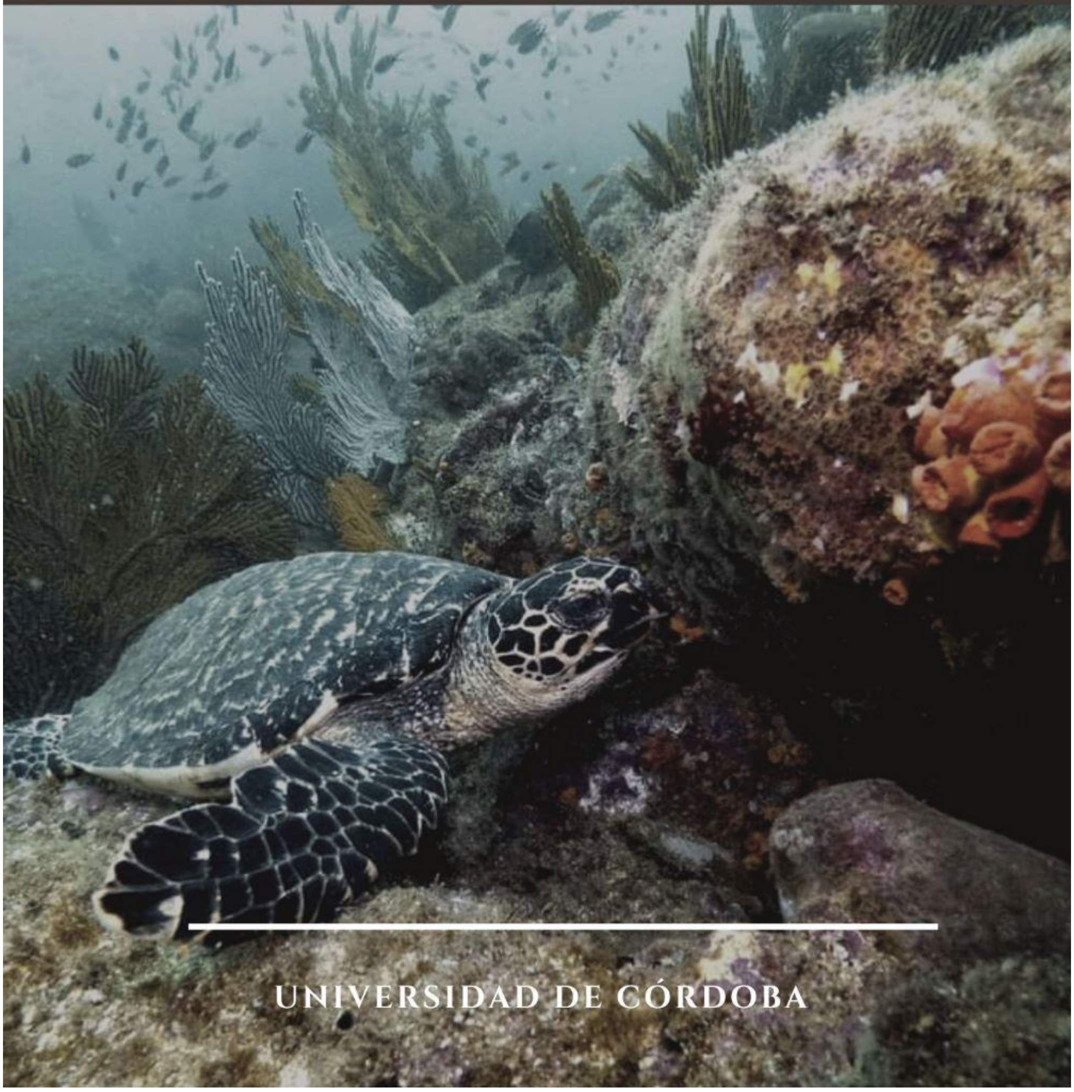
UNIVERSIDAD
DE CÓRDOBA

ANIDACIÓN Y MORTALIDAD DE LAS TORTUGAS MARINAS EN LAS PLAYAS DE MANABÍ, ECUADOR

TESIS DE DOCTORADO

YAMEL DE LAS MERCEDES ÁLVAREZ GUTIÉRREZ



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TITULO: *Anidación y mortalidad de las tortugas marinas en las playas de Manabí, Ecuador*

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UNIVERSIDAD DE CÓRDOBA

Programa de Doctorado en Recursos Naturales y Gestión Sostenible

TESIS DOCTORAL

Anidación y mortalidad de las tortugas marinas en las playas de Manabí, Ecuador

Nesting and mortality of sea turtles on the beaches of Manabí, Ecuador

Directores

Francisco Sánchez Tortosa

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Fecha de depósito en el IDEP: 29/05/2023

TÍTULO DE LA TESIS

Anidación y mortalidad de las tortugas marinas en las playas de Manabí, Ecuador

DOCTORANDO/A

Yamel de las Mercedes Álvarez Gutiérrez

INFORME RAZONADO DE LOS DIRECTORES DE LA TESIS

La tesis se ha desarrollado conforme a lo planteado en el plan de investigación inicial e incluso ampliando algunos objetivos como la predicción de los efectos potenciales de las mareas extremas en la anidación de las tortugas marinas (capitulo III). El desarrollo de la tesis ha sido el previsto, abordando la situación actual de la introducción de las especies exóticas en América Latina (abordado en el capitulo I), y publicado en *Global Ecology and Conservation* como *Intentional introduction pathways of alien birds and mammals in Latin America*. Posteriormente se desarrollaron dos capítulos para evaluar el impacto de los fenómenos naturales extremos en la anidación de las tortugas marinas (capítulo II y capítulo III). En el capítulo II se evaluaron las zonas de nidificación de las tortugas marinas, y cuáles eran los factores determinantes en su éxito de eclosión (aguajes, escalones de áreas…); publicado en *Journal of Coastal Conservation*, como *Nesting failure of sea turtles in Ecuador-causes of the loss of sea turtle nests: the role of the tide*. Mientras que el capítulo III (como se mencionó anteriormente), trata de predecir estos eventos extremos en el futuro y determinar su potencial efecto negativo en la anidación de estas especies; este se encuentra actualmente en proceso de revisión en *Ocean Management* bajo el título *Potential effects of future high tides on sea turtle nesting. Under review Ocean Management*. Finalmente, el último capítulo trata de cuantificar el impacto de la pesca incidental sobre las tortugas marinas y los factores relacionados con las tasas de captura (cebo, anzuelos, pesca objetivo) (capítulo IV), publicado en *Frontiers in Marine Science*, como *By-catch of sea turtles in Pacific artisanal fishery: Two points of view: From observer and fishers.*

De acuerdo con lo mencionado anteriormente la tesis abordó y cumplió con éxito todos los objetivos planteados inicialmente y con gran rigor científico, avalado por la calidad de las revistas donde fueron publicados los artículos.

Por todo ello, se autoriza la presentación de la tesis doctoral.

Córdoba, 10 de Mayo de 2023

Firma del/de los director/es

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INFORME SOBRE APORTACIONES DERIVADAS DE LA TESIS DOCTORAL Y FACTOR DE IMPACTO DE LAS REVISTAS CIENTÍFICAS (JOURNAL CITATION REPORTS)

Publicaciones en revistas científicas (Capítulos de la Tesis)

1. Carpio Camargo, A. J., Álvarez Gutiérrez, Y., Oteros, J., León, F., & Sánchez Tortosa, F. S. (2020). Intentional introduction pathways of alien birds and mammals in Latin America. *Global Ecology and Conservation 22*, e00949. https://doi.org/10.1016/j.gecco.2020.e00949 (CAPÍTULO I DE LA TESIS)
   Factor de impacto: IF 3.38. Posición de la revista con relación a su categoría específica:13/60; Primer cuartil (Q1), primer tercil (T1)

2. Carpio Camargo, A. J., Álvarez Gutiérrez, Y., Jaramillo Véliz, J., & Sánchez Tortosa, F. (2020). Nesting failure of sea turtles in Ecuador-causes of the loss of sea turtle nests: the role of the tide. *Journal of Coastal Conservation*, *24*(5), 1-10 https://doi.org/10.1007/s11852-020-00775-3 (CAPÍTULO II DE LA TESIS)
   Factor de impacto: IF 2.098. Posición de la revista con relación a su categoría específica: 53/110; Segundo cuartil (Q2), Segundo tercil (T2)

3. Carpio Camargo, A. J., Álvarez Gutiérrez, Y., Rivas, M., Gutiérrez, G., Vélez, J., Tortosa, F. S. y Oteros, J. (2022). Potential effects of future high tides on sea turtle nesting. *Research Square*, (Preprint). https://doi.org/10.21203/rs.3.rs-2095408/v1 (CAPÍTULO III DE LA TESIS)

4. Carpio Camargo, A. J., Álvarez Gutiérrez, Y., Serrano, R., Vergara, M. B., Quintero, E., Tortosa, F. S., & Rivas, M. L. (2022). By-catch of sea turtles in Pacific artisanal fishery: Two points of view: From observer and fishers. *Frontiers in Marine Science*, 1689. https://doi.org/10.3389/fmars.2022.936734 (CAPÍTULO IV DE LA TESIS)
   Factor de impacto: IF 5.247. Posición de la revista en relación a su categoría específica: 6/113; Primer cuartil (Q1), Primer decil (D1)

Comunicaciones presentadas en congresos internacionales

1. Álvarez Gutiérrez, Y., Tortosa, F. S., Carpio Camargo, A. J. (2019). Identificar las variables que determinan la selección de playas para la nidificación y evaluación del impacto de la pesca incidental sobre las tortugas marinas en Ecuador. *Primer Congreso Internacional y Multidisciplinar de Investigadores en Formación*. Ecuador. Comunicación oral.

2. Álvarez Gutiérrez, Y., (2020). Acciones educativas para fomentar la protección de las tortugas marinas. *VI Congreso Iberoamericano sobre Ambiente y Sustentabilidad*. Ecuador. Póster.

3. Álvarez Gutiérrez, Y., Tortosa, F. S. y Carpio Camargo, A. J. (2020). Causas de la pérdida de nidos de tortugas marinas en Ecuador: el papel de las mareas. *Segundo Congreso Internacional y Multidisciplinar de Investigadores en Formación*. Córdoba. Comunicación oral.

4. Vergara, M. B., Carpio Camargo, A. J. y Álvarez Gutiérrez, Y. (2020). Efectos de la pesca incidental en la población de tortugas marinas en la costa de Ecuador. *Segundo Congreso Internacional y Multidisciplinar de Investigadores en Formación*. Córdoba, España. Comunicación oral.

5. Carpio Camargo, A.J., Vergara, M. B., Álvarez Gutiérrez, Y. y López-Rivas, M. (2021). Efectos de la pesca incidental en la población de tortugas marinas en la costa de Ecuador. *V Congreso de Biodiversidad y conservación de la naturaleza*. Málaga, España. Comunicación oral.

6. Álvarez Gutiérrez, Y., Vergara, M. B., Sánchez, F. y Carpio Camargo, A. J. (2021). Efectos de la pesca incidental en la población de tortugas marinas en la costa de Ecuador. *III Congreso Internacional Multidisciplinar de Investigadores en Formación* (CIMIF-21). Universidad de Córdoba, España. Comunicación oral.

7. López-Alcívar, G., Vásquez-Sanchez, L. R., Álvarez Gutiérrez, Y. y Carpio Camargo, A. J. (2021). Influencia de la contaminación de los asentamientos humanos sobre los arrecifes de coral en Manabí. *III Congreso Internacional Multidisciplinar de Investigadores en Formación* (CIMIF-21). Universidad de Córdoba, España. Comunicación oral.

8. Álvarez Gutiérrez, Y., Gutiérrez-Zambrano, G. y Vélez, J. (2022). Efectos del cambio climático en la anidación de tortugas marinas en Ecuador. *VIII Seminario Científico Internacional sobre Cooperación Universitaria para el Desarrollo Sustentable (VIII SCICUDS)- XII Taller Estudiantil internacional sobre Medio Ambiente (TEIMA´2022).* Universidad Centro Panamericano de Estudios Superiores, México. Comunicación oral.

9. Álvarez Gutiérrez, Y. (2022). Efectos de la marea en las playas de anidación de tortugas marinas en Ecuador. *IV Seminario Propio del Programa de Doctorado en Recursos Naturales y Gestión Sostenible.* Universidad de Córdoba, España. Comunicación oral.

10. Álvarez Gutiérrez, Y. (2023). Cambio climático y anidación de las tortugas marinas en Ecuador. *I Congreso Internacional de Ciencias Ambientales.* Universidad Estatal del Sur de Manabí, Ecuador. Comunicación oral.

Comunicaciones presentadas en eventos nacionales

1. Álvarez Gutiérrez, Y., Vásquez, L. y Hernández, A. (2019). Factores de riesgo en el ecosistema de las tortugas carey (*Eretmochelys imbricata*) de la playita del Parque Nacional Machalilla. *Simposio de Tortugas Marinas*, Ecuador. Póster.

2. Álvarez Gutiérrez, Y. (2020). Mujeres en la conservación de las tortugas marinas. *Experiencias de investigación, gestión y perspectivas*, Ecuador. Comunicación oral.

3. Álvarez Gutiérrez, Y. (2021). Causa de pérdida de nidos de tortugas marinas en Ecuador. El papel de las mareas. *Foro Salud social y ecosistémica ante los retos climáticos*. Gobierno Provincial de Manabí, Ecuador. Comunicación oral.

4. Álvarez Gutiérrez, Y. (2021). Estado de Conservación de las tortugas marinas. *Ingeniería Ambiental*, Universidad Estatal del Sur de Manabí, Ecuador. Comunicación oral.

La presente ***Tesis Doctoral*** es resultado de la ejecución del siguiente proyecto de investigación:

Proyecto PROG-015-DIP-PROYE-001-2019, *Evaluación del impacto de la pesca incidental y la contaminación marina sobre los arrecifes rocosos y las tortugas marinas en la costa continental de Ecuador* de la Carrera Ingeniería Ambiental de la Universidad Estatal del Sur de Manabí.

Durante el desarrollo de la presente Tesis se contó con la ayuda de La Fundación para la Investigación y Gestión Sostenible de los Recursos Naturales (FIGSO).

Fotografías de portada: Yamel Álvarez Gutiérrez, Antonio José Carpio Camargo y Antonio Santos

INDICE GENERAL

RESUMEN

En el primer capítulo de la tesis se analiza el impacto provocado por la introducción intencionada de especies exóticas sobre la biodiversidad en América Latina, con especial énfasis en las vías de introducción y la finalidad con la cual estas especies fueron introducidas. El mayor impacto ambiental ocasionado por las especies exóticas se debe a las interacciones negativas que generan con la fauna local (185 impactos de especies) seguido del impacto económico (97 impactos de especies) debido a los daños generados a la agricultura/silvicultura. En tercer lugar, se tienen los impactos en la salud (53 impactos de especies), que se dan principalmente por la transmisión de enfermedades. La introducción intencional de especies en América Latina está sesgada a mamíferos (52,7%), fundamentalmente los ungulados, empleados principalmente para la caza deportiva y la alimentación; y algunos grupos de aves como los *Psittaciformes* (47,3%), introducidos principalmente para el comercio de mascotas.

Las tortugas marinas son especies de crecimiento lento, con un complejo ciclo de vida que abarca varios hábitats durante su desarrollo y migraciones, y cuyas poblaciones a nivel mundial ha disminuido drásticamente. Debido a ello se encuentran incluidas en el *Apéndice I de la Convención sobre el Comercio Internacional de Especies Amenazadas de Fauna y Flora Silvestres* (CITES), y en la *Lista Roja* elaborada por la Unión Internacional de Conservación de la Naturaleza (UICN). Estas especies cumplen funciones ecológicas importantes como: traslado de nutrientes, remoción de arena de las playas de anidación, y forrajeo de los pastos marinos, promoviendo así su revitalización y sirven como importantes indicadores de la salud de los ambientes costeros y marinos, tanto a escala local como global.

América Latina es sin duda una de las regiones más megadiversas a escala mundial, pero también una de la más sensible para las tortugas marinas por las actividades antropogénicas y fenómenos naturales. En las aguas jurisdiccionales de Ecuador se encuentran cinco de las siete especies de tortugas marinas que existen a nivel mundial; sin embargo, la información sobre las amenazas para estas especies es limitada. Actualmente, las tortugas marinas se enfrentan a diversos problemas como la introducción de especies exóticas, el desarrollo costero, el turismo masivo, la contaminación, la depredación de nidos, la pesca incidental y otros derivados del cambio climático, como el aumento de la temperatura del agua, cambios en la frecuencia e intensidad de las mareas o el aumento del nivel del mar.

En este contexto, la mayor parte de las investigaciones están relacionadas con los recursos pesqueros, sin embargo, los estudios sobre las poblaciones de tortugas marinas en Ecuador son escasos. Ante esta situación, la presente tesis doctoral pretende analizar los factores antropogénicos y naturales que inciden en la mortalidad y nidificación de las tortugas marinas.

El segundo capítulo aborda el impacto de los aguajes y la formación de dunas sobre el éxito de las anidaciones de las tortugas marinas durante los últimos 10 años. Los resultados mostraron que la presencia de escalones de arena impactó negativamente en la posibilidad de anidar (mayores tasas de abandono en presencia de dunas), mientras que la intensidad y frecuencia de los aguajes afectó el éxito de eclosión de las anidaciones, en mayor proporción a la tortuga verde (*Chelonia mydas*) . Por otro lado, en el tercer capítulo se evalúan los eventos de frecuencia e intensidad de aguajes futuros sobre el éxito de las nidificaciones mediante modelos estadísticos predictivos. Los resultados indican que el éxito de eclosión de las anidaciones de la tortuga carey (*Eretmochelys imbricata*) se verán más afectadas por los múltiples impactos del cambio climático. El cuarto capítulo se centra en determinar qué factores influyen en la captura incidental de las tortugas marinas por la actividad pesquera de la flota ecuatoriana. En este estudio se han comparado varios tipos de cebos, pesca objetivo, tipos de anzuelos y épocas de pesca; lo que permitió cuantificar el impacto de cada variable sobre la captura incidental de las tortugas marinas. Además, para obtener una visión integral de la amenaza, se realizó un análisis de percepción de los pescadores sobre las capturas incidentales, destacando este resultado como una novedad en esta área del conocimiento. De acuerdo con los datos obtenidos sobre la captura incidental, ésta se da con el uso de los anzuelos *tipo J*, en la época de invierno, cuando las especies pelágicas (especialmente el dorado) son el objetivo principal; en este caso la tasa de mortalidad se da en mayor porcentaje en la tortuga verde.

ABSTRACT

The first chapter of the thesis analyzes the impact caused by the intentional introduction of exotic species on biodiversity in Latin America, with special emphasis on the routes of introduction and the purpose with which these species were introduced. The greatest environmental impact caused by exotic species is due to the negative interactions they generate with local fauna (185 species impacts) followed by the economic impact (97 species impacts) due to the damage generated to agriculture/forestry. In third place are the impacts on health (53 species impacts), which occur mainly due to the transmission of diseases. The intentional introduction of species in Latin America is biased towards mammals (52.7%), mainly ungulates, used mainly for sport hunting and food; and some groups of birds such as the Psittaciformes (47.3%), introduced mainly for the pet trade.

Sea turtles are slow-growing species, with a complex life cycle that encompasses various habitats during their development and migrations, and whose populations worldwide have drastically declined. As a result, they are included in Appendix I of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), and on the Red List prepared by the International Union for Conservation of Nature (IUCN). These species fulfill important ecological functions such as: transfer of nutrients, removal of sand from nesting beaches, and foraging of seagrasses, thus promoting their revitalization and serving as important indicators of the health of coastal and marine environments, both at scale local as global.

