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Spatial analysis of coastal cetaceans' critical habitats in Golfo Dulce, Costa Rica: considerations for a marina construction project

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Abstract: Coastal cetaceans are exposed to a series of threats due to their closeness to human coastal settlements; some of these threats have direct incidence in mortality, while some others would add up through a cumulative effect, producing long-terms impacts associated with disruption of their critical habitats. Golfo Dulce is a unique tropical fiord-like embayment in the southern Pacific of Costa Rica; it harbors an important year-round resident population of coastal bottlenose dolphins (*Tursiops truncatus*) and migrating humpback whales (*Megaptera novaeangliae*) during austral and boreal winter months. This contribution deals with a detailed spatial analysis of encounters of inshore bottlenose dolphins (2005 – 2014: n= 407) and humpback whales (2010 – 2014: n= 167) describing the utilization *distribution* within their respective coastal critical habitat. Inshore bottlenose dolphins' nonrandom aggregations (Adaptive-KDE: Density 21.36 records/Km^2; H=0.25; H-REF= 0.49) are associated with all the major river drainages at the inner basin and sill area of Golfo Dulce, representing key critical foraging habitats. Humpback whales' nonrandom aggregations, including mothers and calves pairs (Adaptive-KDE: Density 1.33 records/Km^2; H=0.25; H-REF= 0.49) use the west coast of the sill area as shelter, whereas aggregations of males engaged in singing would use the area as a potential key reproductive ground. Results emphasized two key fitness currencies: foraging returns for bottlenose dolphins and probabilities for mating in humpback whales. As a case study, the results of the spatial analysis are contextualized with the development of a luxury marina project, seeking to capitalize the natural attributes of the coast by outlining the critical habitats of both local species, with the potential to become an important source of pervasive anthropogenic impacts.

Key words: Bottlenose dolphins, humpback whales, foraging, nursing and reproduction, utilization distribution, critical habitat.

INTRODUCTION

Critical habitats are defined and classified within important biological context such as energy acquisition, reproduction, nursing, migration, shelter from predator among others (Hooker & Gerber 2004, Hoyt 2011). A key aspect in the determination of a critical habitat is the density of species actively using the focal area, which would be directly associated with a gradient of the resources availablethat support the quality of the habitat, therefore, a decrease in relative density of those species is expected towards external limits of the core habitat, where key resources would diminish in quantity and quality (Hoyt 2011).

Golfo Dulce could be divided in three main areas, based on the presence of cetacean species : 1) the deep inner basin (Z max= 215 m), which features an anoxic layer below the 100 m depth (Brenes & León, 1988) and restricted water circulation at the surface layer (Quirós 2003). This area represents an important key location used by *Stenella attenuata* (Acevedo & Burkhart 1998: Cubero-Pardo 1998, 2007; Oviedo 2007, 2008) and *Tursiops truncatus* (Acevedo & Burkhart 1998: Cubero-Pardo 1998, 2007; Oviedo 2007; Pacheco-Polanco & Oviedo 2007: Pacheco-Polanco *et al*., 2011), 2) a relatively shallow external area (Z max= 60 m), with a sill at 20 km from the entrance of the gulf, this particular location is of important use by *Megaptera novaeangliae* (Marquez-Artavia *et al.* 2012), as well as by *T. truncatus* (Acevedo and Burkhart 1998, Pacheco-Polanco & Oviedo 2007; Pacheco-Polanco *et al*, 2011) and finally 3) a transitional oceanic area at the entrance of Golfo Dulce (Oviedo *et al.* 2009), which communicates this inner sea with the open Pacific ocean. Around this external oceanic zone, depths close to 1000 m are reached at distance of less than six km from the mouth of the gulf. This oceanic habitat is relevant for pelagic species of odontocetes, including the oceanic morphotypes of pantropical spotted and bottlenose dolphins (Pacheco *et al*. 2011).

The aim of this study is to identify key areas critical in the habitat use of humpback whales and bottlenose dolphins in Golfo Dulce, assessing the potential impact of current projects of coastal development, specifically, as case study, the plan to establish a luxury marina around Puerto Jimenez Bay in Golfo Dulce. Our approach to the analysis presents the utilization distribution associated to ecological responses of coastal cetaceans, in the form of foraging behavior for *T. truncatus* and nursing-reproductive behaviors in *M. novaeangliae*, within the context of management and conservation.

