estimate. Seasonal autocorrelation should be considered in future analyses, as this was not accounted for due to the nature of the dataset and the uneven sampling effort over the study period (2007–2019). Future studies on ranging patterns should aim for year-round survey effort encompassing several seasons.

The individual ranging patterns presented here are the first for this species. An application of these data includes informing the area of occupancy (AOO) (i.e., area occupied within their distribution), which reflects the species vulnerability due to a restricted range, as part of the IUCN conservation assessments. The AOO is calculated by superimposing a grid over the extent of occurrence (EOO) of the species and summing the area of cells occupied by the species. The quantification of the area they occupy through home range estimates will be useful for selecting an appropriate grid cell size used to calculate the AOO for future IUCN conservation assessments (Bouchet et al., 2021). While the estimates we present provide a baseline, given that ten sightings proved inadequate to capture full range size, the estimates of ranging patterns reported here should be re-evaluated when more sightings per individual become available and the survey area has been expanded.

Findings regarding the importance of Yawuru Nagulagun to the snubfin dolphin based on ranging patterns are supported by our results relating to residency and site fidelity. The majority

of individuals (56%) in the area demonstrated some level of residency, either long-term (years) or short-term (months), emphasizing the use of the area across multiple years for a species whose life expectancy is ~28–30 years (Parra et al., 2017).

While results suggested a large proportion of the population (44%) demonstrated no site fidelity to the area, this is likely to be influenced by the restrictions placed on the data for site fidelity analyses (i.e., minimum number of months/days required to be considered a sampling period), and/or the overall relatively low intensity of sampling which may have limited the number of resightings of individuals. It is also possible that these “non-resident” individuals exhibit a home range with less overlap to the survey area than individuals classified as exhibiting greater residency, therefore only occasionally visiting the area of greatest survey effort in the northern half of the bay where the probability of being sighted was greatest.

Brown et al. (2016) suggested there was preliminary evidence of site fidelity within Yawuru Nagulagun, where a majority of individuals were re-sighted between two relatively short study periods (albeit of high survey effort) separated by 5 months (Oct/Nov 2013 and April 2014). The current study has confirmed these findings based on an assessment of 195 individuals in the bay and, further, shown evidence of site fidelity over longer time periods. Future surveys designed to include Yawuru Nagulagun and surrounding areas would clarify the question of whether these snubfin dolphins have core home ranges outside the study area or if these “non-resident” individuals are an artifact of sampling bias. Future studies could survey a broader area, including increasing the survey effort in the southern section of the bay as well as further offshore. This additional information will better inform site fidelity across the entire bay and core areas of use. Another potential bias that could explain these results would be the mis-identification of dolphins due to changes in dorsal fin markings as a result of injury (Smith et al., 2018). This source of bias has been noted for this population, where natural identifying marks on individuals (e.g., resulting from injuries) evolve rapidly and their original identity may not be apparent due to the modifications to their fin and thus they are given a new identification code.

Whilst the estimated site fidelity index for the Yawuru Nagulagun snubfin dolphin population (SSFI = 0.19) was lower than expected given the individual site fidelity results, it indicates some residency. The SSFI is a relatively new measure for site fidelity at the population level (Tschopp et al., 2018) with only one published study available for comparison. Haughey et al. (2020) measured site fidelity for the Indo-pacific bottlenose dolphin (*Tursiops aduncus*) population on the North-West Cape in Western Australia as 0.019, indicating lower levels of site fidelity. Due to inconsistent sampling effort and survey intensity across months and years, our results should be interpreted cautiously and investigated further using systematic sampling across a defined study period before robust conclusions on the site fidelity of the population can be drawn.

Studies have found that ranging patterns and site fidelity are driven by several extrinsic factors including environmental conditions, quality of habitat, distribution of food resources, population density, and potential mates or predators as

well as intrinsic factors such as body size, sex, and age (Switzer, 1993; McLoughlin and Ferguson, 2000; Duncan et al., 2015). Food availability and population density are thought to have the strongest influence in determining the size, shape, and location of ranging patterns (Mitchell and Powell, 2012; Duncan et al., 2015; Schoepf et al., 2015). Studies have also demonstrated that increasing population density decreases range size because individuals' space use patterns are constrained by competitive interactions with neighboring individuals. Parra (2006) investigated resource partitioning between snubfin and humpback dolphins on the east coast of Australia and suggested the main driving factors of habitat selection included diet and inter-specific agonistic interactions. Previous studies in Yawuru Nagulagun have confirmed that other dolphin species (e.g., Australian humpback dolphins and Indo-Pacific bottlenose dolphins) use the area, although they have been recorded in lower numbers than snubfin dolphins (Brown et al., 2016; Raudino et al., 2020). The results from this study can guide future studies investigating driving factors of range and site fidelity patterns in Yawuru Nagulagun (e.g., examining inter-specific interactions or prey availability).