Latin America is undoubtedly one of the most megadiverse regions on a global scale, but also one of the most sensitive for sea turtles due to anthropogenic activities and natural phenomena. Five of the seven species of sea turtles that exist worldwide are found in the jurisdictional waters of Ecuador; however, information on threats to these species is limited. Currently, sea turtles face various problems such as the introduction of exotic species, coastal development, mass tourism, pollution, nest depredation, incidental fishing and other derivatives of climate change, such as the increase in sea temperature. water, changes in the frequency and intensity of the tides or the rise of the sea level.

In this context, most of the research is related to fishing resources, however, studies on sea turtle populations in Ecuador are scarce. Faced with this situation, this doctoral thesis aims to analyze the anthropogenic and natural factors that affect the mortality and nesting of sea turtles.

The second chapter approaches the impact of floodwaters and dune formation on the nesting success of sea turtles over the past 10 years. The results showed that the presence of sand steps had a negative impact on the possibility of nesting (higher abandonment rates in the presence of dunes), while the intensity and frequency of downpours affected the hatching success of the nests, in greater proportion to the green turtles (*Chelonia mydas*). On the other hand, in the third chapter the events of frequency and intensity of future flooding on the success of nesting are evaluated through predictive statistical models. The results indicate that the hatching success of hawksbill turtle (*Eretmochelys imbricata*) nests will be more affected by the multiple impacts of climate change. The fourth chapter focuses on determining what factors influence the incidental capture of sea turtles by the fishing activity of the Ecuadorian fleet. In this study, various types of baits, target fishing, types of hooks and fishing seasons have been compared; which allowed quantifying the impact of each variable on the incidental capture of sea turtles. In addition, to obtain a comprehensive view of the threat, an analysis of the perception of fishermen on incidental catches was carried out, highlighting this result as a novelty in this area of knowledge. According to the data obtained on incidental capture, this occurs with the use of J-type hooks, in the winter season, when pelagic species (especially mahi-mahi) are the main objective; in this case the mortality rate occurs in a higher percentage in the green turtle.

INTRODUCCIÓN

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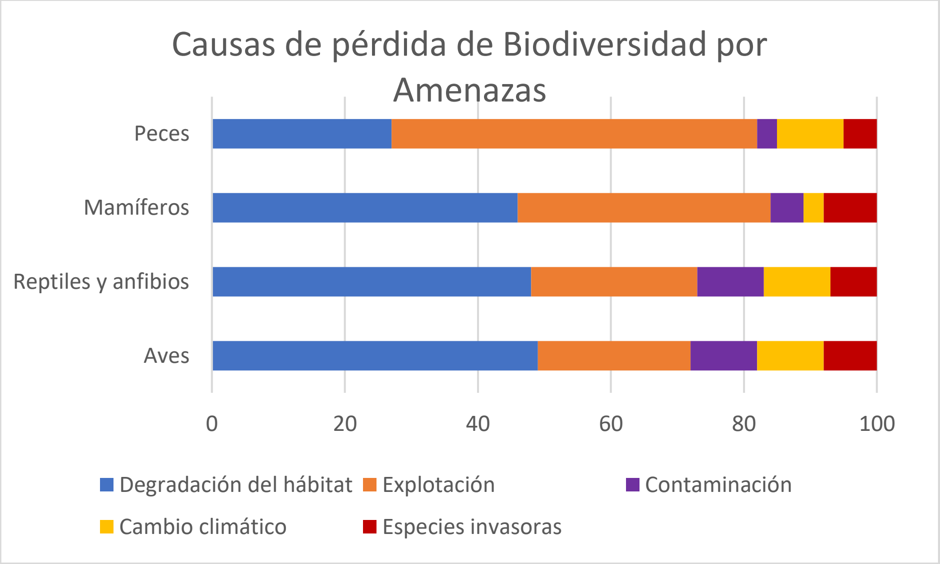
1. Amenazas para la biodiversidad

La biodiversidad o variedad de todos los seres vivos que forman la base de la vida en el planeta, está disminuyendo a un ritmo alarmante en los últimos años según la Organización de las Naciones Unidas (ONU). Este es principalmente debido a actividades humanas, como los cambios en el uso del suelo (deforestación, monocultivos), la explotación de los recursos, la caza, la sobrepesca, la contaminación, la introducción de especies exóticas invasoras o el cambio climático (World Wide Fund for Nature [WWF], 2018). (Figura 1).

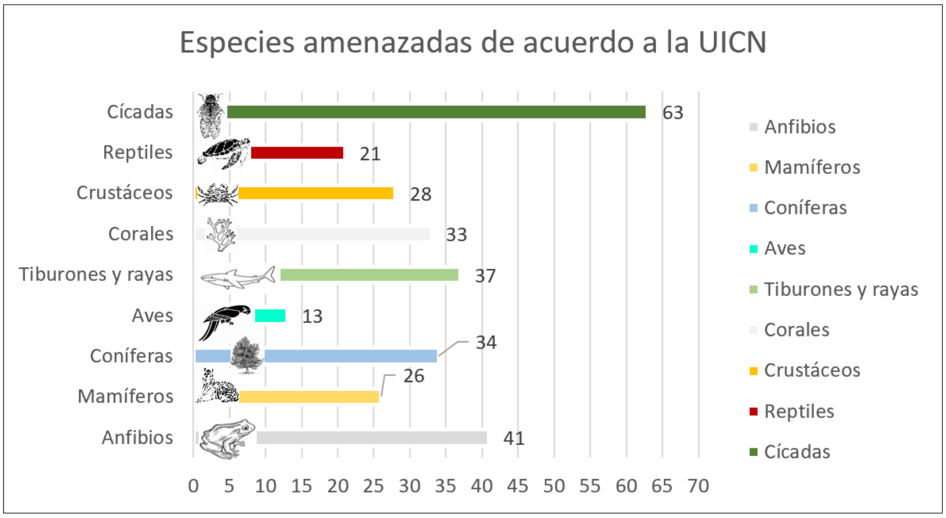
Figura 1. *Causas de pérdida de biodiversidad para cada grupo de vertebrados en función de la amenaza.*



Fuente: Adaptado del Informe Planeta Vivo (WWF, 2018).

En Ecuador, la Plataforma Intergubernamental Científico-normativa sobre diversidad Biológica y Servicio de los Ecosistemas (IPBES) estima que el 77% de la tierra y el 87% de los océanos han sido alterados por acción humana, lo que ha llevado a una pérdida del 83% de la biomasa de mamíferos silvestres. En el mismo informe indica que, más de un millón de especies animales están en peligro de extinción, lo que supondría el inicio de la sexta extinción. La Unión Internacional para la Conservación de la Naturaleza (UICN) ha publicado la lista roja de especies amenazadas (Figura 2).

Figura 2. *Porcentaje de especies amenazadas de acuerdo a la lista roja de UICN. En color rojo el grupo taxonómico abordado en la presente tesis doctoral.*



Fuente: Figura adaptada de UICN (2021).

Especies exóticas

La aparición de especies exóticas es la segunda amenaza, junto a la destrucción del hábitat, para la biodiversidad en nuestro planeta. Algunos estudios indican que las zonas con una mayor biodiversidad nativa tienden a albergar una mayor riqueza de especies exóticas a gran escala espacial (Stohlgren et al., 2003, 2006; Fridley et al., 2007; Dyer et al., 2017a), ya que aquellas áreas con una alta diversidad nativa tienen un mayor número de micronichos (o más heterogeneidad espacial), por lo tanto, permitiría albergar un mayor número de especies exóticas (Davies et al., 2005). Esto es lo que se conoce como la hipótesis “riqueza llama a riqueza”. En este sentido, América Latina posiblemente es una de las regiones con mayor amenaza de extinción a lo que Myers denominó *“hotspots de biodiversidad”* debido a su gran variedad de nichos y biodiversidad (Speziale y Lambertucci, 2010). Los actuales 35 hotspots ocupan sólo el 2,3% de la superficie de la Tierra y albergan más de la mitad de las especies de plantas del mundo, y cerca del 43% de las especies de aves, mamíferos, reptiles y anfibios endémicos (Myers et al., 2011).

Las invasiones biológicas son uno de los principales impulsores del cambio ambiental global y la pérdida de biodiversidad nativa (Bellard et al., 2016; Blackburn et al., 2019). Además, los movimientos transcontinentales antropogénicos implican un tráfico global en continuo aumento y la posterior transferencia intencional y no intencional de organismos (Carpio et al., 2020b). El impacto ecológico de la introducción de especies es la segunda causa de pérdida de diversidad biológica a escala mundial (Álvarez-Romero et al., 2008), en un 40% de las extinciones (Caughley y Gunn, 1995). Según Buitrago (2003), la pérdida de huevos y recién nacidos se da por depredadores introducidos como *Canis familiaris* (perro), *Felis catus* (gato), *Sus scrofa* (cerdo), *Rattus rattus* (rata), que se encuentran entre las 100 especies exóticas invasoras más dañinas del mundo (Lowe et al., 2004). Otros estudios demuestran que el 19% de la pérdida de nidos de quelonios en Costa Rica se da por la depredación de perros domésticos (Malmierca, 2018), lo cual coincide con estudios realizados en la provincia de Esmeraldas (Ecuador) donde se registra una alta incidencia de depredación de nidos por perros (Sosa, 2019). En Ecuador también se ha reportado que el cerdo salvaje depredó el 7,4% de nidos en la región insular (Zarate et al., 2013), lo cual coincide con otros estudios que destacan el papel dañino de los cerdos salvajes sobre las anidaciones de tortugas (Engeman et al., 2019).

Por tanto, es clave evaluar las vías por las que se introducen las especies exóticas para poder identificar los riesgos potenciales y evaluar las decisiones de gestión (Pyšek et al., 2020). Este tema se aborda en el **primer capítulo** de la tesis como una primera aproximación para conocer el impacto y magnitud de la introducción intencional de especies exóticas en América Latina (Carpio et al., 2020b). Además, las políticas sudamericanas parecen reflejar el bajo nivel de interés por las especies no autóctonas que muestran sus ciudadanos (Speziale et al., 2012). En esta región, las políticas nacionales están poco desarrolladas y se ocupan principalmente de las especies exóticas que amenazan los sistemas productivos. Además, tanto el número de especies introducidas como sus impactos están subestimados dado el bajo esfuerzo de investigación dedicado a las especies no nativas en los países de América del Sur (Quiroz et al., 2009).

2. **Las tortugas marinas**

El segundo bloque que compone esta tesis doctoral se centra de forma particular en las tortugas marinas. Se trata de reptiles que habitan los mares tropicales y subtropicales del mundo, desde hace más de 100 millones de años. La forma de su cuerpo y sus aletas hacen que estas especies estén adaptadas a la vida en el mar, manteniendo un vínculo muy cercano con la tierra. Las hembras deben ir a las playas a depositar sus huevos en la arena, donde nacerán las tortugas y retornarán al mar (Carr, 2015). Con ello cumplen una etapa del complejo ciclo de vida, que abarca varios hábitats durante su desarrollo y migraciones, lo que las expone a numerosas amenazas naturales y antropogénicas (Núñez, 2015).

A nivel mundial existen siete especies de tortugas marinas, *Chelonia mydas* (tortuga verde), *Eretmochelys imbricata* (tortuga carey), *Lepidochelys olivacea* (tortuga golfina)*, Dermochelys coriacea* (tortuga laúd)*, Caretta caretta* (tortuga caguama), *Lepidochelys Kempii* (tortuga lora), *Natator depressus* (tortuga plana). De acuerdo a la Lista Roja de la Unión Internacional para la Conservación de la Naturaleza, estas especies se encuentran en alguna de las categorías de peligro de extinción; la tortuga carey y lora están categorizadas como *en peligro crítico*, la tortuga verde *en peligro*, las tortugas laúd, golfina, y caguama como *vulnerable*, y la tortuga plana *datos insuficientes*.

En este contexto, Ecuador es uno de los países pioneros en la conservación de las tortugas marinas en América Latina, iniciando los esfuerzos de conservación en los ochenta, prohibiendo la captura de las tortugas marinas y la exportación de los productos y subproductos de estas especies (Hurtado, 1983). En la última década (2010-2020) se ha fortalecido tanto el marco normativo, como las capacidades institucionales, y se diseñó una importante herramienta al promulgarse el Plan Nacional de Conservación de las Tortugas Marinas (PNCTM 2014-2019), actualizado en el 2020.

A continuación, se describen las especies de tortugas marinas encontradas en Ecuador:

Lepidochelys olivacea **(tortuga golfina)**

De acuerdo al informe anual de la CIT en el 2013, las playas del Refugio de Vida Silvestre y Marino Costera Pacoche reportan que el 88,7% de las tortugas marinas anidadoras monitoreadas pertenecen a esta especie. Al año 2020, la anidación de la golfina se ha reportado a lo largo de toda la costa del Ecuador en 41 playas (SGMC, 2019; Miranda, 2019), con valores de hasta 700 nidos por año (SGMC, 2019).

La anidación de esta especie ocurre durante todo el año. Sin embargo, su pico reproductivo se presenta entre los meses de septiembre a noviembre (MAE, 2014), según reportes en las playas de la Reserva de Producción de Fauna Marino Costera Puntilla de Santa Elena, Refugio de Vida Silvestre Pacoche, Reserva Marina Manglares del Río Muisne y Playa Las Palmas en la Provincia de Esmeraldas.

Chelonia mydas (tortuga verde)

El Ministerio de Ambiente, Agua y Transición Ecológica, durante los años comprendidos entre el 2014 y 2019 ha reportado que anidan: en la playa de San Lorenzo y la Botada (provincia de Manabí); Tres Cruces y Punta Brava (provincia de Santa Elena), y en Esmeraldas. En resumen, se han identificado 15 playas de anidación, siendo Bahía Drake en la Isla de La Plata, Parque Nacional Machalilla, uno de los más importantes, con un promedio de 48 nidos por año (Miranda, 2019). Respecto al área marina, los alrededores de la Isla de La Plata se han identificado como el sitio más importante de agregación de esta especie en el continente.

Dermochelys coriacea (tortuga laúd)

Esta especie cuenta con muy pocos registros en Ecuador. En 1983 se confirma la primera anidación con eclosión efectiva en la playa de Cabuyal, Manabí. En los últimos años se han reportado intentos de anidación en las provincias de Manabí y Esmeraldas, estas han sido las primeras monitoreadas desde el desove, incubación hasta eclosión, aunque fueron infructuosas (Espinoza et al., 2018). Sin embargo y de acuerdo al *Boletín informativo 085* del Ministerio de Ambiente, Agua y Transición Ecológica (MAATE) en enero del 2021 el país marcó un hito histórico con el surgimiento de 60 tortugas de esta especie en las costas, de las cuales nueve eclosionaron en la playa Punta Bikini en el cantón Sucre, bajo supervisión del personal de dicha institución y especialistas de la CIT (MAATE, 2021).

Eretmochelys imbricata (tortuga carey)

La tortuga carey está presente en la costa continental ecuatoriana y las Islas Galápagos. Desde el 2008, la Fundación Equilibrio Azul inició un programa de monitoreo en las playas del Parque Nacional Machalilla, (Baquero et al., 2008). Al momento se han identificado 13 playas de anidación, pero destacan 2 playas, Playita en el Parque Nacional Machalilla; y Playa Rosada en la Reserva Marina El Pelado (SGMC, 2019; Miranda, 2019).

Los esfuerzos de monitoreo de esta fundación han logrado colocar un total de 11 transmisores satelitales para conocer su migración entre anidaciones y después de la temporada de anidación. Los datos dan un promedio de 25 nidos al año y se han marcado un total de 40 hembras anidadoras (Miranda et al., 2018).

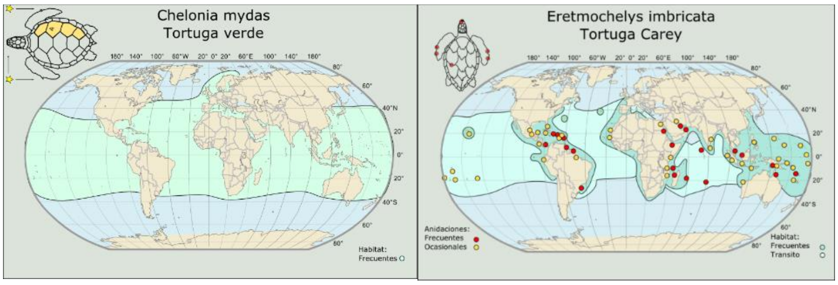
Caretta caretta (tortuga caguama)

La información de su distribución es limitada, pero en base al programa de observadores pesqueros de la pesca de palangre de la Subsecretaria de Recursos Pesqueros (SRP), en el período 2008-2017 se registraron 2206 tortugas capturadas, de las cuales el 1,5% de las tortugas reportadas pertenecen a esta especie (Esparza-Ramírez et al., 2018).

A pesar de que algunas especies como *L. olivacea* fue un importante recurso pesquero comercial (Hurtado, 1987), en la actualidad, debido al interés internacional por la protección de estos carismáticos animales, Ecuador es uno de los países pioneros en la conservación de las tortugas marinas de América Latina (MAE, 2014). En sus aguas jurisdiccionales se encuentran cinco de las siete especies (tortuga verde, tortuga carey, tortuga golfina, tortuga laúd, y tortuga caguama) de ellas con excepción de la caguama el resto anidan en la costa continental del país según el *Plan Nacional Para La Conservación de las Tortugas Marinas* del Ministerio de Ambiente Ecuador (MAAE, 2020). En concreto, la provincia de Manabí es una zona muy importante de anidaciones de varias especies de tortugas, principalmente en el Parque Nacional Machalilla, la Reserva Marina de Cantagallo y el Refugio de Vida Silvestre Marino Costero de Pacoche; sitios donde se han desarrollado acciones para su conservación (MAAE, 2020). Sin embargo, todavía existe poca información sobre el éxito reproductivo, causas de pérdida de nidos o principales causas de mortalidad para estas especies en la costa continental de Ecuador (MAAE, 2020; Alfaro-Shigueto et al., 2018). Por ello la presente tesis aborda las variables (ambientales, antrópicas y bióticas) que determinan el éxito de nidificación y mortalidad de las tortugas marinas en la costa continental de Ecuador.

Las tortugas marinas cumplen funciones ecológicas importantes, trasladan nutrientes, remueven la arena de las playas de anidación, y forrajean pastos marinos promoviendo su revitalización (MAAE, 2021). La especie *E. imbricata* se alimenta de esponjas y contribuye a mantener la dinámica de arrecifes de coral (alivia el epizoismo en corales); la *D. coriácea* se alimenta de medusas, con lo que mantiene el control de sus poblaciones. De igual modo, debido a que realizan migraciones de miles de kilómetros y tardan décadas para madurar sexualmente, sirven como importantes indicadores de la salud de los ambientes costeros y marinos, tanto a escala local como global (UICN, 2001). Estas especies presentan una distribución cosmopolita, preferentemente en las regiones tropicales y subtropicales, aunque también ocupan regiones de aguas templadas (Figura 3).

Figura 3. *Distribución mundial de la tortuga verde (izquierda) y carey (derecha), objeto de estudio en esta tesis.*



Fuente: Fauna especializada, distribución de la tortuga verde y carey 2018.