MATERIAS Y METHODS

Study area: Golfo Dulce is a fiordlike embayment of 50 km in length extension and around 10-15 km width, it is located in the southern Pacific region of Costa Rica at 8°33'N and 83°14'W. The climate is humid – tropical with a rainy season from June to the beginning of November, which generates an average precipitation of 100-700 mm (Quesada y Morales 2004). Fresh water input is provided by the rivers Coto Colorado, Tigre, Esquinas and Rincón, directly influencing the pattern of circulation of a stratified estuary (Svendsen *et al.* 2006). Differences in structure of water masses is what makes Golfo Dulce to resemble real fiord systems, two layers are clearly separated: a) a warm and diluted surface layer at a depth of 50 to 60 m over the sill area and b) a deep homogenous layer where temperature can reach 15.4°C and salinity levels of 34.8 ppm. Water masses mixing and circulation are influenced by the strength of winds, tidal forces and the influx of external water to the system, along with the upwelling of sub-surface layer and the whole topography of the basin (Quirós 2003, Quesada y Morales 2004). Currents' structure in Golfo Dulce are also separated in three layers in the outer gulf, in contrast with an estuary circulation at the inner basin (Svendsen *et al*. 2006). As mentioned before, the study area will be sub-divided into the inner basin, the sill area and the transitional-oceanic area (Oviedo et al. 2015).

Data collection: Data collection have been directed to record and monitor the occurrence of cetaceans in the study area since March 2005 to March 2015, our research platform; a 27 feet, four stroke, 115HP motor boat followed, as survey protocol, a predetermined zig zag route designed to cover homogeneously all the inner basin and increase coverage at the sill and transitional oceanic area. The sampling protocol included two seasons: dry (November – May) and rainy (June – October), all surveys were done during daylight, starting in the morning (07:00 -08:00) and ending at midafternoon (14:00-16:00), our sampling units, sightings, incorporate the group definition used in Karczmarski *et al.* (2005), behavior observations were collected in accordance with the methods in Lusseau & Higham (2004) and Oviedo (2008). Detectability conditions were constantly monitored for effective acoustic and behavior sampling, therefore, every 30 min along the survey route, GPS readings (Garmin etrex H) were routinely recorded along with some environmental variables such as wind stress over the sea surface (Beaufort scale), sea surface temperature (using a field thermometer), tide cycles (tide table from the oceanographic information module MIO-CIMAR) and the presence – absence of cetaceans (Fig 1.) The monitoring protocol described before also allowed the estimation and monitoring of the field effort.

During each encounters, the boat was positioned as close as to 100 m in distance to the focal group. Data pertaining the encounter were taken, such as: time of encounter, species, group size and composition, as well as behavior (at the initiation of the encounter and at ten min after initial behavior reading), these data have been recorded along with the spatial location of the survey boat through GPS readings (assuming this location as the relative position of the target species of the encounter, considering that there is 100 m of approximate distance between the boat and the focal group). Depending on the survey objectives, once standard encounter data collection is taken and ethological monitoring to established significant behavior disruptions is completed, a focal group follow protocol was initiated to achieve: a) ethological sampling under the methods suggested in Lusseau and Higham (2004) and Oviedo (2008) to define critical habitats, b) acoustic sampling. Acoustic data collection was limited to humpback whales sightings. According to the aims of this contribution; *that is to document the spatial relevance of the study area in the acoustic behavior of the species*, spatial location of each vocalization record is considered the sampling unit for this particular data sub-set, we did not include the aural analysis of vocalizations, since we aimed to produce insights on spatial correlates and vocalization occurring in Golfo Dulce. Vocalization recordings were made after checking meticulously for a favorable noise to signal ratio (S/N), using a combination of a tape recorder (Sony TCD D-5 digital tape recorder) and a hydrophone (NSF-PW, SCH40), all calibrated for frequencies within ±5 dB (12.0 Hz to 35.0 kHz). Location of singers was aligned with the location of the recording vessel, and GPS readings were continued during recordings.

Data analysis: Records derived from the methods described before were processed to assess the utilization distribution of humpback whales and bottlenose dolphins in the study area, in contrast with the behavior of theses target species. In the case of humpback whale sightings, group classes were defined as encounters which included calves (mother-calf pairs and triads) and those associated with acoustic records of singing males. Utilization distribution for both target species was described using the *Average Near Neighbour Ratio* (ANNR), combined with a Kernel Density Estimate (KDE), using least square cross validation in the software ArcGIS 9.3. Two main contours where defined in the kernel to illustrate: a) The potential home range portion within Golfo Dulce's premises, using the 95% volume contours, b) the core area representing the potential critical habitat through the 50% volume contour, this core area includes all records associated with particular behavior observations of target species. Temporal autocorrelation was avoided in the analysis; nevertheless we acknowledge spatial autocorrelation as intrinsic of our research topic.

Case Study: Coastal Development Project - The luxury Marina in Puerto Jiménez' Bay: The marina development project in Puerto Jimenez' Bay, integrates the building and operation of areas destined to the docking of small to medium size vessels, equivalent to 5000 m in length. The effective number of parking spaces (for sale or rent) within the premises of the project is 257 units. Additionally, the luxury marina includes a 9000 m^2 area which will be divided in 2674 m^2 for commercial purposes (stores and restaurants) and the rest, 6326 m^2 to the construction of a five stars hotel (74 rooms) to cater the marina customers (Araya-Montero *et al*. 2006). The environmental impact assessment report was approved by the government agency in charge of technical environmental administration in Costa Rica, through the resolution № 2424-2008-SETENA, on august 8th of 2008, later modifications were approved in the resolution № 2084-2011-SETENA on august 11th of 2011. Such modifications reduced the capacity of parking spaces to what have been described above.