Data on ranging patterns is limited for most cetacean species, however, several studies have reported a strong correlation between cetacean movement patterns, patterns of distribution, and abundance of food (Steivick et al., 2002; Silva et al., 2008). In marine mammal populations with high levels of site fidelity and residency, it is likely that there is high food availability and low predation risk (Gubbins, 2002; Gowans et al., 2007; Fury and Harrison, 2008; Zanardo et al., 2016; Passadore et al., 2018). Alternatively, other populations with large ranging patterns in areas where food resources are more dispersed, are required to travel further in search of food (Ballance, 1992; Gowans et al., 2007; Silva et al., 2008). Sprogis et al. (2016) also found that home range size can differ between and within sex classes within a dolphin population potentially due to differences in diet, amongst other factors. Based on previous studies which analyzed gut content from a small sample size of bycaught snubfin dolphins, it is thought they are opportunistic-generalist feeders, preying on a variety of fish and cephalopods, which are available in shallow coastal/estuarine environments (Parra, 2006; Parra and Jedensjö, 2014). Given that Yawuru Nagulagun is a highly biodiverse environment and one of the most productive tropical intertidal areas globally (Department of Parks and Wildlife, 2016a), there is likely to be a large variety of food sources available for snubfin dolphins. Further research using a combination of direct observation, stable isotope analysis and gut analysis of hard parts recovered opportunistically from carcasses would help to determine diet preferences (McCluskey et al., 2021) for the Yawuru Nagulagun population, and may help better understand whether the distribution of prey drives dolphin spatial distribution.

Implications for Conservation

Based on the results from this study as well as those conducted on the east coast of Australia, home range and site fidelity for snubfin

dolphins vary depending on the attributes of the region (Parra, 2006; Cagnazzi et al., 2013b), and investigating and estimating these parameters at each location is key to effective management, particularly for the identification of high use or important areas and potential overlap with anthropogenic activities. We found that some dolphin group sightings occurred in a deep channel (10–50 m) (see **Supplementary Figure 2**) in an area that lies within the Port of Broome tenure, which is excised from the marine park, and experiences a high density of vessel traffic (Beckley, 2015). Not only does the population range overlap with the Port of Broome, but this study also provides evidence of site fidelity, further emphasizing the importance of the area to snubfin dolphins. Overlap with this area can lead to greater exposure for dolphins to pressures such as vessel disturbance (Bejder et al., 2006; Jensen et al., 2009a; Marley et al., 2017b), noise (Jensen et al., 2009a; Erbe et al., 2019), vessel strikes (Thiele, 2010; Schoeman et al., 2020), and potential exposure to contaminants (Cagnazzi et al., 2013a). Given that this area is not within the marine park, dolphin use of the Port of Broome should be noted and considered in management decisions regarding port development activities.

Beckley (2015) found that use of recreational vessels peaked during the dry season, but remained consistent throughout the wet season; therefore, potential pressures on snubfin dolphins such as boat strike, entanglement in fishing gear, increased exposure to underwater noise (and its potential impacts on intra-specific communication and in elevating stress), and general disturbance will occur year-round. Recreational activity likely occurs throughout the representative home range area. The likelihood of impacts in these areas should be evaluated so that measures could be taken to mitigate them if required, particularly if these pressures increase as predicted. Wildlife tourism (i.e., dolphin watching) represents another potential pressure on snubfin dolphins in the bay. Future research, including a spatial risk assessment, could evaluate the distribution of pressures (i.e., vessel traffic and areas used by tour operators) relative to dolphin high use areas to further inform management. For example, the findings from this study on range patterns could be compared with areas identified in the spatial risk assessment to quantify the spatial overlap. To minimize potential impacts from the tourism industry, managers should understand the basic interactions between marine mammals and tourism vessels, including the timeframe and locations where these occur and the potential for displacement or disruption of activities so that appropriate management strategies can be considered (Waples, 2003; Tyne et al., 2018).

CONCLUSION

This study provides the first insights into ranging patterns and site fidelity of a significant population of snubfin dolphins and confirms that there is a resident community of dolphins that use Yawuru Nagulagun. These important insights into the local population contribute new information for continued conservation and management of snubfin dolphins at the

broader species level as well as more specifically for the local population. Where there is a data deficiency for a species or where a single standardized long-term dataset does not exist, we recommend combining data from separate sources as we have shown this can significantly extend the current knowledge on the species' and could potentially improve the power to detect changes in the population and response to pressures over decadal timeframes. This approach could be applied to improve conservation management strategies for other cryptic, data deficient, vulnerable, and long-lived species.

DATA AVAILABILITY STATEMENT

All sightings compiled in this study have been previously published, with the exception of observations collected by Rangers from the Yawuru Native Title Prescribed Body Corporate (Yawuru P.B.C) and Dolphin Watch citizen scientists. Available data can be accessed through the State-wide catalogue (Dolphin database) hosted and managed by DBCA (see <https://dolphin.dbca.wa.gov.au>). Requests to access these datasets should be directed to HR, holly.raudino@dbca.wa.gov.au.

ETHICS STATEMENT

Ethical review and approval was not required for the animal study because this study collated data from six different projects over 11 years. Each research project had animal ethics approval.

AUTHOR CONTRIBUTIONS

HR, KW, and CSK conceived the study. Data was collected by many contributors (see **Supplementary Table 1**). ADC processed and analyzed the data with advice and contributions to data analysis from CSK and HR. ADC

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fmars.2021.758435/full#supplementary-material>

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