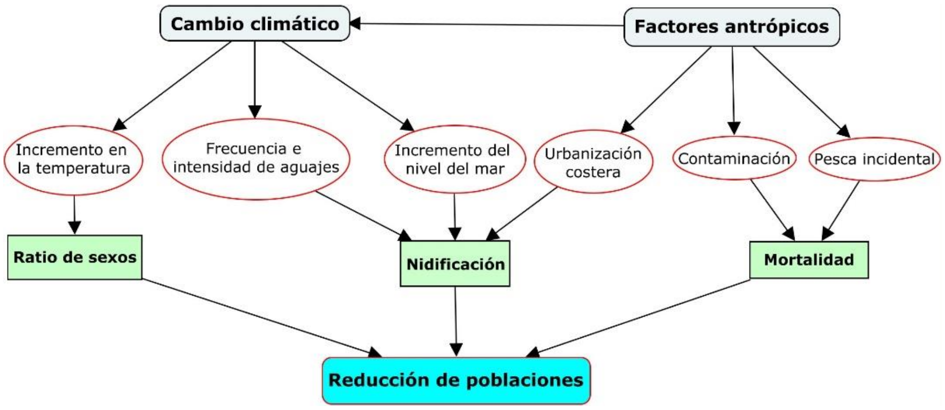
A nivel mundial, las poblaciones de tortugas han disminuido drásticamente, principalmente por la cacería para la obtención de cuero y carne, el expolio o depredación de huevos, la pesca incidental o el cambio climático entre otros (Mazaris et al., 2017; MAE, 2014). Estas disminuciones han motivado los esfuerzos de conservación en todo el mundo desde la década de 1950 (Hamann et al., 2007; Wallace et al., 2011). Los esfuerzos incluyeron varias medidas de protección de playas, regulaciones estrictas de captura incidental en pesquerías (Lewinson et al., 2003) y el establecimiento de áreas marinas protegidas (Hamann et al., 2007). Esta preocupación ha llevado a que las tortugas marinas se incluyan en el *Apéndice I de la Convención sobre el Comercio Internacional de Especies Amenazadas de Fauna y Flora Silvestres* (CITES, por sus siglas en inglés), y en la *Lista Roja* de la Unión Internacional para la Conservación de la Naturaleza (UICN). Aproximadamente el 62,8% de las poblaciones de tortugas marinas sufren un cierto grado de amenaza, de los cuales el 19,4% están clasificados como amenazados críticamente, 17,4% como amenazado y 30% como vulnerable (Gibbons et al., 2000). La explotación directa de la carne se ha reducido (Ceriani et al., 2019), pero otras amenazas antropogénicas siguen causando preocupación como el turismo, la pérdida de hábitat, la urbanización, la contaminación lumínica costera o la recolección de huevos (Wallace et al., 2013; Brei et al., 2016; Sella y Fuentes, 2019; 2020) sumado a ello la pesca incidental mediante diferentes artes de pesca de quienes se dedican a esta actividad.

Entre las principales amenazas para la conservación de tortugas marinas se encuentran los factores antropogénicos, como la contaminación de los mares y la destrucción de los sitios de anidación, turismo, pesca, urbanización, entre otros; así como por los efecto del cambio climático (Esteban et al., 2018). La pérdida de playas como consecuencia de la erosión y las variaciones en el nivel del mar por el calentamiento global puede producir eventos catastróficos (Bolongrado et al., 2015;

Palomino-González et al., 2020). El aumento del nivel del mar y un incremento de la frecuencia de eventos de nivel de oleaje excepcionalmente alto han sido relacionados con la pérdida de nidadas, particularmente en aquellas playas donde las tortugas se encuentran con una pérdida de disponibilidad de zonas óptimas donde variables como la humedad, salinidad o pendiente de la playa resulten adecuadas (Wood y Bjorndal, 2000; Palomino-González et al., 2020; Hawkes et al., 2018). De otro lado, el cambio climático genera dos problemas en la reproducción de las tortugas, un aumento del nivel del mar y la consiguiente pérdida de zonas adecuadas (Fish et al., 2005), además del aumento de la temperatura que afecta la determinación del sexo de las crías (Yntema y Mrosovsky, 1980) (Figura 4).

Otras amenazas que afectan a las poblaciones de tortugas están relacionadas con los impactos de la pesca incidental, el uso de diferentes artes de pesca (especialmente palangres y redes de enmalle) una de las amenazas más graves para las poblaciones de tortugas marinas (Lewison et al., 2004; López-Barrera et al., 2012; Wallace et al., 2013; Gilman y Huang, 2017; Fiedler et al., 2020; Marco et al., 2020)

Figura 4. Factores relacionados con la reducción de las poblaciones de tortugas marinas.



Pérdida de hábitat de las tortugas marinas

El hábitat de las tortugas marinas puede verse afectado por causas antropogénicas (turismo, pesca, urbanización, entre otros), los contaminantes de las actividades humanas llegan al mar, provocando lesiones, enfermedades e incluso la muerte, las fuentes de contaminación van desde las aguas residuales de los asentamientos humanos hasta las redes de pesca (Wallace et al., 2015). Un informe de *National Geographic* en el 2021 menciona que cada año llegan más de ocho millones de toneladas de residuos al océano y el 90% de éstos son plásticos. Algunos estudios en las Islas Baleares encontraron residuos sólidos como plástico en los tractos digestivos de 13 tortugas que vararon muertas (Alonso, 2018).

La pérdida de hábitat por causas naturales (erosión, aumento del nivel del mar, intensidad de las mareas, huracanes), también pueden suponer una importante causa de pérdida de huevos y muerte de embriones en el nido (Buitrago et al., 2003). Dado que el criterio de selección del sitio no es el mismo para todas las especies, hay diferencias entre estas, en la misma playa (Esteban et al., 2018). Esta selección de los sitios para anidar depende de características como pendiente, topográfica, amplitud y tipo de sedimento (Zurita et al., 1993), así como de la presencia o no de obstáculos (escalones de arena, vegetación, etc.) (Carpio et al., 2020a). Uno de los problemas que se han identificado como causante de la disminución de estas poblaciones es el bajo éxito reproductor (Buitrago et al., 2003). Esto puede deberse a la falta de lugares adecuados para la nidificación, a la pérdida de nidos por depredación, a la inundación de los nidos, entre otros factores (Mazaris et al., 2013). En algunas playas sujetas a erosión se forman cantiles y terrazas verticales que constituyen serias barreras físicas y las tortugas a menudo están obligadas a recorrer grandes distancias paralela a la costa para finalmente regresar al mar y anidar en otros tramos más alejados (Márquez, 1996; Rivas et al., 2016). A las barreras naturales se suman otras creadas por el hombre como son los muelles, escolleras, desarrollos turísticos y urbanos (Salazar, 1998).

A este problema se añade otro fenómeno conocido como estrechamiento costero, debido a la expansión continua de construcciones en la playa que va reduciendo las zonas de nidificación para estas especies (Mazaris et al., 2009). Además, otros factores como la extracción de arena (Baquero, 2008), la depredación tanto de huevos y neonatos por parte de animales domésticos como cerdos, gatos y perros (Heithaus, 2013), la presencia de vehículos motorizados en las playas (Baquero, 2008), y la eliminación de la vegetación natural, la cual promueve significativamente la erosión afectan negativamente a la reproducción y supervivencia de las poblaciones de tortugas marinas.

En este sentido, el **segundo capítulo** intenta abordar esta problemática, evaluando el impacto de los aguajes y los escalones de arena en el éxito de nidificación (anidan o no) y eclosión (porciento de éxito) de las tortugas marinas. Trabajos previos como los de Rivas et al. (2016) y Siqueira et al. (2021), ya destacan la necesidad de conocer el efecto que la mayor frecuencia de tormentas y el aumento del nivel del mar debido al cambio climático podrían causar sobre la pérdida de playas. Resaltando que faltan estudios que recopilen conocimientos sobre la influencia de la vulnerabilidad costera a la erosión y el asentamiento para evaluar la anidación de tortugas marinas.

2.3 Cambio Climático

De acuerdo con el informe de la Organización Meteorológica Mundial (OMM), cuatro indicadores claves que miden el cambio climático alcanzaron niveles récord en el 2021 como lo son las concentraciones de gases de efecto invernadero, subida del nivel del mar, contenido calorífico de los océanos y acidificación de éstos. Los datos son un reflejo de que las actividades humanas están provocando cambios a escala global, lo que representa uno de los mayores problemas ecológicos, sociales y económicos del planeta (IPCC, 2021). Estos cambios se manifiestan en los sistemas biológicos como cambios en la distribución y abundancia de especies, alteración de la fenología, cambios de distribución a los polos en muchas especies marinas que van desde plancton a los peces (Beaugrand et al., 2002; Perry et al., 2005).

El sexto informe del IPCC 2022 estima que el aumento del nivel del mar (SLR) entre 1901 y 2018 fue de 0.2 m., y de acuerdo con las proyecciones continuarán aumentando a un ritmo acelerado para el 2030. Lo que conlleva a un aumento de inundaciones de zonas costeras (Lin et al., 2012) y alteración de las mareas (Hagen et al., 2013). Todas estas proyecciones de aumento del nivel del mar muestran escenarios desfavorables para las anidaciones (Patricio et al., 2019; Rivas et al., 2022). La subida del nivel del mar conduce al fracaso de los nidos de tortugas cuando el desarrollo embrionario se detiene debido a la reducción de oxígeno (Martin, 1996). Se estima que el 38% de las playas pueden sufrir una pérdida del hábitat para anidación debido a las inundaciones (Fuentes et al., 2010). Los impactos esperados incluyen la pérdida de hábitat y disminución del éxito reproductivo, la feminización de las poblaciones, cambios en la periodicidad reproductiva, cambios en los rangos latitudinales y cambios en el éxito de alimentación en la fase de la historia de la vida marina (Patricio et al., 2021).

Un efecto directo, derivado del cambio climático es el aumento del nivel del mar (tabla 1). Estudios previos como Baker et al. (2006), Fuentes et al. (2010), Lyons et al. (2020), Varela et al. (2019) y Rivas et al. (2022) reportan pérdidas de nidos de hasta el 67% bajo el escenario de IPCC de 1,2 m y concluyen que hasta el 40% de las playas de anidación de tortugas podrían ser inundadas. Otros estudios realizados en Barbados demostraron pérdidas del 50% del hábitat de anidación de tortugas carey (Fisher et al., 2005).

Esto puede tener un impacto letal sobre las tortugas, ya que trabajos previos muestran como la inundación de 1 a 3 horas reduce la viabilidad de los huevos en un 10%, mientras que si esta inundación dura 6 horas la reducción de la viabilidad aumenta en un 30% (Pike et al., 2015). Por tanto, el impacto negativo que tiene el aumento del nivel del mar e intensidad de mareas en las playas tienen implicaciones no solo para los nidos, sino también para los juveniles y adultos (Von et al., 2019), y esta amenaza está dada por el incremento de marejadas por efecto de fuertes vientos en las costas por ejemplo en Ecuador donde desovan tortugas golfinas (MAE, 2017).

Otro efecto derivado del cambio climático es el aumento de la temperatura (tabla 1), el cual es un factor condicionante en especies con determinación del sexo dependiente de la temperatura (TSD), donde el sexo del individuo está determinado por la temperatura de incubación en etapa embrionaria (Janzen, 1994). El cambio climático afecta todas las etapas de vida de las tortugas marinas, una de las principales preocupaciones con respecto a los efectos es el impacto en la proporción de sexos, ya que las temperaturas más altas pueden provocar que la arena se caliente, solo con el aumento de 2°C aumentaría la proporción de crías hembra (Wibbels, 2003; Poloczanska, 2009). Se prevé que la temperatura media anual aumente 2,6°C para el 2100 (IPPC, 2014), por lo que se espera una clara tendencia a la feminización de las poblaciones. Por ejemplo, estudios recientes muestran resultados de tres especies que han tenido una producción de crías sesgada hacia las hembras durante las últimas décadas con menos del 15,5%, 36,0% y 23,7% de machos producidos cada año para tortugas verdes, carey y laúd, respectivamente, desde finales del siglo XIX (Laloë et al., 2016).

Otro estudio realizado en la Gran Barrera de Coral (GBC) mostró un sesgo sexual femenino en el 99,1% de los juveniles, 99,8% de los subadultos y 86% de adultos en colonias de tortugas verdes durante más de dos décadas (Jensen et al., 2018).

Tabla1. Impactos del cambio climático en el hábitat de tortugas marinas, adaptado de Poloczanska et al. (2010).

Etapa de vida de las tortugas	**Hábitat y distribución**	**Calentamiento del aire y temperatura del océano**	**Alteración de lluvias, tormentas y ciclones**	**Aumento de nivel del mar**	**Alteración de vientos y corrientes oceánicas**	**Alteración de los patrones oceánicos a gran escala**	**Acidificación de los océanos**
Incubación y eclosión	Playas de arena en los trópicos y subtrópicos	Aire	X	X		X	
Cría y anidación	Aguas costeras y playas de arenas en los trópicos y subtrópicos	Océano	X	X		X	
Oceánicos Juveniles y adultos	Océano abierto, trópicos a latitudes de temperatura fría	Océano			X	X	X
Neríticos Juveniles y adultos	Aguas costeras y de plataforma, trópicos a latitudes de temperatura	Océano	X	X		X	X
Migración	Mares de plataforma y océano abierto cientos de kilómetros a través de cuencas oceánicas	Océano			X	X	

En este sentido el **tercer capítulo** de la tesis pretende evaluar el papel del cambio climático sobre la nidificación de las tortugas marinas a través de los cambios en los episodios (frecuencia e intensidad) de los aguajes. Siqueira et al. (2021), mencionan que la mayoría de los estudios sobre la actividad de anidación de tortugas marinas en la actualidad se centran en los impactos del cambio climático (especialmente incremento del nivel del mar y efecto de la temperatura en los sex-ratio), sin embargo, muy pocos trabajos evalúan el efecto potencial de los eventos extremos de aguajes en el futuro sobre el éxito de eclosión (Thompson y Curran, 2015; Palomino-González et al., 2020).

2.4 Pesca incidental

Le pesca incidental definida como la captura de organismos o especies no objetivo, es un tema de preocupación crítica para la conservación de los océanos y la gestión de recursos (Davies et al., 2009). La captura incidental emplea diferentes artes de pesca como palangres y redes de enmalle, que se convierten en una de las amenazas más graves para las tortugas marinas (Fiedler et al., 2007; Marco et al., 2020). Este problema se vuelve crítico cuando las especies no objetivo son animales de larga vida o se encuentran en peligro de extinción como es el caso de las tortugas marinas (Dayton et al., 1995; Lewison et al., 2004).

Alfaro-Shigueto et al. (2018) muestran datos preocupantes, solo al hablar de la pesca incidental, con una tasa de captura anual de 40.480 tortugas en Ecuador y una tasa de mortalidad del 32,5% (lo que equivale a 13.225 tortugas al año). De la información existente se sabe que, en Ecuador, *L. olivacea* es la especie más capturada en palangres artesanales, seguida de *C. mydas*. No hay reportes sobre captura de *D. coriácea*, pero probablemente debe haber interacción, ya que existen registros de captura en palangres y redes de enmalle en Perú (Alfaro-Shigueto et al., 2007). El impacto de la actividad pesquera hacia las poblaciones de tortugas marinas incluye golpes, ingesta de anzuelos y ahogamiento por enredo de redes de pesca (MAAE, 2020).

La interacción con los anzuelos tradicionales (anzuelo J) puede causar mortalidad en las tortugas cuando los tragan y se producen lesiones en el tracto digestivo, o cuando producen lesiones severas en otra parte del cuerpo, que inhabilitan al animal. Adicionalmente, ha sido común que los pescadores golpeen al animal para liberarlo. Vera (2009) reportó que de 156 tortugas varadas en la playa de Mar Bravo (provincia Santa Elena), 44 (28,2%) tenían anzuelos, principalmente en la boca (65,9%).

En el Centro de Rehabilitación de Fauna Marina localizado en el Parque Nacional Machalilla de Ecuador, hasta el 2018 se recibieron 306 tortugas de las especies *C. mydas, L. olivacea, y E. imbricata.* Entre las principales causas de varamiento se identificó que el 80.5% fue por golpes producidos por pescadores (fracturas de cráneo, fracturas de caparazón, desgarre de esófago), el 39% fue causado por anzuelos en intestino, estómago y el 19,5% por ahogamiento producido por enredo de redes de pesca (Alemán et al., 2018)

Debido a la alta incidencia de esta pesca incidental, el **cuarto capítulo** de esta tesis pretende evaluar los factores que determinan la pesca incidental de tortugas marinas en Ecuador. Como se ha mencionado anteriormente factores como el tipo de anzuelo (Wallace, 2013), tipo de cebo (Zárate, 2009), pesca objetivo (Parga et al., 2015), época del año (Barragán, 2003), resultan claves en las tasas de capturas de las tortugas marinas. Por tanto, resulta prioritario identificar estos factores para diseñar medidas de mitigación que permitan una pesca más integrada y sostenible.

OBJETIVOS Y ESTRUCTURA DE LA TESIS

La estructura de la tesis se corresponde al formato de tesis por compendio de artículos científicos.

De acuerdo a este formato, cada uno de los capítulos se redactaron siguiendo los apartados convencionales de un artículo científico, teniendo por tanto su propia introducción, materiales y métodos, resultados y discusión. Asimismo, cada artículo dispone de la bibliografía citada en el mismo. No obstante, para facilitar la localización de las citas incluidas en la introducción general y en la discusión final, se incluyen estas referencias bibliográficas al final de esta tesis, con independencia de que hayan sido igualmente citadas en los distintos capítulos.

La relación de artículos, cuyo contexto se ha explicado anteriormente en la introducción de cada capítulo que constituyen esta tesis, es la siguiente:

Como parte de la investigación se desarrollaron **dos objetivos generales**, el primero fue analizar la introducción de especies exóticas en Latinoamérica y el segundo objetivo, analizado en tres capítulos independientes, está relacionado con la evaluación de los factores que afectan el proceso de anidación y mortalidad de las tortugas marinas en las playas de Manabí, Ecuador.

Objetivos específicos

Muchos estudios indican que las zonas con mayor biodiversidad tienden a albergar una mayor riqueza de especies exóticas. América Latina, es sin duda uno de los continentes con mayor presencia de especies. De manera concreta un **primer objetivo específico** (capítulo uno), es analizar las vías de introducción de las especies exóticas en América Latina**.**

En el capítulo dos se hace referencia a las zonas de nidificación de las tortugas marinas, las cuales pueden verse afectadas por múltiples factores como el cambio climático; para lo cual se analizó la frecuencia e intensidad de las mareas entre el 2009 y 2019, como parte del **segundo objetivo específico** se planteó determinar las variables que causan la pérdida de nidos de las tortugas en los sitios estudiados.

Debido a la falta de información, sobre los escenarios futuros de cambio climático sobre esta especie en las costas de Ecuador, el capítulo tres responde al **tercer objetivo específico** para proyectar el éxito de anidación de las tortugas marinas a lo largo de la próxima década, basado en los cambios de los eventos de mareas extremas a lo largo de la costa continental de Ecuador.

Otra de las causas de mortalidad de las tortugas marinas se debe a la captura incidental, en la que se emplean diferentes artes de pesca, siendo una de las amenazas más graves para las poblaciones de estos quelonios. Como parte del **cuarto objetivo específico** (capítulo cuatro), es comparar la percepción de los pescadores artesanales frente a la de los observadores oficiales que acompañan a las embarcaciones nodrizas.

Finalmente se realiza una **discusión general** y se presentan las **conclusiones** de la investigación.

INTENTIONAL INTRODUCTION PATHWAYS OF ALIEN BIRDS AND MAMMALS IN LATIN AMERICA

CAPÍTULO 1

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Review Paper

Intentional introduction pathways of alien birds and mammals in Latin America

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Intentional introduction pathways of alien birds and mammals in Latin America

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ABSTRACT

Assessing the pathways by which alien species are introduced is essential if we are to identify potential risks and evaluate management decisions. Intentional introductions are responsible for the introductions of millions of animals throughout Latin America. We explore: (1) the relative role of several intentional introduction pathways (hunting, feeding, fur, biological control, the pet trade and others) in the general context of introductions of alien species; (2) the relative importance of the intentional pathways across the different taxa; (3) similar patterns as regards the composition of alien species across countries, (4) the underlying factors that drive the richness of alien species in Latin America, and (5) the potential impacts of alien species on the region. According to our results, 69 species of mammals and 62 species of birds were introduced into Latin America by means of intentional pathways, of which the most important taxa were Artiodactyls, Primates, Passeriformes and Psittaciformes. The main introductions pathways were the pet/ornamental trades (70.9%) for birds, and hunting (39.1%) and pet trade/ornamental purposes (37.7%) for mammals. The composition of species differed among countries, with a higher richness of species in those countries with a high percentage of urban populations, with a higher native species biodiversity, with a high % of GDP owing to imports (birds) and in those with a high number of trafficked species (mammals). This review stresses that the pet trade and hunting are important pathways for the introduction of alien species, some of which have had severe impacts on many countries.