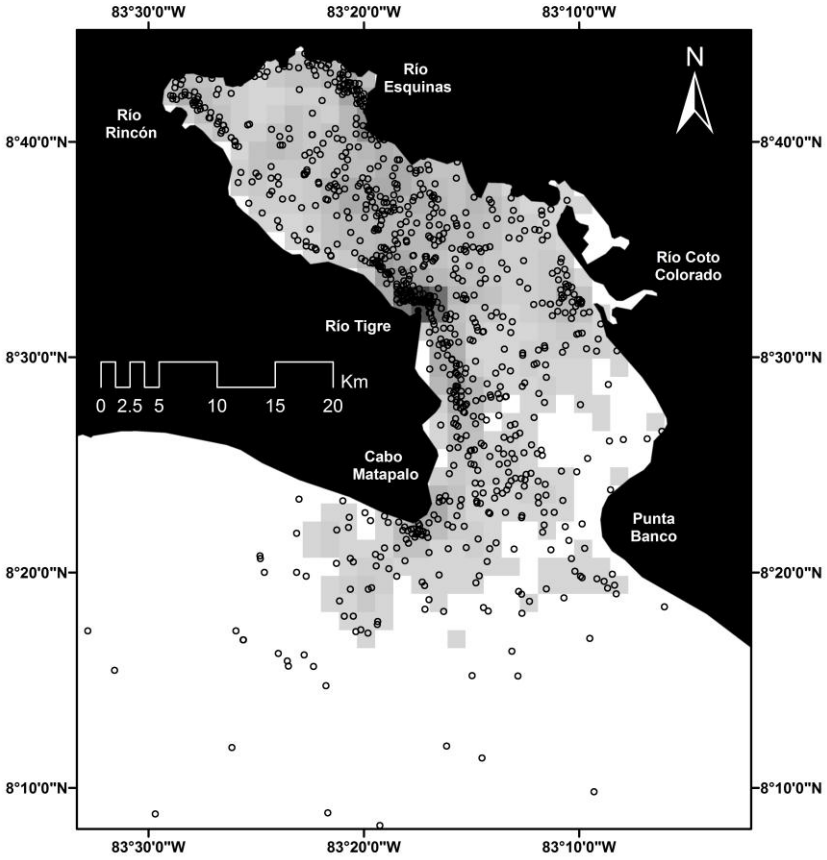

Fig.1. Field effort distribution in Golfo Dulce: The study área is divided into 1.6x1.6km (n=1 293). Spatial coverage is illustrate by means of a qualitative gradient scale, where the maximum effort invested implied 85h and 267km covered in each cell of 2.56km2. Sightings analyzed in this study are represented by unfilled circle, in contrast with the field effort coverage.

RESULTS

For over ten years of field research, we have achieved a homogenous coverage of the inner basin (Fig. 1). Field coverage for the sill and the transitional oceanic areas are increasing steadily. The latter implied an investment of 3490 hours in the field, which is approximately equivalent to 79.300 km covered in active search effort and group follow protocols.

Observations on bottlenose dolphins yield 407 sightings records, 60% of these encounters (n=244) were associated to foraging behavior, 28% with traveling (n= 144), while 6% of the sightings were of dolphin groups engaged in social behavior (n=24), dolphins resting and milling also correspond with 6% of the behaviors observed (n=12 y n= 13 respectively). Humpback whales' sighting records, in coastal areas of Golfo Dulce (n=167) were majorly constituted by groups with the presence of calves (mother-calf pairs, triads, n=95 ≈ 57%). From these groups, more than 50% were associated with resting activities (n=36 ≈ 38%), which includes nursing. Behaviors associated with social affiliations (n= 14 ≈ 15%), where conspicuous surface activities such as breaching, had a minor occurrence. The most important portion of the activity budget of humpback whales is represented by sightings related with traveling (n= 43 ≈ 45%). Adults only groups (n=72, ≈ 43%), including lone whales, were mostly observed engaged in social bouts (n= 38 ≈ 53%), including singing (n=35 ≈ 49%) and competitive groups.