Keywords: Delivering alien species Geographical pattern Global database Intentional species introduction Invasion pathways

INTRODUCTION

Biological invasion is one of the main drivers of global environmental change and the loss of native biodiversity (Bellard et al., 2016; Blackburn et al., 2019). In addition, anthropogenic transcontinental movements involve a continually increasing global traffic and the subsequent intentional and unintentional transfer of organisms, and a diverse array of human-mediated pathways have appeared to transport numerous species between different eco-regions (Kuhlenkamp and Kind, 2018). Global databases (e.g. GSID, GAVIA, or GRIIS) provide an overview of global geographic patterns of species invasions and/or introductions, origins and introduction pathways (Turbelin et al., 2017).

Mammals and birds were the first organisms to be intentionally introduced around the world for sport hunting, commercialization and domestication as livestock (e.g. feeding, fur, transport or work animals), pets or for pest control (Long, 2003; Lever, 2005; Clout and Russell, 2008; Blackburn et al., 2009). Some other species have been accidentally introduced (e.g. hitchhiker species, such as rats in ships). However, most established mammals originate from intentional releases into natural environments (Blackburn et al., 2011). The establishment of alien species has, therefore, primarily occurred near human populations, after which they have spread into natural and semi-natural areas (Da Rosa et al., 2017; Carpio et al., 2017a).

The impact and risk of biological invasions is particularly high in Latin America owing to its invaluable world biodiversity hotspots (Myers et al., 2000). However, the introduction of alien species has been poorly studied in this region (Speziale et al., 2012) compared to scientific production in the United States, Europe, or Australia. According to the Global Invasive Species Database (GISD), 283 of the 613 invasive species (46%) that are listed in the GISD are present in some Latin America and Caribbean countries (Pauchard et al., 2011), and 20% of the known world-wide mammal introduction events have occurred in Latin America (Novillo & Ojeda, 2008). In addition, at least 41 of the 100 of the world's worst invasive alien species are already established in Latin America (IUCN-ISSG, 2000). However, the role of intentional pathways as a source of alien species in Latin America has received relatively little attention (Speziale et al., 2012; Essl et al., 2015; but see; Buenavista & Palomares, 2018) and the information available is biased towards some specific regions, such as Chile (Jaksic, 1998; Jaksic et al., 2002; Iriarte et al., 2005), the Galapagos Islands (Toral-Granada et al., 2017), Argentina (Lizarralde et al., 2004; Bonino and Soriguer, 2009) or Brazil (Da Rosa et al., 2017). Information about alien species is, on the contrary, often scarce, inaccurate or reported only in grey literature (Pereira-Garbero et al., 2013).

Goods transported as a result of the intensive international trade have been identified as an important factor affecting the occurrence of invasive species (Hulme, 2009). The magnitude of merchandise imports, specially commodities is a significant determinant of the number of species (Westphal et al., 2008) as well as the rate of new species introductions of a wide range of alien taxa. Moreover, a further increase in the number of alien species can be expected when associated with the increase in gross domestic product (GDP) and trade (Pyšek et al., 2008; Hulme, 2009; Seebens et al., 2017), since GDP reflects levels of infrastructure (roads, canals, railways etc.) that can also facilitate invasions (Hulme, 2009). Cardador et al. (2019) demonstrated the magnitude of a trade ban as regards preventing biological invasions. Another important factor is the proportion of urban population (McKinney, 2009), since areas with dense human populations are relevant sources of alien species owing to: (1) the release and escape of alien species kept as pets (Spear et al., 2013), (2) the intensity of tourism, which is directly associated with both intentional and unintentional introduction pathways (Anderson et al., 2015) and (3) the intensity of anthropogenic disturbance, which can be considered as a proxy for the risk of invasion (Hulme, 2009; Spear et al., 2013; Carpio et al, 2017a).. Moreover, some studies indicate that areas with a higher biodiversity tend to host a higher richness of alien species on large spatial scales (e.g. Stohlgren et al., 2003, 2006; Fridley et al., 2007; Dyer et al., 2017a), since those areas with a high native diversity have a greater number of microniches (or more spatial heterogeneity), which would, therefore, allow a greater number of alien species to be accommodated (Davies et al., 2005). We accordingly predict that Latin America will possibly achieve the highest richness globally of alien species because of its great variety of niches and biodiversity, along with an increase in trade, GDP and other correlated activities (Speziale and Lambertucci, 2010).

In this paper, we aim to identify cases of alien species of birds and mammals that were introduced into Latin American countries through intentional pathways. Our specific objectives are: (1) to review the relative role of intentional introduction pathways (hunting, feeding, fur, biological control, the pet trade and others) in the context of alien species introductions; (2) to assess the relative importance of the intentional pathways across the different taxa; (3) to identify similar patterns in the composition of alien species across countries, (4) to assess the underlying factors that drive the richness of alien species in Latin America, and (5) to quantify the potential impacts of these species on this region.

MATERIAL AND METHODS

Data collection

We reviewed several lists of species introduced into South America, Mesoamerica and Caribbean Islands, which were obtained from scientific papers, books and technical reports (Kairo et al., 2003; Long, 2003; Lever, 2005; Flueck, 2010; Pimentel, 2014; Da Rosa et al., 2017; Dyer et al., 2017b; Buenavista and Palomares, 2018). We used the following search terms: "non-native species" OR "invasive species" OR "non-indigenous species" OR "alien species" OR "exotic species" OR "introduced species" AND "intentional purposes" OR "intentional introduction pathways" OR "hunting" OR "pet " OR "feeding" [or "feed" or "food"] OR "biological control" OR "fur" [or "fur trapping"] OR "acclimatization society" [or "rewilding" or "ecological replacement"] AND "mammal" OR "bird" AND "Latin America' OR "Central America" OR "South America" OR "Mesoamerica" OR "Caribbean Islands". We also used databases, such as the Global Invasive Species Database (''GISD'' http://www.iucngisd.org/gisd/), and those of the International Union for Conservation of Nature (''IUCN'' https://www.iucnredlist.org/), The Convention on International Trade in Endangered Species of Wild Fauna and Flora (''CITES'' https://www.cites.org/) the Invasive Species

Compendium (https://www.cabi.org/isc/), Inter-American Biodiversity Information Network (http://bd.institutohorus.org.br/www/), Global Avian Invasions Atlas (GAVIA http://dx.doi.org/10.6084/m9.figshare.4234850) and the Global Register of Introduced and Invasive Species (GRIIS http://www.griis.org/). The sources of information used for this study are shown in List S1a. Scientific papers addressing the introduction of species for intentional purposes were searched using three main web engines: Google Scholar™, ISI Web of Science® and Scopus®. All of this information was then combined to draw up a list of the species intentionally introduced into each country (Figure S3). Finally, only those species with a documented introduction pathway in any Latin-American country were included in Table S3. The species that are native to one part of Latin America but alien to another were included. Those species for which references concerned another introduction purpose (natural dispersal, accidental, stowaway, etc.) or when no reliable confirming references were found (databases without a reference to confirm it), were, however, rejected. Notwithstanding, several species required more detailed investigation to be considered as intentionally introduced species. Rodents (such as *Rattus rattus, Rattus novergicus, Peromyscus fraterculus* and *Mus musculus*) have been introduced into many areas around the world as a result of their having following humans (Atkinson, 1985; Pimentel, 2014) and were therefore not considered as intentional introduction. However, some species, such as *Rattus exulans, Cavia porcellus* and *Dasyprocta punctata,* have been introduced as a source of food (Fiedler, 1990) and therefore considered in this study. Another case is that of *Bubulcus ibis*, whose introduction may have occurred as the result of natural range extensions without human assistance (Kairo et al., 2003) and was not included in the study, or *Didelphius marsupialis*, which was introduced into the Lesser Antilles in Trinidad, although the species could be native (Long, 2003), or into Saint Lucia, where it is classified as native by some authors and alien by others (therefore we have considered it as alien), who believe that it was introduced by Amerindians (Caribbean Conservation Association, 1991). Therefore, species that were accidentally introduced have not been included in this analysis (e.g. *Mus musculus, Bubulcus ibis* or some species of the *Rattus* genus).

The biogeographic region from which each species was derived (native range according to IUCN and GISD) was also identified (Palaearctic, Nearctic, Afrotropics, Indomalaya, Neotropics, Australasia and Oceania). Those widespread species that occupy several regions were classified as either Holarctic, New World or multiregional (Abellán et al., 2016; see Fig. S1). Finally, we evaluated in which country or countries each species occurs in Latin America, according to GISD, GAVIA, GRISS and CABI (Fig. S3).

Intentional introduction pathways of alien species in Latin America

The term ‘introduction pathways’ describes the processes that result in the introduction of alien species from one geographical location to another (Richarson et al., 2011). A species may have different introduction pathways in different countries. The analysis was carried out for a species only when the main reason for its introduction was “intentional” mainly release and escape (Hulme et al., 2008): (hunting, feeding, pet/aesthetic, biological control, fur and others; Kraus, 2003) in at least one Latin America country. The ‘others’ group includes aspects such as scientific research, working animals or military activities (CBD, 2014). The introduction pathway relevant to each intentionally introduced species is documented in Table S3.

Relative importance of different taxa in the global introductions

In order to show the distribution of the different taxonomic groups (order or clade in the case of ungulates), the species were grouped as birds and mammals separately, along with their taxonomic group (Ungulates, Rodentia, Primates…). The number of aliens species intentionally introduced were classified according to the introduction pathways, although some species have multiple pathways of introduction and therefore were classified in more than one pathway (Table S3). In addition, we assessed taxonomic biases in the introduction of alien species at order or clade level by comparing the number of species per taxonomic group introduced intentionally with a random expectation generated using the hypergeometric distribution (Van Wilgen et al., 2010) in R v. 3.4.0 (R Core Team, 2017). The hypergeometric distribution is similar to a binomial distribution and describes the probability of a given number of successes given a specified number of draws, without replacement. In this instance, a set number of species are sampled from a pool of orders and clades of known size (species available per clade worldwide). Taxonomic groups outside the 95% confidence intervals were deemed to be either over- or under-represented in the introduction process, compared to expectations based on the size of the order or clade and the total number of species that were introduced intentionally (Van Wilgen et al., 2018).

Composition of alien species introduced intentionally throughout the countries

Similarities in the composition of alien species introduced intentionally throughout the countries studied were explored by using clustering analyses. A visualisation of the five closest Euclidean distances to each country is shown by means of a network plot. The elements were clustered by employing hierarchical clustering, using the Ward method and Euclidean distances (Fig. S3). The Euclidean distance between two countries is based on a multidimensional imaginary space in which each coordinate is the presence/absence of an alien species (Fig. S4). The distance between two elements (two countries in our case) is calculated using function 1, where n is equal to the number of variables (in our case, alien species), and p and q take two values according to the presence/absence of each species (1,0) on each one of each couple of countries (p and q) (Carpio et al., 2019; Oteros et al., 2019).

$$\mathrm{d}(\mathbf{p},\mathbf{q}) = \mathrm{d}(\mathbf{q},\mathbf{p}) = \sqrt{(q_1 - p_1)^2 + (q_2 - p_2)^2 + \cdots + (q_n - p_n)^2}$$

$$= \sqrt{\sum_{i=1}^{n}(q_i - p_i)^2}.$$

The analyses were computed by using R statistical software (R Core Team, 2017). The most relevant packages where from the family tidyverse (Wickham, 2016; 2017), circlice (Gu et al., 2014) and cluster (Maechler et al., 2018).

Factors that drive intentionally introduced species richness in Latin America

The underlying factors driving the richness of alien species introduced intentionally per country were determined by performing two Generalised Linear Models (GzLM) using the total number of alien bird species introduced into each country (Model 1) and the total number of mammal species introduced into each country (Model 2) as response variables. Country size, percentage of rural population (refers to the population in areas that have a lower population density than urban areas and are spread over a larger area out than urban centres), No. of pieces confiscated / million inhabitants (quantity of specimens reported as imports by the importing country), No. of trafficked species / million inhabitants, % of GDP imports (% of GDP due to imports) and the gross domestic product (GPD) per capita were included as explanatory variables in the models (the data sources are shown in List S2). In addition, a third GzLM was performed with the number of species established in each country (Model 3) as response variable. In this model, number of species of native birds, species of native mammals and total number of intentional introduced alien species were included as explanatory variables. All models were fitted with a gamma distribution and with a log link. The most plausible models were selected by comparing Akaike's information criterion (AIC) in the models (Burnham and Anderson, 2002), following a backward procedure (Zuur et al., 2009). In particular, we compared the Akaike information criteria for small sample sizes (AICc value) in each candidate model and the best model (that with the lowest AICc). Statistical analyses were performed using InfoStat software (Balzarini et al., 2008).

Impacts of the alien species introduced intentionally

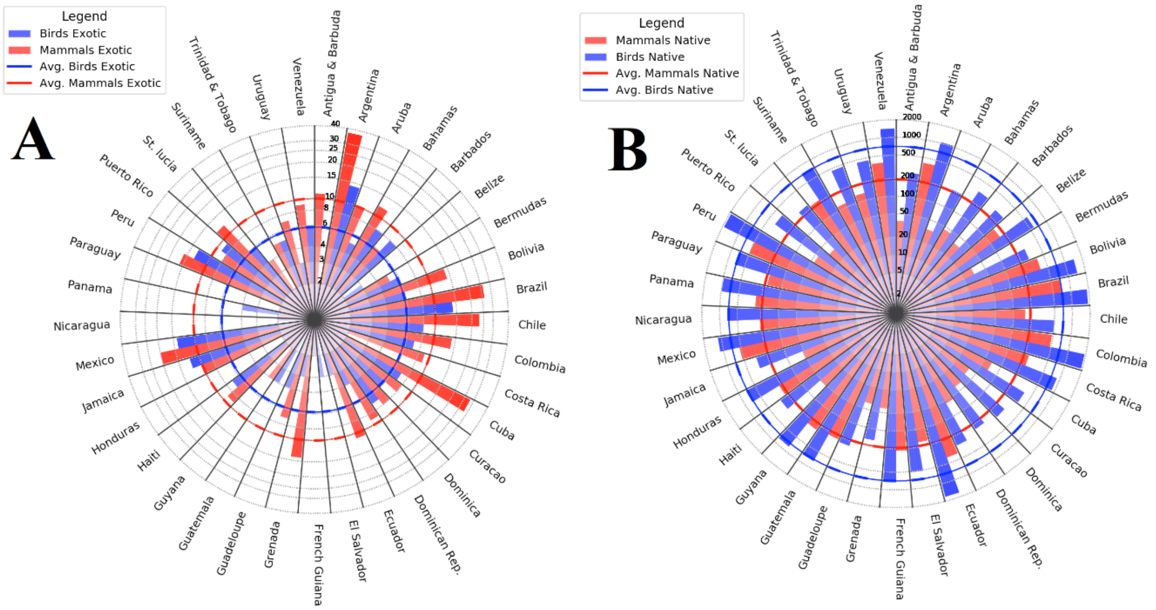
Many introduced species commonly have a high reproductive rate, which is one of the reasons why they are commercially exploited for sport hunting, feeding, or fur resources (Stokes et al., 2006). The impacts of each species were obtained by using the scientific species name and impacts as a search term in databases such as Google Scholar, ISI Web of Knowledge and databases above mentioned, manually filtering through the sources identified by reading titles and (if applicable) abstracts (List S1c). The impacts were grouped into three categories: environmental, economic, or health impacts (according to Vilà et al., 2009; Keller et al., 2011; Kumschick et al., 2015). Environmental impacts include hybridization, a reduction in native biodiversity, the modification of hydrology/water regulations, purification and quality/soil moisture, the modification of nutrient pools and fluxes, habitat degradation and the modification of successional patterns. Health impacts include disease transmission and parasitism, while economic impacts include damage to agriculture/forestry, a reduction in/damage to livestock and products, human nuisance, damage to aquaculture/mariculture/fish, damage to infrastructures, alteration of recreational use and tourism, and other economic impacts (Mack et al., 2000). Therefore, the number of species that has each type of impact were determined, although some species may have more than one impact (Table S4). In addition, we used the Socio-Economic Impact Classification of Alien Taxa (SEICAT) and Environmental Impact Classification of Alien Taxa (EICAT) to determine the magnitude of socio-economic and environmental impacts respectively (Table S3), and to classified the species in six categories (massive: MV, major: MR, moderate: MO, minor: MN, minimal concern: MC and data deficient: DD) according to Bacher et al. (2018) and Blackburn et al. (2014).

RESULTS

General distribution patterns of intentionally introduced species

According to our results, 69 species of mammals and 62 species of birds were intentionally introduced into some Latin American countries. Of the 131 aliens species, 11 (ten mammals and one bird) are included in the list of the 100 of the world's worst invasive alien species (Luque et al., 2013). However, the introduction of these species has not been spatially uniform, and countries such as Argentina, Brazil, Cuba, Mexico or Chile stand out in this respect (30 or more intentionally introduced species). On the contrary, other countries such as Nicaragua, El Salvador, Honduras, Paraguay or French Guiana have a lower incidence of species introductions (Fig. 1). Although this may also be due to the lower scientific production in these countries.

Figure 1. *Number of aliens´ species of mammals and birds per country (A), and number of native species of mammals and birds per country (B). The data are shown on a logarithmic scale.*



Furthermore, this pattern is not the same for birds and mammals. For example, in the case of birds, countries such as Peru, Mexico, Brazil, Argentina, and islands such as Puerto Rico, Jamaica, the Bahamas or Barbados, stand out in terms of the number of aliens' birds (Fig. 1A). In contrast, in the case of mammals, countries such as Argentina, Brazil, Chile, Cuba, Peru, Mexico, Grenada or St. Lucia harbour a large variety of intentionally introduced species (Fig. 1A). However, normalized intentionally introduced alien species values (nº alien species intentionally introduced/ land area of the country in km^2; Turbelin et al., 2017) show that tropical islands such as Bermuda, Aruba, Grenada or Antigua & Barbuda have highest ratio of alien species per land area of the country (between 0.1 and 0.025 species/km^2 for these four islands). In contrast, the countries with the lowest ratio of alien species per land are of the country were Brazil, Paraguay, Nicaragua, Guatemala or Venezuela (<0.00001 species/km^2). The origin of these species is also highly heterogeneous. The Neotropics biogeographic region stands out as the source of the majority of introduced species (34%). It is followed by Indomalaya (18.3%), the Palearctic region (14.5%) and the Afrotropic region (9.9%) (see Fig. S1).

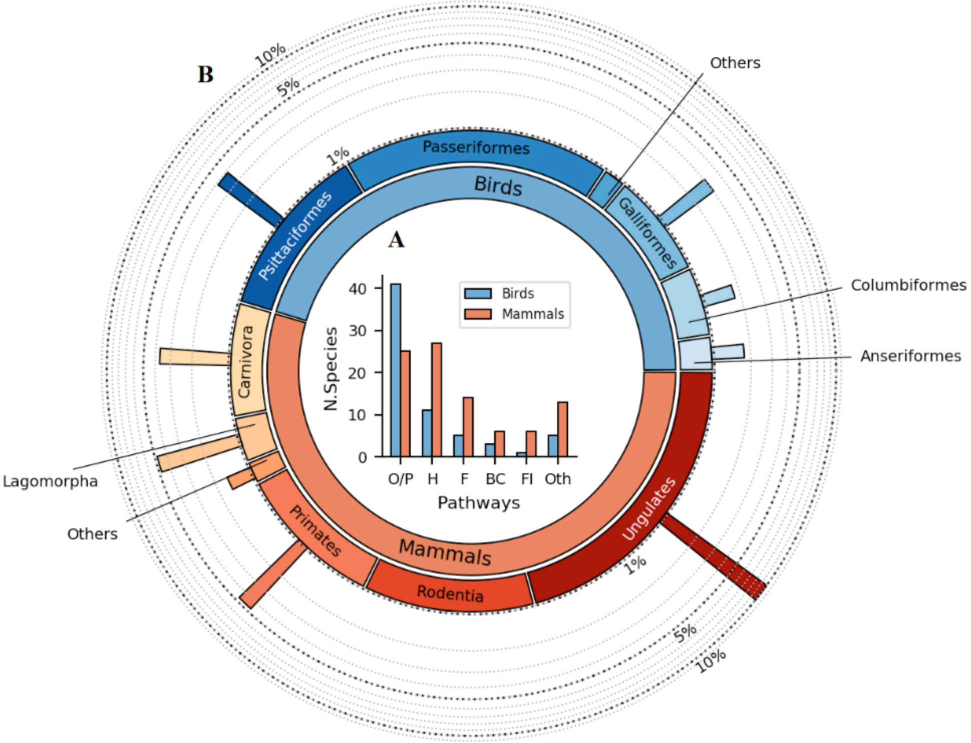
Role of intentional introductions pathways in the context of alien species introductions

Of the 131 introduced species, 42.6% were introduced as pets or for aesthetic purposes (especially cage birds, 22%), while 23.7% are currently exploited as hunting species (Figure 2B). We specifically noticed that of the 69 mammals and 62 birds introduced into Latin America (Fig. 2B), 27 mammal species (39%) and 13 bird species (22%) were introduced primarily for hunting purposes, 11.2% were released for feeding purposes, 5.3% for biological control, 4.2% for fur industry and 13% for others intentional purposes (research, military, working animals…) (Fig. 2B). Overall, our results further show that aesthetics and the pet trade were the most important pathways in the case of birds (at least 75% of the introduced species), while hunting was the main reason in the case of the introductions of mammals (39% of introduced species). (Fig. 2B).

Relative importance of different taxa

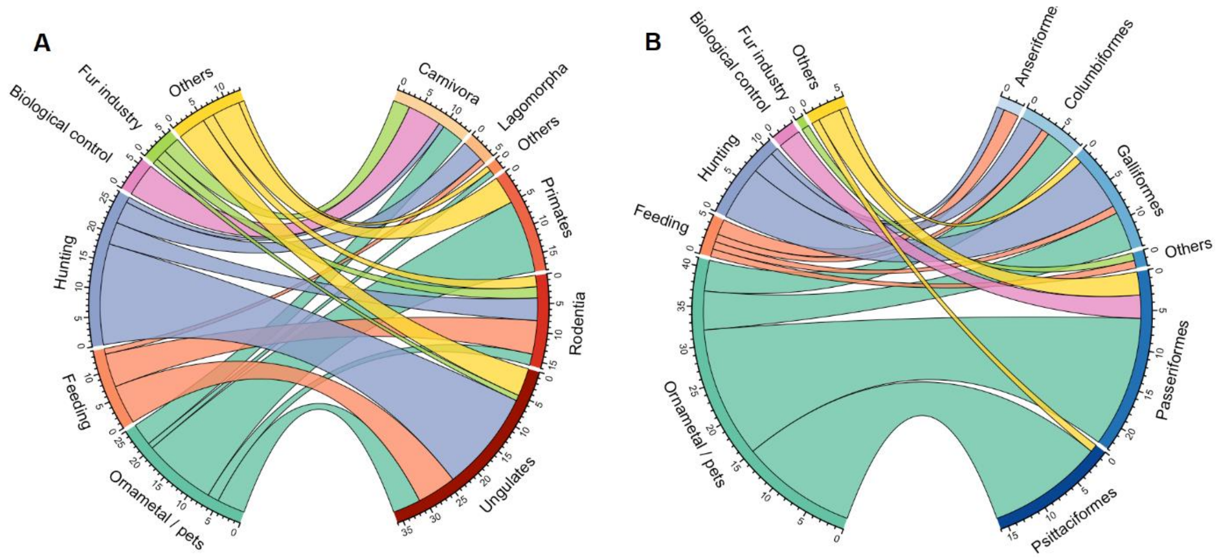
According to our results, 69 species of mammals (52.7%) and 62 species of birds (47.3%) were introduced by means of multiple intentional pathways (Fig. 2A). Most of the introduced mammal species were ungulates (n= 27) (Fig. 2B). In this respect, ungulates represent 39.1% of all the mammal species introduced into Latin America, where at least 18 species have been introduced as hunting species (Fig. 3A). Another well-represented group of mammals was that of primates, and at least 14 species were introduced for intentional purposes (pet/research/experimental), representing 20.3% of the introduced mammals (Fig. 2B). Rodents are also noteworthy, with 12 species (with different purposes: feeding, hunting, fur), which represented 17.4% of the mammals introduced (Fig. 2B).

Figure 2. *A) Proportion of species from different taxonomic groups of birds and mammals that were, according to our review, intentionally introduced into Latin America. Vertical bars indicate the proportion of alien species in a group/total number of species in that group * 100 (in logarithmic scale). B) Number of species introduced based on the introduction pathway: O/P=Ornamental/Pet; H=Hunting; F= Feeding; BC=Biological control; FI=Fur industry and Oth = Other pathways, for birds and mammals separately.*



Our results further show that the majority of intentionally introduced bird species belong to two orders: Passeriformes and Psittaciformes, accounting for 38.7% and 25.8% of the total number of introduced bird species, respectively (Fig. 2A). The main introduction pathway for these two taxa was the pet trade/aesthetic purposes (90% of species) (Fig. 3B). Galliformes is also a very important taxon, with a total of 9 introduced species (14.5% of the introduced birds). However, Ungulates and Psittaciformes are the most introduced groups, the number of species from these groups present in Latin America countries actually over-represents these groups (Ungulates and Psittaciformes). When comparing the number of introduced species in relation to total available species within such taxa in the world, both groups are overrepresented in the Latin America (10% and 4%) of species from these respective groups occur in at least one of the countries included in this review (Figure S3). Instead, Rodentia and Passeriformes are the largest mammals and birds' groups and as such, the number of species from these groups were under-represented (only 0.6% and 0.4% of species from these groups were intentionally introduced in at least one country).

Figure 3. *The number of exotic species intentionally introduced by introduction pathways to a taxonomic group using chord diagrams: A) mammals, B) birds. The sources of information used for this analysis are shown in List S1a.*

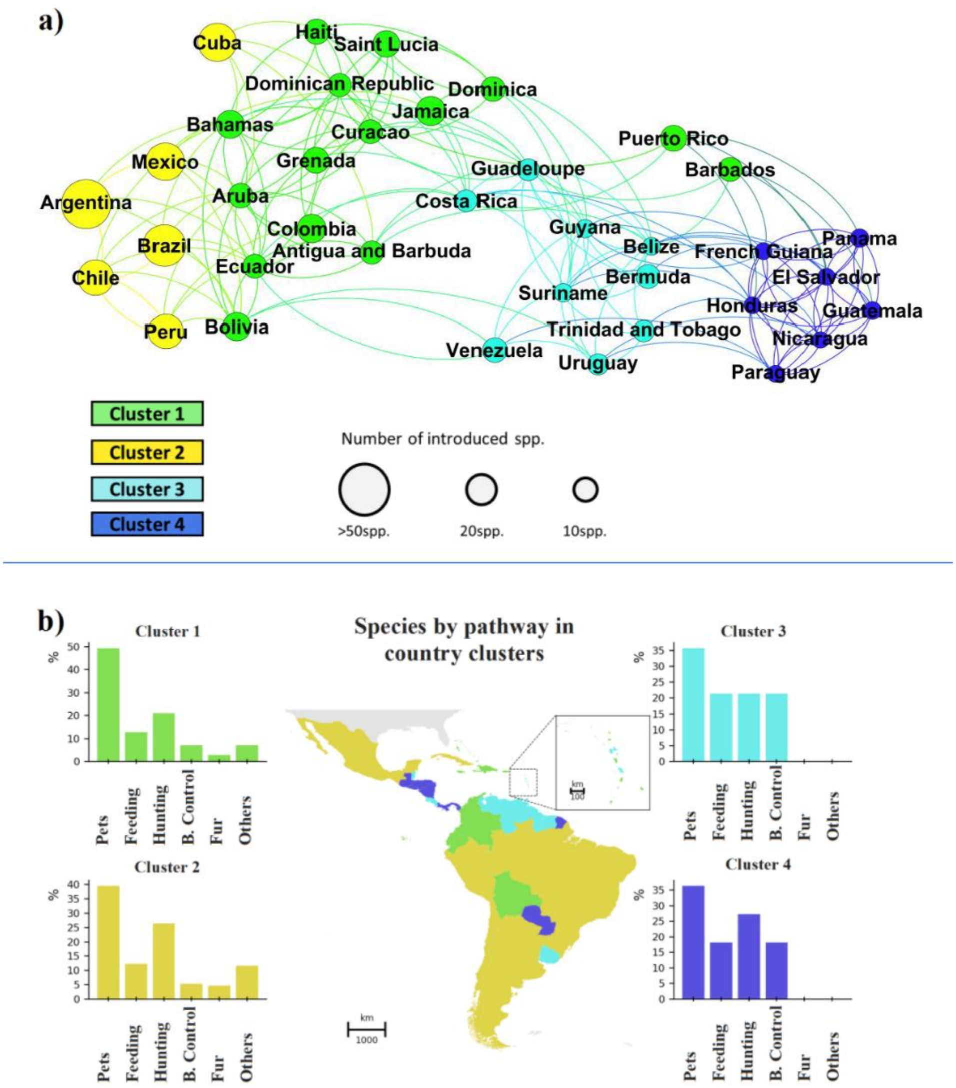


Composition of intentionally introduced species throughout the continent

The clustering analyses carried out grouped different countries according to the similarity of the intentionally introduced species in their territories (Fig. 4A). Countries were grouped in 4 clusters (Fig. S2A, S2B), and some countries had intermediate features: i.e. Puerto Rico and Barbados belong to cluster 1, although the distance between them and the rest of the cluster is greater than that of the other countries (Fig S2B). The network plot displays those countries between cluster 1 and cluster 4. Costa Rica and Guadeloupe in cluster 3 are, similarly, transitional cases between clusters 3 and 1. C1 is formed of large countries into which the greatest number of species was introduced (Fig. S3). In Figure 4A, each cluster is represented by a different colour. All the countries are clustered in four groups. The closer the countries in the figure, the more similar they are in terms of alien species. The farther the countries in the figure, the more different they are. For example, Guatemala and El Salvador are located both countries very close in Cluster 4, meaning that both have similar amount and kind of alien species introduced. Argentina and Chile are also together in Cluster 2. Keeping the same example, the couple of countries Guatemala-El Salvador are very far from the couple Argentina-Chile, meaning that the features of the species invasion are very distant. The main introduction pathway in all the clusters was the pet/ornamental trade, followed by hunting.

Feeding and biological control were also an important pathway, especially in C3 and C4. However, other pathways stand out in C2 (Fig. 4B).

Figure 4. *A) Network plot showing countries distributed according to the composition of intentionally introduced species. The five closest Euclidean distances to each element are represented. The size of the nodes is related to the amount of species (Max: 55 Argentina, Min: 3 Nicaragua), while the longitude of the edges is related to the Euclidean distance between the two connected nodes. The Euclidean position of the elements is used for clustering: Cluster 1 (green), cluster 2 (yellow), cluster 3 (light blue) and cluster 4 (dark blue). B) Percentage of intentionally introduced species by means of different introduction pathways in each cluster. Map representing the clusters of grouped countries. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)*



Factors that drive intentionally introduced species richness in Latin America

The factors retained in the best models (Models 1 and 2) employed to assess the effect of countries' characteristics on the total number of alien bird and mammal species intentionally introduced into each country are shown in Table 1. The results show that the % of GDP imports was statistically and positively associated with the total number of introduced bird species per country, while the % of rural population and number of pieces confiscated / million inhabitants were negatively related to this variable (Model 1). Furthermore, the number of mammals' species introduced per country was positively affected by the number of trafficked species / million inhabitants, whereas it was negatively associated with the % of rural population and number of pieces confiscated / million inhabitants (Model 2). Regarding the number of established species (Model 3), the results show that the three variables (number of native bird and mammal species and total number of introduced species) positively affected this variable (Table 1). However, the variable with the greatest effect was the number of species introduced (F = 108.9; p <0.001)

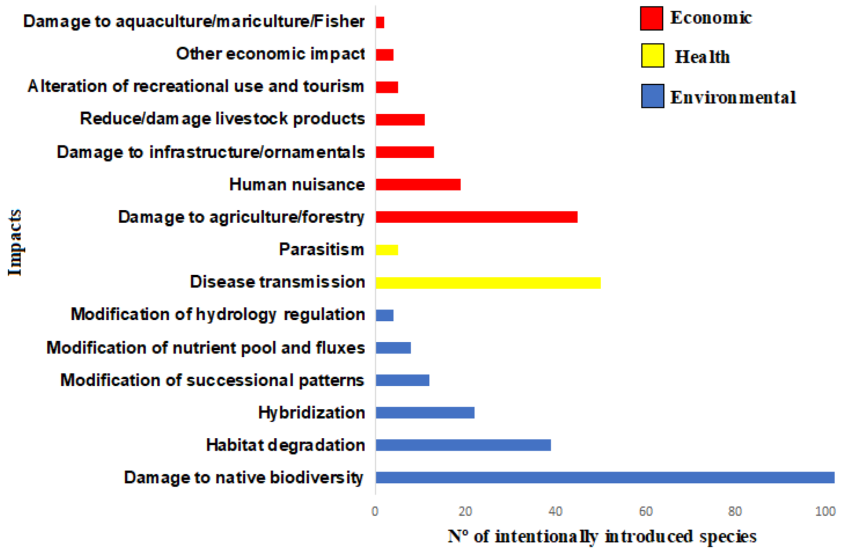
Table 1. *Best models explaining the number of intentionally introduced alien bird (Model 1), alien mammal (Model 2) and number of established species (Model 3) in each country.*

Variable	Estimate ± S.E.	*F*-value	*p*-value
Number of intentionally introduced species of birds (Model 1)			
Intercept	2.8 ± 0.24	11.64	<0.001
% GDP imports	0.002 ± 0.01	19.5	<0.001
No. of pieces confiscated / million inhabitants	-0.005 ± 0.006	6.65	<0.01
% Rural population	-0.02 ± 0.01	4.91	<0.05
Number of intentionally introduced species of mammals (Model 2)			
Intercept	3.88 ± 0.33	11.73	<0.001
% Rural population	-0.07 ± 0.01	28.2	<0.001
No. of trafficked species / million inhabitants	0.06 ± 0.02	10.92	<0.01
No. of pieces confiscated / million inhabitants	-0.018 ± 0.005	10.36	<0.01
Number of established species (Model 3)			
Intercept	1.20 ± 0.14	70.31	<0.001
No. of introduced species	0.07 ± 0.01	108.87	<0.001
No. of species of native mammals	0.004 ± 0.001	9.57	<0.01
No. of species of native birds	0.001 ± 0.0004	6.17	<0.05

Potential impacts of species intentionally introduced into Latin America

Finally, in this study, the impacts of these species are quantified according to the sources of information consulted (List S1c). Of the 131 species introduced intentionally, the results show 335 potential species-impacts (expressing that each species causes impacts in more than one category; Fig. 5). The greatest number of species-impacts (measured as the number of species in each category) are on the ecosystem (185 species-impacts), followed by economic impacts (97 species-impacts) and health impacts (53 species-impacts). Of the environmental impacts, the reduction in native biodiversity stands out (with 101 species-impacts), while with regard to the impacts on health, impact disease transmission stands out (48 species-impacts) and damage to agriculture/forestry was the main economic impact (44 species-impacts).

Figure 5. *Number of species intentionally introduced according to the impact generated.*



In addition, suitable data for socio-economic and environmental impacts was found in literature and database involving 95 species (72.5%) with EIACT and 69 species (52.7%) with SEICAT (List S1c). Most alien mammals and birds had low impacts, categorized as either minimal concern (MC) or minor (MN) (51.04% for EIACT) and (53.62% for SEICAT). However, 28 and 21 species had (MO) impacts (EIACT and SEICAT, respectively), 9 with major (MR) and 9 with massive (MV) and 10 with major (MR) and 1 with massive (MV) environmental and socioeconomic impacts, respectively (Table S3).

DISCUSSION

General distribution patterns of intentionally introduced species

The Convention on Biological Diversity (Aichi target 9) states that ‘by 2020, invasive alien species and pathways must be identified and prioritised (UNEP, 2011-2020). The identification of the introduction pathway can inform management strategies that in turn can reduce the number of alien species (i.e. colonisation pressure) and individuals (i.e. propagule pressure) introduced (Hulme et al., 2008; Pergl et al., 2017). This work provides the first assessment of the introduction pathways for exotic mammals and birds in Latin America, which, together with earlier national contributions (Jaksic, 1998; Jaksic et al., 2002; Kairo et al., 2003; Novillo and Ojeda, 2008; Ballari et al., 2016; Da Rosa et al., 2017; Toral-Granda et al., 2017), broadens our understanding of the biological invasion pathways in the region.

Alien species have only recently (last 25 years) been considered as a problem for biodiversity in Latin America (Rodríguez, 2001; Speziale and Lambertucci, 2010; Ballari et al., 2016; Buenavista and Palomares, 2018). The International Council for Science (ICSU) has recognised that information on invasive species in this region is highly asymmetrical between the countries in terms of what information exists, what is readily available in each country, and research breadth (ICSU, 2017). In addition, Latin America has historically been a region into which many mammals and birds have been introduced since European colonisation (Crosby, 2003). According to our review, 69 mammal and 62 bird alien species were intentionally introduced into Latin America. Of the 869 alien and invasive species that negatively impact biodiversity found in GSID (including all taxa), 498 (57%) are registered as invasive in one or more countries/territories in Latin America (including all taxa), of which 41 appear in the list of 100 of the World’s Worst Invaders, and 11 were intentionally introduced (Luque et al., 2013).

Role of intentional introduction pathways in the context of alien species introductions

According to our results, pet and ornamental traffic and hunting were the two most important introduction vectors for birds (44 and 12 species, respectively) and mammals (27 and 26 species) (Fig 3A, B). This is of particular concern in Latin America, where pet keeping is popular, and is consequently increasing the consumer community for exotic pets, mainly birds (Alves et al., 2010; Bush et al., 2014). These results also coincide with Kraus (2003) or Carrete and Tella (2008), who showed that hunting and the pet trade were the dominant pathways for bird introduction (76% of the birds introduced), while feeding and hunting are the main reasons for the introductions of mammals (Goss and Cumming, 2013). Similar results were also found by Carpio et al. (2017b) in Europe, where 24% of the mammals and 30% of the birds introduced were released for hunting purposes. With regard to food production, Hulme et al (2008) pointed out in a review that feeding and hunting were the primary introduction pathways for birds and mammals. In our case, feeding was the third most important reason for the introduction of mammals, with 14 species.