Table 1. Results describing the aggregation pattern of coastal cetaceans in Golfo Dulce

Spatial Analysis of Coastal Cetaceans in Golfo Dulce				
	ANNR	*Z-score*	*Value-p*	*Pattern*
Bottlenose dolphin	0.55	-13.11	< 0.01	Clumped
Humpback whale	0.74	-4.15	< 0.01	Clumped
Groups with calves	0.78	-3.8	< 0.01	Clumped
Singing males	0.63	-4.11	< 0.01	Clumped

Spatial distribution of bottlenose dolphins: All results described here were obtained from a subset of 244 records associated with foraging behaviors. The average near neighbor index

indicated a clumped spatial patterns of bottlenose dolphins groups, which were statically significant (*p < 0.001*, Table 1). The distribution and habitat use of *T. truncatus* in Golfo Dulce is illustrated in figure 2, through the contour including 95% of the records of bottlenose dolphins (KDE-adaptive: Density 5.50 records/Km^2; H=0.042; H-REF= 0.40), this contour would represent the portion of the population' home range within the marine habitats in Golfo Dulce. The core area contour containing 50% of the records are all located at river mouths along the Gulf (KDE-adaptive: Density 76.76 records/Km^2; H=0.042; H-REF= 0.40**)**.

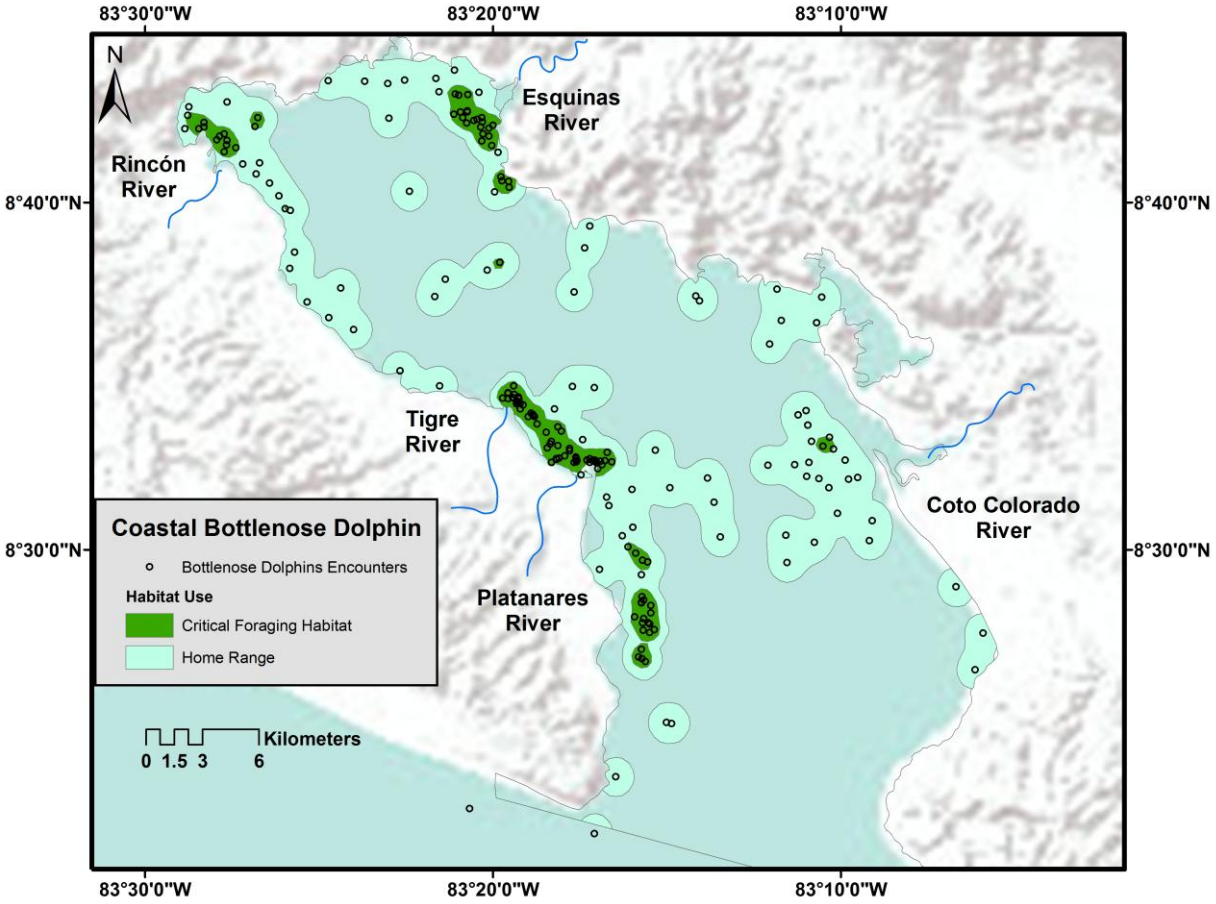

Fig.2. Utilization distribution of bottlenose dolphins in Golfo Dulce, with details of the potential home range and the critical foraging habitats**.**

Spatial distribution of humpback whales in Golfo Dulce: The humpback whale in Golfo Dulce concentrated in clumped aggregations (*p < 0.001,* Table 1), as reflected by the *average near neighbor index*. These aggregations which includes groups with calves are illustrated in figure 3, where the contour that would represent the potential home range extent on a great

portion of the entire gulf (KDE-adaptive: Density 1.33 records/Km^2; H=0.25; H-REF= 0.49). The core area of aggregation (KDE-adaptive: Density 21.36 records/Km^2; H=0.25; H-REF= 0.49) is located in shallow waters of the west coast. This trend is complemented by the data obtained in the acoustic sampling, where 64% (n=35) of the vocalizations recorded were identified as songs, of males potentially in courtship and aggregated in clumped clusters at the sill area (figure 4).