Relative importance of different taxa

Our review shows that the introduction of these species has been biased towards several wildlife orders, mainly Artiodactyls, Primates, Passeriformes and Psittaciformes (Fig. 2A). Ungulates stand out from the others (39% of the introduced mammal species), probably because of their importance in sport hunting (Spear and Chown, 2009; Flueck, 2010) and for feeding (Jenkins, 1996). The Primates constituted the mammal order with the second most introduced species (n=14), mainly for the pet trade and research experiments. The most common species of primates introduced for experiments are *Chlorocebus aethiops*, *Macaca mulatta*, and *M. fascicularis* (Carlsson et al., 2004). Bush et al. (2014) showed that the mammals most frequently introduced as pets were primates and carnivores. This study also showed that Parrots (*Psittaciformes*), and songbirds (*Passeriformes*), were the most common avian orders in the pet trade, which is in line with our results, in which Psittaciformes and Passeriformes represented 41.9% and 25.8% of the total bird species. Similar results are shown in Abellán et al*.* (2016), in which 70% of bird species introduced belonged to just three orders (Passeriformes, Psittaciformes and Anseriformes), and were introduced primarily as cage birds and ornamental species.

The overrepresentation of some taxa is shown in Figure 2A. Parrots (pet trade) and Ungulates (hunting purposes) were reported more often than randomly expected (Bush et al., 2014), while other orders such as Passeriformes or Rodentia are underrepresented, principally owing to the large number of species in these taxa (Van Wilgen et al., 2018).

Composition of intentionally introduced species throughout the continent

We found well defined clusters of countries as regards the composition of intentionally introduced species (Fig. 4). Cluster 1 is formed mainly of Caribbean countries and the main reason for introducing species into those countries was ornamental/pets (~50% of the cases). This cluster is also characterised by a larger proportion of introduced bird species. Cluster 2 is formed of the largest countries, i.e. Argentina, México and Brazil. Hunting was a key reason for introducing species into these countries (>25% of the cases). Clusters 3 and 4 are quite similar as regards the composition of introduced species. Both clusters are formed of Caribbean countries, although islands (e.g. Guadeloupe, Belize, Bermuda, Trinidad and

Tobago, …) and south American countries (e.g. Guyana, Suriname, Venezuela, ...) are more common in cluster 3 and those from central America (e.g. Panama, Guatemala, El Salvador…) are more common in cluster 4. The pathways Feeding and Biological control are very high in both clusters.

Factors that drive intentionally introduced species richness in Latin America

The country size variable was not retained in any model, therefore the spatial distribution of intentionally introduced species is independent of the size of the country. Larger continental territories often receive similar numbers of introduced species to smaller islands (Van Klunen et al., 2015; Dawson et al., 2017; ICSU, 2017) because tropical and temperate oceanic islands seem to be especially sensitive to alien species (Loehle and Eschenbach, 2012). However, Argentina (37 species), Brazil or Chile stand out as regards the introduction of mammals (Novillo and Ojeda, 2008; Da Rosa et al., 2017; Jaksic, 1998). According to ‘‘extinction-based saturation’’, which is consistent with Island Biogeography Theory (IBT) the total number of species present in an area could be maintained as a balance between extinction and colonization. One possible explanation for the lack of relationship between area and number of alien species is that biotic exchange when intentionally promoted by humans has little to do with the size of a country (Weber, 1997; ICSU, 2017).

Interestingly, countries with a higher rural population, such as Guatemala, Belize or Guyana, were characterised by a low number of intentionally introduced species, which reflects an increasing social demand for pets in largely urban societies (Carrete and Tella, 2008), unlike rural societies, which have a wide range of local pets (Paul and Serpell, 1982). Because of the intentional nature of these introduction pathways, those areas in which concentrated anthropogenic activities take place are, therefore, points of entry or release for alien species (Padayachee et al., 2017). This also concurs with the result that the % of GDP owing to imports is related to the number of aliens species, which is directly related to the transportation and movement of different products. Hulme (2009) showed that the exposure of economies to trade is highlighted by the significant role of merchandise imports in biological invasions, particularly in the case of island ecosystems. This result also coincides with those of Westphal et al. (2008) or Marini et al. (2011), who showed that the value of merchandise imports was a strong predictor of the number of exotic species. Our results coincide with those of these authors since country area or GDP per capita were not found to be important determinants of a country’s degree of biological invasion. With regard to border controls, our results also show that the highest number of intentionally introduced species (birds and mammals) appears in countries with a lower number of pieces confiscated/million inhabitants, which may be owing to the lack of border controls. Recently, Cardador et al. (2019) demonstrated the effectiveness of a trade ban as regards preventing biological invasions. However, a regional ban can produce geographic redirections in trade, with important consequences for a worldwide invasion risk (Cardador et al., 2017), i.e. a redirection of trade toward developing countries or less regulated countries. Contrary to this, the number of trafficked species/million inhabitants was positively associated with the number of alien species of mammals, which is not surprising since the greater the number of species, the greater the risk of escape or release (Rosen and Smith, 2010). On the other hand, a significant predictor of number of established alien species was the number of native species (both birds and mammals), which had a positive relationship with the number of established alien species. This result coincides with the "the rich get richer" acceptance hypothesis, which predicts a higher number of established alien species in areas in which there is a high diversity of native species (Stohlgren et al., 2003, 2006; Fridley et al., 2007), since those areas with a high native diversity have a greater number of microniches (or more spatial heterogeneity), which would, therefore, allow a greater number of alien species to be accommodated (Davies et al., 2005). In addition, as expected, the number of introduced species was positively related to the number of established species. As the number of releases and/or the number of individuals released increases, propagule pressure also increases (Lockwood et al., 2005).

Potential impacts of intentionally introduced species in Latin America

Several studies have reported the impacts of alien mammals' species in the region. The European rabbit has impacted on a large part of Chile (Iriarte et al., 2005) or Argentina (Bonillo and Soriguer, 2009). Barrios-Garcia and Ballari (2012) showed the impacts of wild boar on the economy (crop damage), health (transmit diseases) and the environment in the form of the predation of some animal communities. Other studies, such as that by Flueck (2010), show the impacts of a certain group (Ungulates), or in a certain region (mammals in Argentina, Chile and Uruguay: Ballari et al., 2016). Information on birds is much more limited in the region, although species such as *Passer domesticus* or *Columbia livia* could potentially displace native passerines through competition for food or transmit parasites and diseases to native avifauna (Valenzuela et al., 2014).

The most common impacts of animal species are through changes in native biodiversity and habitat degradation (Ehrenfeld 2010). Simberloff (2011) suggested that most invasions produce impacts on ecosystems, although many of these impacts are idiosyncratic, subtle or indirect. This author also proposes that the lag phenomenon in invasions implies that at least some existing alien species that are currently having little or no impact will eventually have much greater ones. It is, therefore, possible to predict that many alien species whose impact has not yet occurred or has not yet been recognised will eventually have impacts on ecosystems, which is very worrying in such a mega-diverse region.

CONCLUSIONS

Understanding the introduction pathways of alien species implies carrying out risk assessments, management, monitoring, and surveillance (Essl et al., 2015). This is especially important in Latin America, since it is one of the most biodiverse places in the world (Myers et al., 2000). In this respect, our review shows that countries with a higher rural population are characterised by a low number of intentionally introduced species, while there is no relationship between area and number of alien species. The results also show a higher number of alien species in areas with high native species diversity.

We recommend improvements to risk assessment and education in order to prevent escapes and translocation, and prioritised inspection strategies to reduce intentional introductions, since the % of GDP owing to imports was an important predictor of alien species. The traffic reports of CITES species should also be improved or increased, since the number of animals confiscated was related to a lower introduction of alien species (Cardador et al., 2019).

NESTING FAILURE OF SEA TURTLES IN ECUADOR – CAUSES OF THE LOSS OF SEA TURTLE NESTS: THE ROLE OF THE TIDE

CAPÍTULO 2

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Nesting failure of sea turtles in Ecuador - causes of the loss of sea turtle nests: the role of the tide

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Nesting failure of sea turtles in Ecuador - causes of the loss of sea turtle nests: the role of the tide

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ABSTRACT

The nesting environment is known to significantly affect the breeding success of sea turtles. Sandy beach habitats, where sea turtles nest, are frequently affected by high tides and waves on Ecuadorian beaches during windy events. The objectives of this study were: i) to determine the variables that affect nest site selection by two sea turtle species, Eretmochelys imbricata and Chelonia mydas in Ecuador, ii) to compare features of the nesting places of successful vs. failed clutches and iii) to quantify the changes in the intensity and frequency of the tide and its relation to the loss of eggs for the last 10 years. We monitored 15 hawksbill and 26 green turtle nests for two years on five beaches on the mainland coast of Ecuador. The results show that the presence of a dune scarps negatively affected successful nesting, while the proportion of eggs lost was positively associated with road distance, sea distance and nest depth. In addition, the results showed that the loss of eggs was greater for the green turtle, the presence of dune scarps and tides. Finally, using the data available on hatching success over the last 10 years we found a significant relationship between the intensity of the tides and the loss of eggs during this period. We conclude that nest site selection and hatching success vary with beach microhabitats and therefore local information is needed to protect suitable habitats.

Keywords: Anthropized beaches, *Chelonia mydas*, Climatic change, Dune scarps, *Eretmochelys imbricata*, Nesting

INTRODUCTION

Sea turtles are a classic example of a widely distributed group that has historically suffered from declining populations (Jackson et al. 2001). According to the International Union for Conservation of Nature (IUCN, 2019) approximately 62.8% of sea turtle populations suffer a certain degree of threat, of which 19.4% are classified as critically threatened, 17.4% as threatened and 30% as vulnerable (Gibbons et al. 2000). Despite this, recent studies such as Mazaris et al. (2017) or Valdivia et al. (2019) have documented an estimated increasing, rather than decreasing, trend in population size in sea turtles across the globe, which they attribute to the effective protection of eggs and nesting females, as well as the reduction of by-catch (Finkbeiner et al. 2011). On the other hand, although by-catch and direct exploitation for meat and eggs has been reduced (Ceriani et al. 2019), several other anthropogenic threats continue to cause concern such as: tourism, habitat lost, urbanization, coastal light pollution or the collection of adults and eggs (Wallace et al. 2013; Brei et al. 2016; Sella and Fuentes 2019; Arlidge et al. 2020).

One of the most prominent negative factors affecting sea turtles worldwide is climate change (especially climate warming; Esteban et al. 2018). However, the negative effect of global warming and subsequent effects may also significantly affect migratory reptiles such as sea turtles because of the stressful thermal conditions during nesting (Mitchell et al. 2008; Telemeco et al. 2013). Nest-site placement by the female strongly affects the hatching success due to the physical locations of the nest (such as altitude, moisture, salinity, or slope; Wood and Bjorndal 2000) and local environmental conditions (climate influences; Hawkes et al. 2007; Pike 2013; Tomillo et al. 2015; Rivas et al. 2019).

Extreme weather events (Dewald & Pike 2014), rising water table levels by protracted precipitation (Rivas et al. 2018), tides (Palomino-González et al. 2020), rising sea levels (Fish et al. 2005), or beach erosion (Mazaris et al. 2009) may also be affecting sea turtle populations. Seasonal disturbances are among the most common and destructive (Goldenberg et al. 2001; Webster et al. 2005; Pike & Stiner 2007) and can be particularly devastating for populations because they often coincide with the reproductive seasons (Spiller et al. 1998; Schoener et al. 2004; Tomillo et al. 2020). Previous studies have shown that warmer temperatures can influence post-hatch growth rates (Marn et al. 2017; Rivas et al. 2018) and hatchling locomotor performance (Booth et al., 2013); thus, warmer temperatures result in slower growth for some species (Layfield et al. 1991; Rivas et al. 2019). Pike (2014) demonstrated that loggerhead sea turtle populations in the tropics produce nearly 30% fewer hatchlings per nest than temperate populations. For example, Tanner et al. (2019) estimated that there is currently an 84% chance of hatchlings being female across the Cape Verde population of *Caretta caretta,* which will reach over 99% female, with >90% of nests incubating at lethally high temperatures. Similar results are found in Costa Rica for the *Dermochelys coriacea* with an 85% bias towards females (Tomillo et al. 2018).

To minimise nesting failure in sea turtles at the time of incubation, conservation plans include management of nesting beaches, translocation of nests to protected hatcheries, reduction or destruction of natural predators (Marine Turtle Specialist Group 1995), as well as maintaining a permanent presence on beaches where poaching pressure is high (Tomillo et al. 2017). However, some factors such as the increase and intensity of tides (Caut et al. 2010), as well as rising sea levels (Fuentes et al. 2010; Katselidis et al. 2014) or the formation of dune scarps ``where the tides create a berm-like impediment to progress up the beach in the sand´´ (Witherington et al. 2011; Rivas et al. 2016; Kelly et al. 2017), are difficult to predict and therefore it is very difficult to avoid nest losses. For example, Caut et al. (2010) found that the hatching success was, on average, significantly lower in flooded nests than in non-flooded, highlighting the existence of embryonic developmental arrest due to tidal inundation.

In sea turtles, nest site selection is influenced by a balance between forces that drive nest placement inland (inundation and egg loss due to sand erosion) (Wood and Bjorndal 2000). Another important factor is the distance to vegetation, since nests are clumped close to the border between the open sand and the supra-littoral vegetation that back the beaches (Hays et al. 1995), as well as a low slope (Garmestani et al. 2000; Wood and Bjorndal 2000). This is an important factor in the conservation of hawksbill sea turtles, since it increases the amount of non-hatched eggs, negatively influencing the hatching success of this species (Serafini et al. 2009). Patrício et al. (2018) showed that females tended to nest close to the vegetation (the contrary to what was found in the hawksbill turtle by (Serafini et al. 2009), above the highest spring tide, which enhanced clutch survival. Finally, the proximity of turtle nests (and surrounding beach locations) to urban areas and their exposure to artificial light, can also affect the selection of nesting sites (Kelly et al. 2017).

In Ecuador, the green turtle (*Chelonia mydas*) and the hawksbill turtle (*Eretmochelys imbricata*) nesting activity occurs along the continental Ecuadorian coast (Alava et al. 2005), mainly in the Machalilla National Park, a protected coastal zone (Barragan 2003).

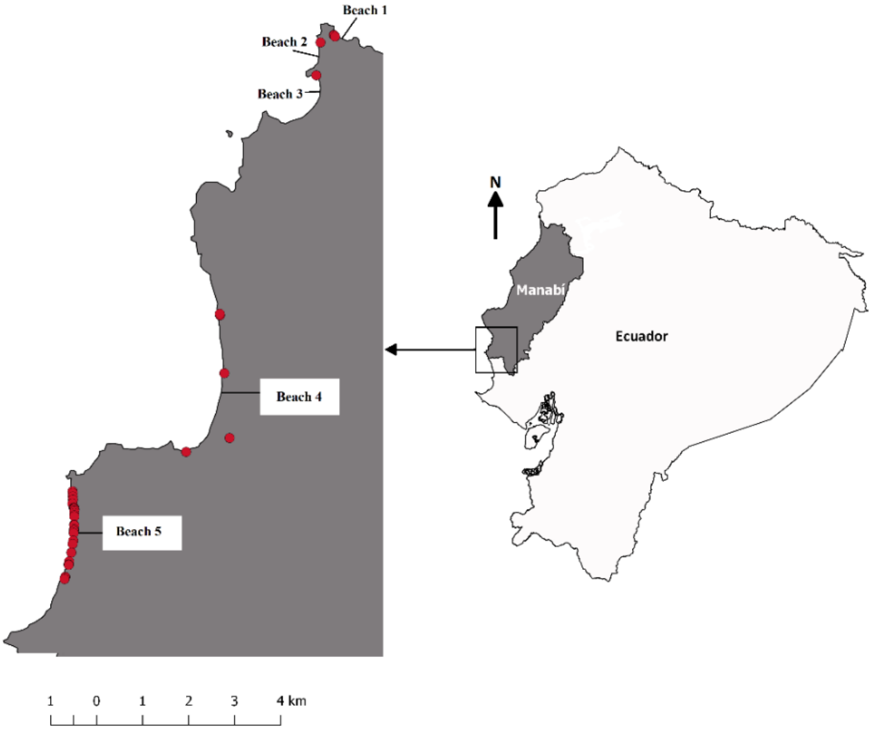
The objectives of the study were: i) to determine the variables that affect nest site selection by the two sea turtle species, *Eretmochelys imbricata and Chelonia mydas* in Ecuador, ii) to compare features of the nesting places of successful vs. failed clutches and iii) to quantify the changes in the intensity and frequency of the tide and its relation to the loss of eggs during the last 10 years.

MATERIAL AND METHODS

Study area

The study area is located on the continental coast of the province of Manabí, the central coast of Ecuador (-1.05222222º lat -80.45055556º long) with an extension of 350 km (Fig. 1). On the coast of the province of Manabí, 22 sites have been confirmed as nesting sites along 32 km of the coast, of which 10 km are within protected areas in the Machalilla National Park and in the Pacoche Marine and Wildlife Refuge (Alcívar & López 2014).

Figure 1. *Map of the study areas showing monitored beaches and sampling plots in red*



Nest monitoring

The study was conducted on 5 beaches, the largest with a length of 4,750m, with confirmed nesting, which were monitored weekly during the nesting months of sea turtles between December and April from 2017 to 2019 (Table 1). We conducted morning surveys to scan for nesting activities that had occurred during the previous night. We considered a nesting attempt successful ('nest' from now on) when we found a body pit, an area where sand had been disrupted, and sand spray was present. A nesting attempt was considered as aborted when a body pit was not found adjoining the turtle tracks, or a body pit did not contain any remains of sand spray (Rivas et al. 2016). The nests were georeferenced (Trimble Juno SB) in situ and, after hatching, the number of successful and failed eggs were counted to know hatching success. Flooding was registered daily (coinciding with the time of high tide https://www.inocar.mil.ec/mareas/TM/2020/PUERTO_LOPEZ.pdf) and all the nests affected by the increasing water level were identified following Madden et al. (2008), and the nest depth was measured to the bottom of the cavity.

Geomorphological and environmental measurements

A series of topographic and geomorphological measurements were carried out on these five beaches, such as the total surface, slope, beach width, texture, morphological unit, type of rock, or vegetation. To obtain the width of the beach, the profiles and shorelines of each beach were created through photo-interpretation (we use the vegetation as the back-beach boundary). Each beach was vectorised from orthophotos taking the last wet mark left by the tide as a reference. This allowed us to create transects perpendicular to the coastline at equidistant distances every 100 m. The width of the beach was measured in each of these transects. The slope and altitude were calculated from a digital elevation model (with a resolution of 90 meters provided by the Ecuadorian Space Institute), and the slope values were verified in percentages in the field by obtaining the altitude levels from the external line and the coast profile.

For the geomorphological and edaphic aspects, the data catalogue of the National Information System and Management of Rural Lands and Technological Infrastructure (SIGTIERRAS) was used (http://metadatos.sigtierras.gob.ec:8080/geonetwork/srv/spa/catalog.search#/home), where the geodynamic processes (texture, morphological unit, rock type or vegetation) of each beach were identified. The climatic characterization was compiled from the available files of the Cantagallo - Granja UNESUM meteorological station (Latitude -1.2889; Longitude -80.7312), and it was verified with the shapefile of the generation of Geoinformation for the management of the territory at the national level through the Space Institute Ecuadorian (IEE).

Characteristics of the nests monitored are shown in table 1. Beaches 1, 2 and 3, have an annual precipitation of 200-300 mm, and with an atmospheric temperature> 25, whose potential evaporation ranges between 1,350-1,400mm. Beaches 4 and 5 have precipitation ranges between 100-200 mm, with an atmospheric temperature> 25 and an annual potential evaporation that oscillates between 1300-1350 mm.