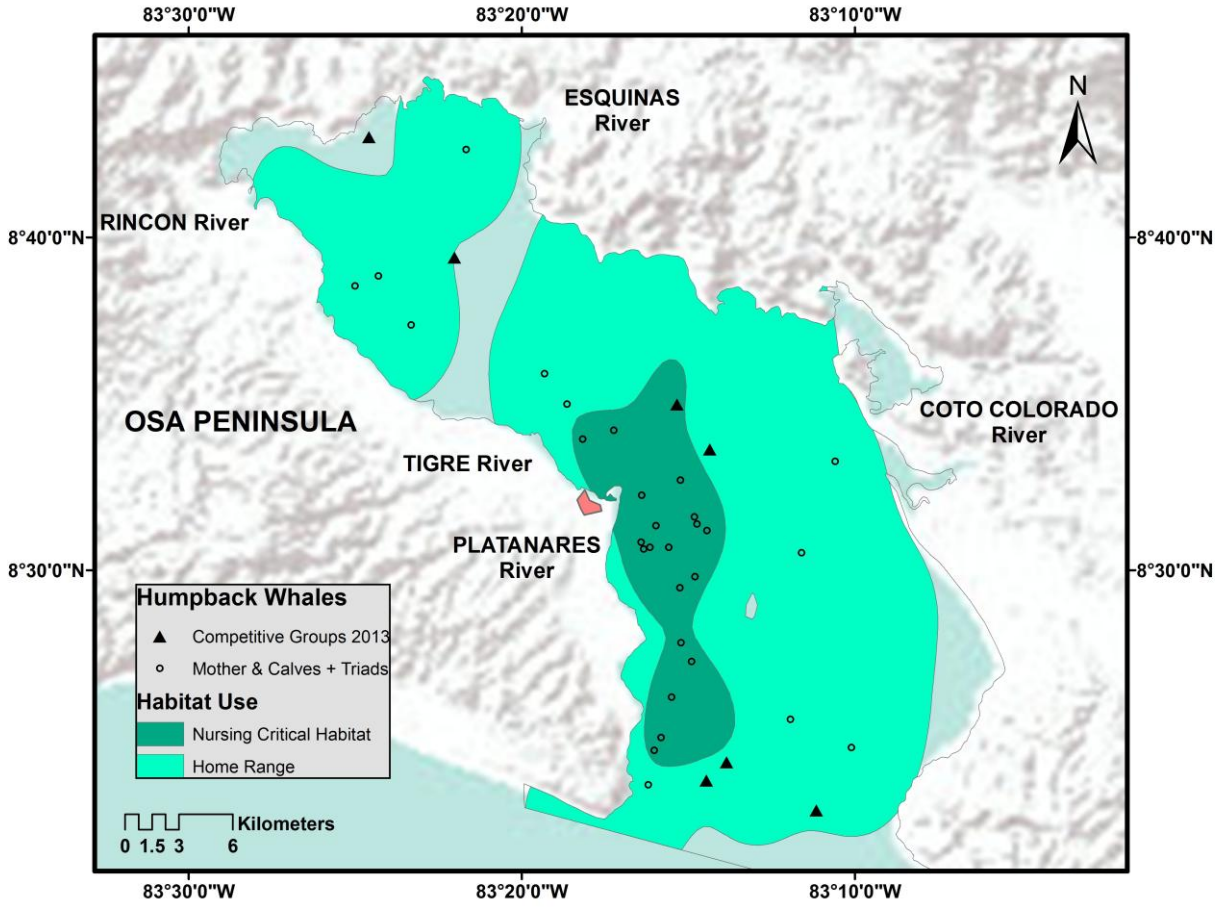

Fig.3. Utilization distribution of humpback whales in Golfo Dulce, with details of the potential home range and the critical calving - nursing habitats. The red polygon correspond with the urban area of Puerto Jimenez.

Figure 5 illustrate the mid-portion of the coastline in Golfo Dulce, where both critical habitats; that of the foraging habitat of bottlenose dolphins and the nursing - calving habitat of humpback whales, overlap and spatially coincide with the specific location of the luxury marina project in Puerto Jimenez' Bay

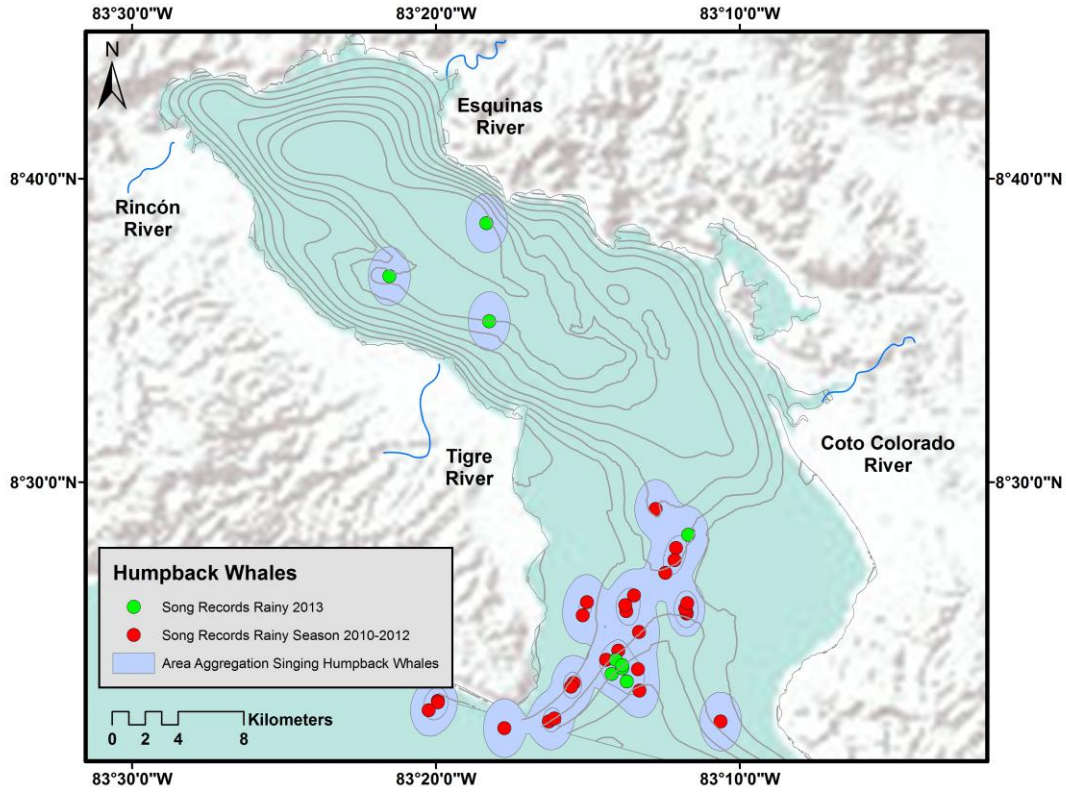

Fig.4. Clustering of humpback whales'song records at the sill area in Golfo Dulce.

DISCUSION

The foraging critical habitat of bottlenose dolphins: The results of the spatial analysis highlight clumped aggregation patterns for both target species in Golfo Dulce. Parrish and Edelstein-Keshet (1999) pointed out that such aggregations respond to an underlying ecological reason, which motivates these clustering. Based on the latter, the results described for bottlenose dolphins emphasized two particular tendencies, the first one, is that the potential home range in Golfo Dulce would correspond with all the coastal portion of the Gulf, with a major presence of the species in the inner basin (Oviedo *et al*. 2012; 2015). It is particularly important to consider the major occurrence of *T. truncatus* around the adjacent marine habitats in Puerto Jimenez' Bay, which progressively integrate and connect with marine habitats in the sill area. The second tendency, emphasizes that all core areas are centralized in estuaries of all major rivers draining into the gulf, specifically Rincon, Esquina, Coto Colorado and specially the subsystem made up by Tigre and Platanares Rivers. According to the elements mentioned before, we can identify as foraging critical habitats the areas of major use within the premises of all river mouths, with special consideration of the marine habitat at the Tigre and Platanares'

estuaries, supported by the occurrence of 190 records of foraging behavior in this discrete location alone (Pacheco and Oviedo 2007, Oviedo 2007, Oviedo *et al*. 2012; 2015). These behavior reflects a dynamic ecological response of the organism to the resources available and the structure of the habitat, therefore, in addition to the determination of habitat use, these results also discriminate the realized niche of this target species (Oviedo 2008, Wheeler *et al*. 2012).