Table 1. *Characteristics of the nests monitored at the 5 study beaches (n=41)*

Beach	*Nest depth (cm)*	*Altitude (m)*	*Distance to vegetation*	*Distance to sea*	*Distance to road*	*Distance to house*	*Slope (%)*	*Beach width (m)*	*Length (km)*
1	55.7±6.1	12.6±2.9	1.69±0.39	32.9±3.9	25.3±9.3	1496±17.1	8.73	14.85	0.11
2	56	16	1.2	35.9	35	1310	6.84	16.9	0.65
3	54	13	0.8	40.6	38	613	13.8	43.8	1.8
4	64.2±3.1	3.3±4.4	1.5±1.2	25.9±6.9	82.3±63	51.3±22.3	2.81	124.5	4.75
5	61.3±6.9	11.6±10.5	1.05±0.64	29.2±4.1	171±142	450±304.9	22.3	102.6	4.1

For each of the beaches monitored (n = 5), the climatic and anthropic variables were determined at nest level. We recorded tidal height, distance from nest to high tide and low tide (https://www.inocar.mil.ec/mareas/TM/2020/PUERTO_LOPEZ.pdf), distance to human settlements, distance to road and distance to vegetation for every nest located in the sampling point using QGIS 2.18 (GRASS Development Team 2017). Also, during the weekly visit to every beach sampled, we recorded the presence or absence of dune scarps. Dune scarps happen when a high tide and high waves occur and the berm in the sand was registered when its height was 40 cm or higher because of the difficulties for the females to nesting (Rivas et al. 2016).

Frequency and intensity of tide

The tidal data for each day, with the time and maximum height for the last 10 years were obtained from Inocar (https://www.inocar.mil.ec/web/index.php). Data for Puerto Lopez were selected and extreme tidal events when rising above 3 meters were considered and the intertidal amplitude was calculated as the difference between this maximum of 3 or more meters and the minimum of that same day. This allowed us to calculate the number of days that these events occurred (frequency) and their intensity (difference between max-min tide) during the last 10 years. Further, data on nest loss from 2009 to 2019 were obtained from the Machalilla National Park Biodiversity Monitoring System on a total of 157 nests (86 of green turtles and 71 of hawksbill turtle).

Statistical analysis

In order to determine the underlying anthropic and climatic factors driving the nesting failure and egg loss, two Generalised Linear Mixed Models (GLMMs) were performed using the variable successful nesting attempts and aborted nesting attempts (model 1) and the proportion of eggs lost in relation to the total number of eggs in each nest (model 2) as response variables. Model 1 fit a binary distribution with a logit-link and model 2 fit a binomial distribution with a logit-link, respectively. The variables, species (2 levels), dune scarp (2 levels) and tide (2 levels) were added as fixed factors, whereas road, sea, vegetation distance and distance to human settlements were included as continuous variables in model 1. Model 2, also included nest depth and altitude above sea level on the basis of the high tide as continuous variables. The beach (five levels) was considered as a random factor. The selection of the most plausible models was carried out by comparing Akaike's information criterion (AIC) (Burnham and Anderson 2002) following a backward procedure (Zuur et al. 2009). Fisher's least significant difference test (LSD test) for comparisons of the estimated means within a mixed analysis was developed to check the differences among the levels of categorical variables. Statistical analyses were performed by employing InfoStats software.

Finally, a linear regression was carried out to determine the frequency (number of tides per year) and intensity (difference between max-min tide) of the tides and their relationship with the proportion of nests lost in the last 10 years. In addition, a Spearman correlation test was performed between the number of tides per year and the maximum height reached.

RESULTS

Descriptive results

In total, 41 nests (26 green turtle and 15 hawksbill turtle) were located and monitored with an average of 107 ± 61 eggs per nest. In addition, 13 aborted nesting attempts were recorded. Average hatching failure (percentage of eggs lost per nest) was 35.9% ± 31.31%. Highlighting the tide along with the natural barriers or remains left by the tides were the main cause of egg loss at 63.4%, followed by predation at 17%. The mean altitude of nest placement was 9.3±8.6m, while the average of nest depth was 0.60±0.07m (Table 1). The mean nesting distance was 29.4±5.1m and 1.2±0.8m to the sea and the vegetation, respectively. According to our observations, the turtles were able to pass over the berms when they are lower than 40cm in height.

In relation to the 157 nests monitored by Machalilla National Park Biodiversity Monitoring System from 2009 to 2019, the data showed a total of 6,894 eggs lost with respect to the total of 17,510 (represented a percentage of losses of 39.4%, of which 68.6% is due to tide washing).

Underlying factors for nest failure and egg loss

Candidate models assessing the effect of climatic and anthropic characteristics on the total number of aborted nesting attempts (model 1) and the proportion of eggs lost with regard to the total number of eggs in each nest (model 2) are shown in Table 2. The factors retained in the best models (model 1 and 2) are displayed in Table 3. The results show that the presence of a dune scarp was negatively associated with successful nesting (Figure 2). Furthermore, the proportion of eggs lost in each nest was positively associated with road distance, sea distance and nest depth and negatively only with altitude (model 2). In addition, the results showed significant differences between species, dune scarp and tide, the loss of eggs for the green turtle was greater in the presence of a dune scarp and high tides (Figure 3).

Table 2. *Candidate models assessing the effect of anthropic and climatic characteristics on successful nesting attempts vs. aborted nesting attempt (model 1) and the proportion of eggs lost in relation to the total number of eggs in each nest (model 2).*

	k	AICc	∆AICc	*wi*
Candidate models (model 1)				
Sand step + Tide + Road distance	3	46.17	0	0.258
Sand step + Tide + Road distance + Specie	4	46.49	0.32	0.219
Sand step	1	47.12	0.95	0.160
Sand step + Tide	2	47.44	1.27	0.137
Sand step + Road distance	2	47.69	1.52	0.120
Sand step + Specie	2	47.95	1.78	0.106
Candidate models (model 2)				
Tide + Specie + Sand step + Altitude + Nest depth + Sea D. + Road D.	7	156.03	0	0.487
Tide + Specie + Sand step + Altitude + Nest depth + Sea D. + Road D. + House D.	8	156.79	0.76	0.333
Tide + Specie + Sand step + Altitude + Nest depth + Sea D. + Road D. + Vegetation D	8	158.03	2	0.179

The number of model parameters (*k*), the Akaike information criteria for small sample sizes (AICc), the difference between each model and the best model (∆AICc), and the Akaike weight (*wi*) are shown.

Table 3. *Best models explaining the causes of successful nesting attempts vs. aborted nesting attempt (model 1) and the proportion of eggs lost in relation to the total number of eggs in each nest (model 2). Estimates for the level of fixed factors were calculated using the reference values of 'No' in the variable 'tide', 'no' in the variable 'dune scarp' and 'hawksbill sea turtle' in the variable species.*

Variable	**Estimate ± SE**	***F*-value**	***p*-value**
Successful nest vs failed nest (model 1)			
Intercept	4.58 ± 1.57	8.97	<0.01
Sant step	Yes= -3.36±1.09	9.44	**<0.01**
Tide	Yes= -1.77±1.02	3.04	0.089
Road distance	-0.01 ± 0.004	2.92	0.096
Proportion of eggs lost (model 2)			
Intercept	-12.9 ± 2.35	27.1	<0.001
Sand step	Yes = 2.21 ± 0.74	8.89	**<0.01**
Tide	Yes = 1.89 ± 0.68	7.79	**<0.05**
Specie	Green turtle=0.6±0.26	5.21	**<0.05**
Road distance	0.01 ± 0.002	11.3	**<0.01**
Sea distance	0.17 ± 0.03	24.4	**<0.001**
Altitude	-0.07 ± 0.02	11.5	**<0.01**
Nest dept	0.05 ± 0.02	7.02	**<0.05**

Significant *p*-values are highlighted in bold type.

Figure 2. *Predicted mean values (± S.E.) of probability of successful nesting according to the presence or absence of dune scarp. Capital letters indicate significant differences (p < 0.05) between the presence vs. the absence of a dune scarp according to Fisher LSD tests.*

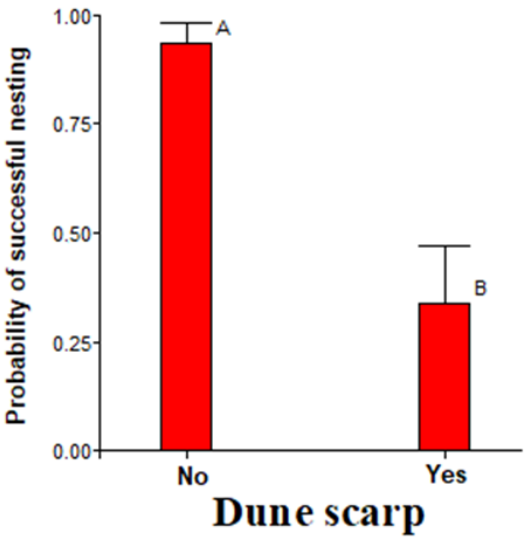
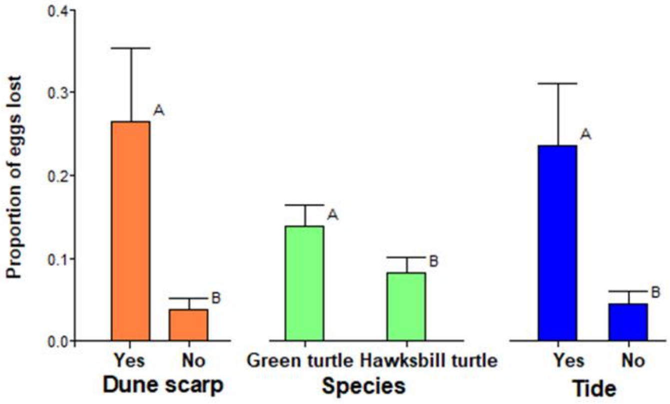


Figure 3. *Predicted mean values (± S.E.) of proportion of eggs lost when a dune scarp occurs (yes vs. no), species (green vs. hawksbill turtle) and extreme high tide (yes vs. no). Capital letters indicate significant differences (p < 0.05) between the two levels of the factors according to Fisher LSD tests.*



Changes in the intensity and frequency of the tide

The results show an increase in both the frequency and intensity of the tides during the last 10 years (Fig 4). The Spearman correlation shows a positive relationship between both the variables of frequency and intensity of the tides (r =0.83, p<0.05). In the same way, the results show an increase in the percentage of eggs lost during this period. An exponential regression shows a positive and significant relationship between the intensity of the tide and the loss of nests (r=0.76 p<0.05; Fig. 5B), but not with the frequency of the tides.

Figure 4. *Frequency of days with an extreme high tide (3m o more)* ***(A)*** *and average difference between the MAX and MIN tide* ***(B)*** *during the period 2009-2019. In grey, the 95% confidence intervals.*

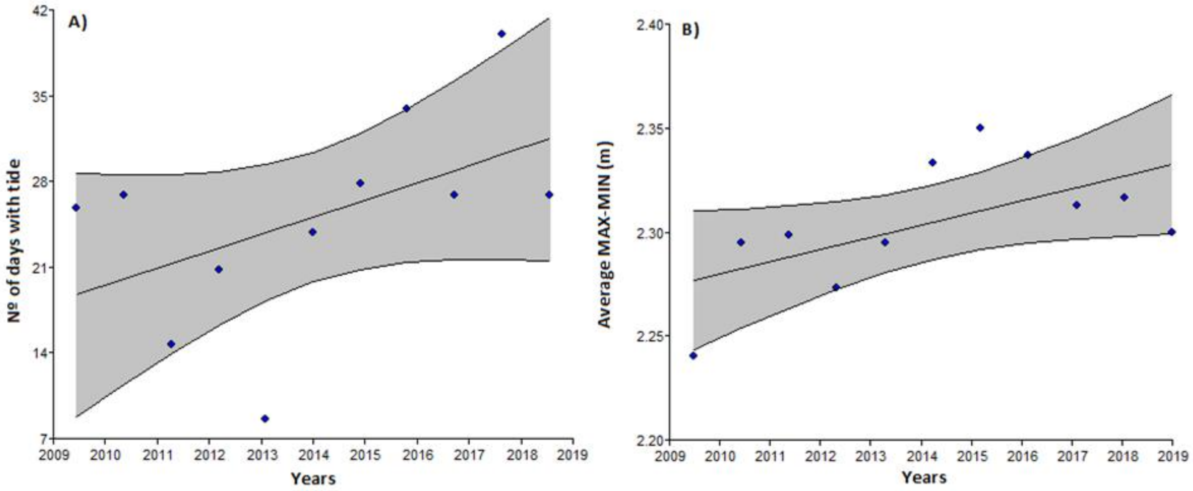
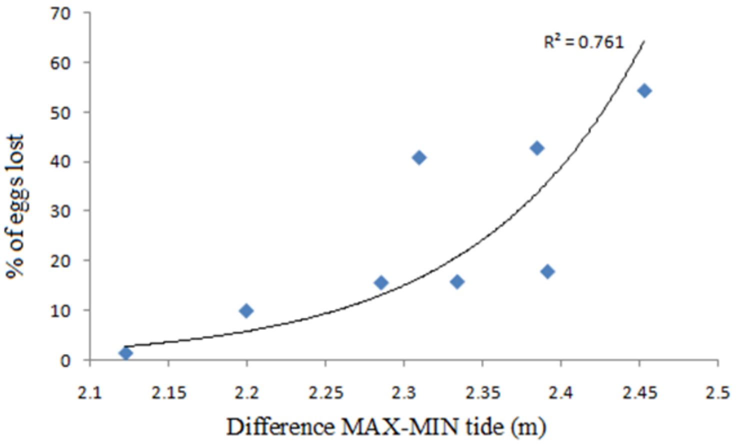


Figure 5. *Exponential regression between the percentages of eggs lost and average Difference MAX-MIN tide (m) (B) during the period 2009-2019.*



DISCUSSION

Sea turtles play important roles in marine ecosystems, both as prey and predators, as competitors, as substrates for epibiont organisms, as nutrient transporters, or as modifiers of the marine landscape (Bjorndal and Jackson 2002). However, their populations have suffered significant declines due to a combination of factors (Mazaris et al. 2017) such as bycatch in pelagic long-line fishing and global climate changes (Chaloupka et al. 2008; Laloë et al. 2017). Our results show that the intensity and frequency of extreme wave height events and their associated consequences (formation of dune scarps) have a great impact on the nesting success of sea turtles. In addition, the results indicate an increasing trend in the frequency and intensity of these events in recent years, with detrimental negative effects on the hatching of eggs in the nests as found in the Caribbean Sea for the leatherback sea turtle (Palomino-González et al. 2020).

Previous studies have showed that rising sea levels and an increase in storm frequency can inundate lower beach areas and destroy nests of turtles prevented from upper-beach access (Hawkes et al. 2009; Poloczanska and Limpus 2009; Patrício et al. 2019; Varela et al. 2019). Recently, Lyons et al. (2020) have suggested that even low levels of beach loss could have substantial impacts on future nesting densities and population growth. This is especially worrisome in developing areas like the coast of Ecuador, where beaches become narrower which is known as “coastal squeeze” (Fish et al. 2005; Mazaris et al. 2009; Noss 2011). Our results show an average hatching failure (percentage of eggs lost per nest) of 35.9% while tides are the main cause of eggs loss at a rate of 63.4%. Tidal inundation has been previously reported as an important factor affecting nest failure. Foley et al. (2006), found than one-third (38.9%) of the nest sites experienced tidal inundation which is half the impact found in this study. Caut et al. (2010) highlighted the existence of embryonic developmental arrest due to tidal inundation, since flooding affects the exchange of gases and changes in sand temperature (Booth 1998; Ralph et al. 2005; Chen et al. 2010), decreasing hatching success (Cheng et al. 2015). The formation of dune scarps by beach erosion might be determined by tides (Rivas et al. 2016), but also is typically associated with storms, typhoons or currents, and is influenced by the slope (van Bemmelen et al. 2020). These dune scarps affect both the possibility of nesting (that is, due to them the turtle returns to the sea without nesting; model 1), and the loss of eggs (model 2).

Beach armoring, light pollution and other shoreline stabilization structures (such as groins and jetties) have a great impact on marine turtle nesting grounds (Sella and Fuentes 2010; Rivas et al. 2015). Along the same lines, our results show that shortened distances to roads negatively affected nesting success. In Ecuador, the continental coast has undergone a process of urbanization that has negatively affected the nesting of sea turtles by altering the beaches and generating light pollution (Gutiérrez et al. 2019) which reduces nesting success of sea turtles and could cause greater predation on sea turtle nests (Silva et al. 2017).

Other natural factors related to nest-site selection and lost sea turtle eggs were altitude, nest depth and the distance to the sea. Our findings agree with previous studies, where the degree of slope appears to have a strong positive influence on nest-site selection since more slope signifies more nest elevation and therefore less flooding risk (Wood and Bjorndal 2000; Spanier 2010) and higher altitudes or buried shallower are less likely to experience such floods. While most nests can withstand minimal tidal inundations without drastic impacts on hatching success (Whitesell 2018), nests at low elevations are more frequently inundated by tides and experience a lower hatching success (Foley et al. 2006; Brig 2014). Regarding the depth of the nests, this is the consequence of (a) dry surface sand and (b) large females (Hays et al. 1993), the nests are deeper when there is more dry sand, larger females or both (Cheng et al. 2009). In the case of shallower nests, the surrounding substrate (sand) may help to drain the water after washovers. In addition, the water table below the nest rises and falls depending on the tide, which may cause flooding of eggs deposited deeper (Thompson and Curran 2015). If the mean of high tides rises, the distance between the nest and the water table will decrease, and the probability of a nest being flooded will increase (Ware and Fuentes 2018). Similarly, Rivas et al. (2018) showed how protracted rainfall increased the water table levels and sand moisture in some places, which consequently increased egg mortality in deeper nests.

Finally, when the two species studied were compared, we found a higher proportion of egg loss in the green turtle nests. Overall, this species tended to nest close to the vegetation (Patrício et al. 2018), while hawksbill turtles showed no preferences for either the sand or vegetation zone (Serafini et al. 2009). Patrício et al. (2018) showed a lower rate of success when emerging in forest areas than in the forest border and open sand. Our results showed that the hawksbill turtle nests are higher and therefore are exposed to a lower risk of flooding as found by Kamel and Mrosovsky (2005).

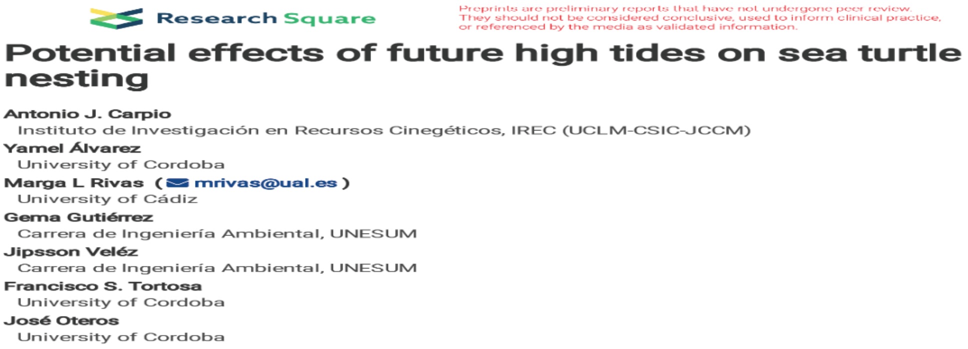
CONCLUSION

According to our results, there has been a decreasing percentage of hatching success associated with an increasing trend in both the frequency and intensity of floods in recent years. Climate change poses a threat to sea turtles because of the limited range of environmental and physical conditions that can be tolerated for hatching success (Butler 2019). These conditions are likely to evolve towards more unfavourable conditions as climate change progresses (Lyons et al. 2020). In addition, the projections of sea level rise show very unfavourable scenarios for the nesting of turtles (Patrício et al. 2019; Varela et al. 2019). To date, the management and conservation of sea turtles has focused almost entirely on non-climatic stressors due, at least in part, to practitioners not knowing what strategies to adopt and the feasibility and risks of potential strategies. For example, monitoring programmes use relocation techniques to avoid egg lost, therefore microhabitat assessments should be done to minimize potential skewed of sex ratios and low hatching success (Rivas et al. 2019).