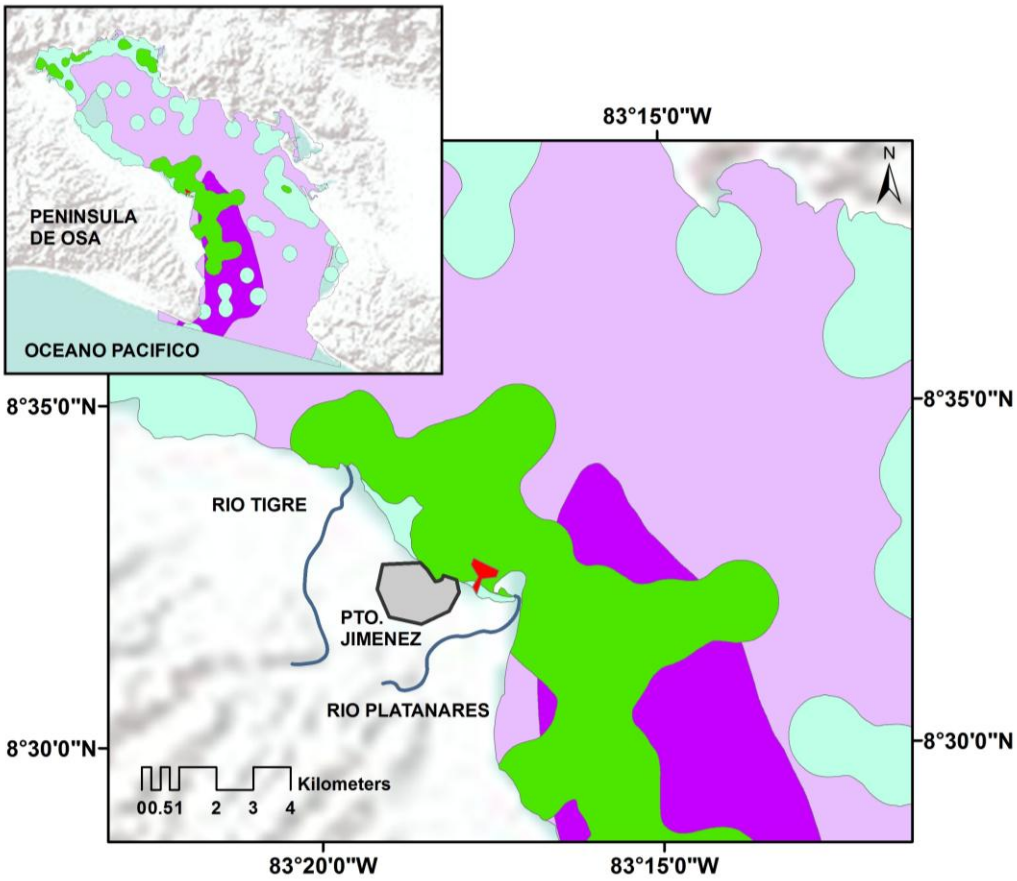

Fig. 5. Spatial overlap of both target species critical habitats: foraging critical habitat for bottlenose dolphins (green) and calving-nursing critical habitat for humpback whales (purple). The red polygon correspond with the location projected to harbor the luxury marina.

Coastal dolphins are upper level predators, playing a significant role in the structure and function of coastal marine communities, which are exposed to anthropogenic disturbance (Bowen 1997, Whitehead *et al*. 2000, Gowans *et al.* 2007). The foraging critical habitats adjacent to Puerto Jimenez are relevant to a group of bottlenose dolphins affected by a skin condition known as LLD (Lacaziosis Like Disease), as discussed in Bessesen *et al*. (2014). Such

skin disease is associated to a fungal infection, probably linked to the environmental degradation of the water column. It is suspected that a previous compromised inmunotoxic condition, due to exposure to pollutants, might increase the morbidity of the skin disease (Reif *et al*. 2009), which particularly impact coastal dolphin populations (Van Bressem *et al*. 2009), due to the important level of exposure to environmental pressures derived from human activities near their critical habitats (Bowen 1997, Thomson *et al*. 2000, Whitehead *et al*. 2000, Gowans *et al.* 2007).

Critical habitat for nursing, calving and reproduction of humpback whales: The sill area of Golfo Dulce is a key critical habitat for nursing and calving humpback whales, but also for effective reproductive purposes. The whole extension of the gulf might represent a key seasonal home range. However, 50% of all records are aggregated in a discrete area off Platanares River adjacent to Puntarenitas in the inner basin, until it is connected to the west coast at the sill area and the transition to open waters in the Pacific. This area harbors an important portion of groups with calves (majorly mother-calf pairs), mothers with calves seek out the warm and shallow waters over the western region of the sill-area and the relative quiet waters in the southeast-end of the inner-basin. The incidence of sexually mature whales, might be explained by the need to engage in activities associated with courtship and reproduction. This is supported by the clustering of records of singing males, which could be considered as a behavioral aspect crucial for courtship and reproduction (Tyack 1981, 2000; Clapham 2000; Oviedo *et al*. 2008; Smith *et al*. 2008). The differences in habitat use of this target species between calving groups and active reproductive clustering of whales might be masked by the reduced geographic scale where all this biological relevant events take place, also by the implicit male biased ratio in wintering aggregations of this migrating mammals (Clapham 2008), which might equally explain the incidence of competitive groups chasing females, even those with calves in the season (Clapham 2002).

Case Study: Coastal Development Project - The luxury Marina in Puerto Jiménez' Bay: The results discussed above concord with previous studies that documented the important distribution of bottlenose dolphins in Golfo Dulce (Acevedo & Burkhart 1998; Cubero-Pardo 1998, Oviedo 2007, Pacheco & Oviedo 2007; Pacheco *et al.* 2011), this key aspect of the biological attributes of this species induced a conflict with the planned location for the marina project, therefore, this target species might be the first to be impacted by the imminent disturbance of their critical foraging habitat, specifically in their core area of distribution (Tigre River - Platanares River), where there is a major incidence of activities related with energy

acquisition and consumption. Alterations in crucial habitats to biological functions such as foraging, might disrupt other biological functions relevant to survival and population growth (Lusseau *et al.* 2009). An element of particular concern is the proportion of the local population already affected by LLD (Bessesen *et al.* 2014), which might imply a detrimental effect that could result in an increase in morbidity and the chronic progression of the disease in sick individuals. There is no assessment of carrying capacity of the Gulf as a systems and the specific marine habitats as subsystems, therefore, alteration in habitat structure could result in disruption in resource availability to sustain current predators' populations.

Márquez-Artavia *et al.* (2012) identified the critical habitat for calving and reproduction within Golfo Dulce, which correspond with those locations highlighted in this assessment. The marina construction and operation will bring, as associated effect, an increase in maritime traffic, which have been documented as a cause of mortality in calving areas for mysticetes whales (Jensen & Silver 2003, Guzman *et al.* 2013, Laist *et al*. 2014). Collisions with juveniles and calves of whales in wintering aggregations had been documented in detail (Guzman *et al.* 2013, Laist *et al*. 2014). For instance, it is known that 80% of the ship strike with humpback whales in U.S. waters, involve juveniles and babies of less than three years of age (Laist *et al.* 2001). The increase in maritime traffic would also affect potential processes involved in courtship and reproduction, specifically, noise as by product of vessel traffic, might mask important vocalizations such as songs, this kind of induced sonic pollution (Nowacek *et al*. 2007, Sousa-Lima & Clark, 2008), would disrupt the behavior of singing males and probably affect reproductive success (Darling 2008). Sousa-Lima & Clark (2008) was able to relate the increase in maritime traffic with the decrease in song duration and structure richness, due to the disruption cause by noise masking whole songs recorded in Abrolhos National Park (Brazil), a key wintering location in the South-American Atlantic coast for *M. novaeangliae*. Sousa-Lima & Clark (2008) described the consequences related with song masking: the possibility that the song is shortened and the complete abandonment of singing locations are the ones of major concerns, in contrast to areas with no disrupting elements (such as boat traffic) to singing males.

The spatial information presented in our results and discussed above, derived from records of behavior observations in the study area, therefore, these behaviors are associated with a specific fitness currency by target species (Spencer 2012): in the case of bottlenose dolphins, such value is the energy gain by foraging, for humpback whales, fitness value would be reflected as increased possibilities for mating and effective reproduction, added to a rather secured calving process. Considering the latter, we concord with Spencer (2012) in defining home range

as the area that an organism would regularly exploit, while in the process update and compile information on the characteristics of such location. In the case of Golfo Dulce, the survival value of these discrete spatial arrangements, establish them as critical habitats for coastal cetaceans. A key aspect to highlight, would be that cognitive capabilities to process information, would play a key role to achieve fitness and would reflect the adaptation to the ecological niche (Real 1993; Healy and Braithwaite 2000; Gowans *et al*. 2007, Stephens 2008).

Initiatives to coastal development should integrate in their design and planning process, the spatial needs of the marine organism to be affected by the imminent structural modifications of the coastal-marine habitat. Neglecting the occurrence of critical habitats, would increase the likelihood of impacting key biological functions of wild populations. The resulting consequences would go beyond the local environmental level, such in the case of bottlenose dolphins in Golfo Dulce, It would equally impact migratory species, as it is the case for wintering humpback whales in our study area. The consequence mentioned before is magnified by the fact that environs within Golfo Dulce and Osa Peninsula are wintering areas for two subspecies of humpback whales; *M. n kuzira*, which correspond to the north pacific stock and *M. n. australis* corresponding with whales of the southern hemisphere subpopulation (Jackson *et al*. 2014).

Management and conservation strategies are obligated to integrate into the base level, the comprehensive understanding of habitat requirements for susceptible species (Gerrodette & Eguchi 2011). This is particularly true for critical foraging habitats, since these locations are influenced by ecological processes that result in changes in the water column (Hoyt 2011). Based in the considerations above, we suggest that management objectives in Golfo Dulce should emphasize in: a) observe and concord with the precautionary principle, b) a decision making process that should rather be conservative, due to uncertainty and information gaps, such decision making process should always favor the protection of natural resources. (Mangel *et al.*1996).

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