Forecasting tidal inundation on sandy beaches and how that directly impacts on coastal nesting species is necessary for their successful conservation and management. Understanding which populations will be exposed to flooding scenarios in the future and which areas are at a greater risk is essential to manage these species effectively.

POTENTIAL EFFECTS OF FUTURE HIGH TIDES ON SEA TURTLE NESTING

CAPÍTULO 3



Potential effects of future high tides on sea turtle nesting

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Potential effects of future high tides on sea turtle nesting

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Running head: sea turtles by-catch

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ABSTRACT

Sandy beaches are the preferred nesting habitat for sea turtles. Multiple climate change events may, however, impact on this habitat, since the projected increase in the intensity and frequency of high tides as a consequence of rises in sea level and storm events may cause a higher rate of flooding of nests. Knowledge regarding future scenarios of tidal inundation and nest-site selection is required to design action plans with which to protect suitable habitats. The objectives of this study were: i) to quantify the impact of high tides on the nesting of two endangered species of sea turtles, Eretmochelys imbricata and Chelonia mydas in Ecuador, ii) to identify relevant trends regarding tides that might impact on the hatching success of the nests and, iii) to project the hatching success of these sea turtles' nests in next decade using changes in high tides events as a basis. We measured microhabitat characteristics along seven beaches on which sea turtles nest on the mainland coast of Ecuador. The tidal data and the hatching success of 210 nests were monitored from 2013 to 2020. We observed a positive trend as regards future high tide occurrences, which are a key factor in explaining nest hatching success. This increase in high tide might cause a reduction in the hatching success of these endangered species of sea turtles; with the E. imbricata being the species most affected by this threat. Considering that Eretmochelys imbricata is categorized as critically endangered and Chelonia mydas is listed as endangered, estimations of the potential risk of climate events on their reproductive success might contribute to management strategies, and in turn, to the conservation of their populations.

Keywords: global warming; overflooding; green turtle and hawksbill turtle; hatching production; nesting sites; rising sea levels and sea turtles

INTRODUCTION

Can biologists predict the effects of climatic change on the distributions of species? This question has already been raised by Araujo & Rahbek (2006), who pointed out the importance of anticipating the impacts of climate change. Climate change is expected to be one of the main causes of worldwide biodiversity loss in the future (Sala et al., 2000; Harley, 2011; Warren et al., 2013). Large numbers of species thus-far largely unaffected by human actions are consequently in danger of extinction as a result of climate change (Pimm, 2008). However, the effects of climate change will be uneven for different taxa. For example, many invasive species share traits that will allow them to capitalize on the various elements of global change (Dukes & Mooney, 1999). In terrestrial ecosystems, dispersal has been identified as the widespread response of species to recent climate change, usually via range shifts from lower to higher latitudes (Parmesan & Yohe, 2003). Furthermore, intraspecific variations in physiological, phenological, behavioral or morphological traits allow species to cope with rapid climatic changes within their range (Skelly et al., 2007: Holf et al., 2011; Urban et al., 2014). Climate change will, therefore, have a greater impact on taxa such as reptiles or amphibians, because as ectotherms their life history traits, behavior, and physiology are strongly influenced by environmental temperature (Bickford et al., 2010; Sinervo et al., 2010; Winter et al., 2016; Cox et al., 2022).

Sea turtles deserve a special mention because they differ from most terrestrial reptiles as regards their life history, ecology, body size, and conservation (Poloczanska et al., 2009). The risk is even higher for these species because an increased nest temperature will subsequently lead to an increase in population feminization (Hays et al., 2010; Laloë et al., 2016; Rivas et al., 2019; Tomillo & Spotila, 2020). In addition, a rise in sea level, coupled with human encroachment, will minimize available nesting locations (Fuentes et al., 2010; Patino-Martinez at al., 2014; Varela et al., 2019; Von Holle et al., 2019). Also, increased tidal activity will likely damage sea turtles' nest hatching as a result of overflooding (Carpio et al., 2020; Rivas et al., 2016). The impacts on sea turtles could, therefore, be profound, as they will no longer be able to locate their breeding grounds in many localities and many populations may consequently be drastically affected (Bickford et al., 2010; Fuentes et al., 2011).

Although the effect of rising sea levels and disturbances resulting from increased storm activity on the diminishing coastal ecosystems that are available for nesting sea turtles has been studied (Fish et al., 2005; Hawkes et al., 2009; Fuentes et al., 2010; Butt et al., 2016; Rivas et al., 2018; Varela et al., 2019; Veelenturf et al., 2019; Von Holle et al., 2019; Tomillo et al., 2020), little is known about the effect of unusual high tides on the hatching success of sea turtles (Wilson, 2018; Carpio et al., 2020; Palomino-González et al., 2020). These extreme high tide events occur as a consequence of storm surges and wind and are of particular concern on vulnerable sites with low lying, narrow or inland beaches (Fish et al., 2005; Baker et al., 2006; Mazaris et al., 2009) and may increase nest flooding through rises in water table levels (Witt et al., 2010; Rivas et al., 2018). This impact may consequently be critical in areas in which the tidal ranges are compounded by the increase in coastal development and its associated hard structures (e.g. sea walls, jetties, roads, etc.). This phenomenon, which is denominated as 'coastal squeeze', results in reductions in the number of sandy beaches that are available (Schlacher et al., 2008; Mazaris et al., 2009), or losses in dry upper intertidal shore (Dugan et al., 2008).

These windy weather events that have the potential to damage and erode shorelines, such as hurricanes and typhoons, are also increasing in number, duration, and intensity with global warming (Goldenberg et al., 2001; Webster et al., 2005; IPCC, 2013; Wilson, 2018). Previous studies carried out with leatherback (Dermochelys coriacea), green (Chelonia mydas) and hawksbill turtles (Eretmochelys imbricata) found a reduction in nest hatching success on beaches with higher water content owing to inundation events (Patino-Martinez et al., 2014, Carpio et al., 2020; Palomino-Gonzalez et al., 2020). Baker et al. (2006) projected terrestrial habitat loss under simulated medium and maximum flood scenarios, in which they found periodic flooding of the entire land below elevations of 89 cm and 129 cm, respectively. Extreme high tide events, which are currently relatively rare, may, therefore, increase in frequency and intensity, which could decrease sea turtle nesting success (Wilson, 2018; Carpio et al., 2020).

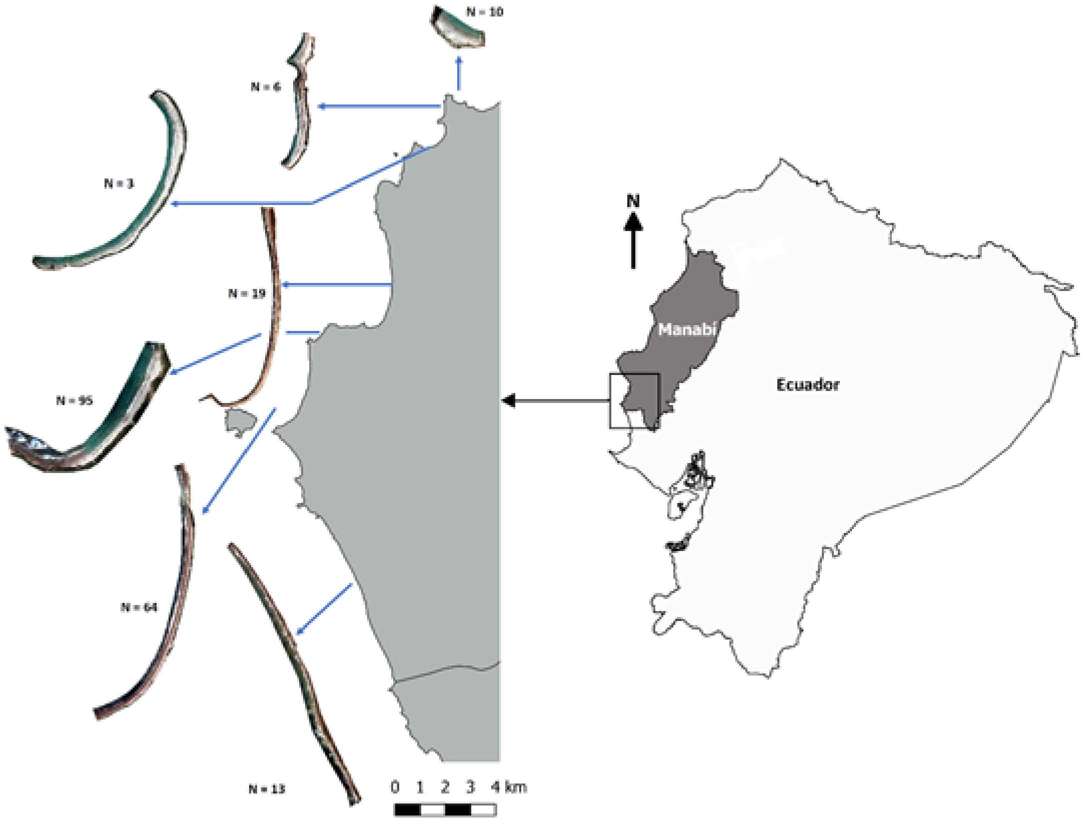
The objective of this study was to identify the probability of future extreme high tide events and their consequences for the reproductive success of two endangered sea turtle populations in Ecuador: the green and hawksbill turtles. The main goals were, therefore: i) to quantify the impact of high tides on the hatching success of green and hawksbill turtles in Ecuador, ii) to identify trends and future projections as regards tides that might impact on the hatching success of the nests, and iii) to project the hatching success of the sea turtles' nests in the next decade on the basis of changes in high tide events.

MATERIALS AND METHODS

Study site and nesting data

Machalilla National Park (1°03′08″S 80°27′02″O) is a major sea turtle nesting area on the mainland coast of Ecuador (Barragan, 2003) and is composed of several beaches with a total length of 350 km. It has been confirmed that there are 22 nesting sites along 32 km of the coast of the province of Manabí, of which 10 km are within protected areas in the Machalilla National Park and in the Pacoche Marine and Wildlife Refuge (Alcívar & López, 2014). Seven beaches hosting the nests of the hawksbill turtle and green turtle were, therefore, selected for this study (Fig. 1).

Figure 1. *Map of the study areas showing monitored beaches and number of monitored nests.*



Nests were monitored in the nesting seasons (between early October and late April) from 2013 to 2020. Each beach was patrolled on foot every week by a team of two people. The precise location of the nests was recorded using a handheld GPS (Trimble Juno SB) (accuracy of ± 2-5 m). We considered a nesting attempt (from here on, 'nest') to be successful when we found a body pit, an area in which sand had been disrupted, and the presence of sand spray (Carpio et al., 2020). Each nest was georeferenced and, after hatching, the number of successful and failed eggs were counted in order to estimate hatching success $H = S / (S + U)$, where S = number of eggshells and U = number of unhatched eggs. Eggshell fragments +-50 % of the egg surface were considered as one hatched egg (Miller, 1999), and the nest depth was measured to the bottom of the cavity. The number of nests overflooded by the water level was measured following the suggestions of Madden et al. (2008).

The slope and altitude were calculated with a resolution of 90 m using a digital elevation model provided by the Ecuadorian Space Institute. Slope values were verified in the field by obtaining the altitude levels from the external line and the coast profile, which were obtained by means of trigonometry from the data concerning the distance to the water in meters and the slope (by employing a clinometer).

Tide events in the study period

The tidal data for Puerto López for each day, along with the time and maximum height for the study period (2013-2020), were obtained from Inocar (**https://www.inocar.mil.ec/web/index.php**). Extreme tidal events were considered as rising tides above 3 m, and the intertidal amplitude was calculated as the difference between 3 or more meters and the minimum of that same day (Carpio et al., 2020). This allowed us to calculate the number of days on which these events took place (frequency) and the difference between max-min tide (intertidal range or intensity) during the study period.

Selection of the optimal definition for a high tide event

We also investigated what the most significant features of a tide **(**height, number of overwasher days, moment in the incubation period) were for it to become relevant for sea turtles' hatching success (Caut et al., 2010). We, therefore, calculated the Pearson correlation between the hatching success and the maximum height of the tide. We also calculated the correlation between the hatching success and the delay in days with respect to the occurrence of the tide event.

Impact of tide events on hatching success

We aimed to predict hatching success on the basis of the incubation period coinciding with extreme tide events occurrences. We did this by developing several predictive statistical models using only aspects of tide information as predictor variables.

This was done using an ensembled approach. The database was spliced into two sets for modeling purposes: 1.80% was randomly selected as the training dataset, and 2. The remaining 20% was selected as the validation dataset.

We tested 107 different statistical methods in order to model the relationship between hatching success and the selected parameter, which was an extreme tide event, differentiating by sea turtle species. All the methods were applied by using R statistical software and the caret package (Kuhn et al., 2008). We used the internal mean absolute error (IMAE) from the training database to select the best fitting models (IMAE < 4% of error), and subsequently performed an ensemble of the predictions of the selected methods in order to calculate the predicted values. The ensemble of all the selected methods was calculated by applying a Tukey's Biweight robust mean of the predictions (Tukey, 1960; Shewchuk, 1997). This method decreases the weight of the extreme values on the mean calculation.

Of the 57 methods selected, most were from the family of Random Forest based methods, Support Vector Machine methods or artificial neural network-based approaches (Annex 1). With regard to the Random Forest family, some of the methods employed were: Quantile Random Forest (qrf) from the quantregForest R package, Random Forest by Randomization (extraTrees) from the extraTrees R package (Simm et al., 2014), Regularized Random Forest (RRF) from the randomForest R packages (Liaw and Wiener, 2002) and RRF or Random Forest (rf) from the randomForest R package. Random forest is already an ensemble method that uses multiple decision tree algorithms to maximize predictive performance. The standard random forest methods calculate the mean or average prediction of all the decision trees.

Some methods based on the Support Vector Machine were also selected. Support Vector Machine (SVM) methods were originally developed solely for binary classification purposes, but their application has since been extended to multiple classification and regression problems. SVMs have proven to be one of the best classifiers for a wide range of situations (Cervantes et al., 2020). Support Vector Machine methods are based on the concept of the hyperplane, while Artificial Neural Networks (ANN) are methods based on biological neural networks. These algorithms, as biological neurons, are a collection of connected nodes. Each connection between two nodes modulates the relationship between nodes.

Projection of hatching success of sea turtles

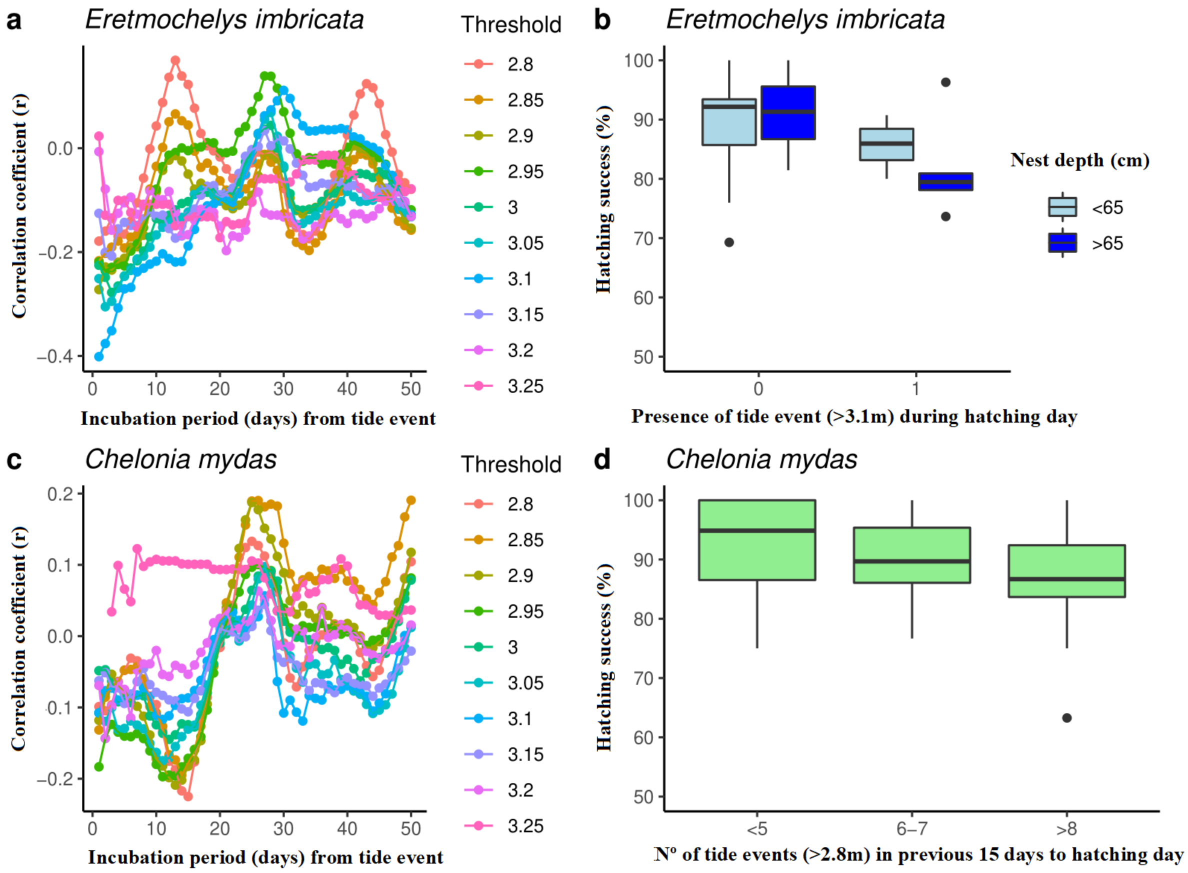
In order to be able to project the changes in hatching success owing to future tide events, we first estimated the future occurrences of extreme tide events on the basis of a time series analisis of daily tide information for Manabi beaches over an 11-year period (2009-2019). We fixed two ARIMA models (Autoregressive Integrated Moving Average models) based on the optimal threshold for each sea turtle species (Max tide >2.8 m and >3.1 m). These models take two components in to account: a non-seasonal part of the time series and a seasonal component. ARIMA models are summarized by a series of parameters: ARIMA(p,d,q)x(P,D,Q), where in AR, the parameter p denotes the order of the autoregressive part, and in MA, the parameter q denotes the order of the moving average part. I (d) is the number of differentiation steps. P, D and Q refer to the seasonal terms: P=number of seasonal autoregressive (SAR) terms; D=number of seasonal differences and Q=number of seasonal moving average (SMA) terms. ARIMA analises were performed using the R package “forecast” (Hyndman & Khandakar, 2008).

Finally, all the models developed in section 2.4 were applied (Annex 1) using the tide projections generated by the ARIMA models as predictors.

RESULTS

A total of 199 nests (88 green turtles and 111 hawksbill turtles) were located and monitored, with an average of 108.1 ± 48 eggs per nest (99 ± 51 for the green turtle and 112 ± 48 for the hawksbill turtle). The number of nests monitored per year was 29.1± 13.6, of which 10.5±5.24 nest per year were washed. The average number of eggs damaged by floods (percentage of eggs lost per nest) was 10.5% ± 7.46% (10.48% ± 7.69% for the green turtle and 10.53% ± 7.2% for the hawksbill turtle). More than one-third (40%) of the nest sites underwent tidal inundation (41% for the green turtle and 39% for the hawksbill turtle). The mean altitude and slope of nest placement was 12.5 ± 10.7m (11.5 ± 11.0m for the green turtle and 12.8 ± 10.7m for the hawksbill turtle) and 9.6 ± 5.7% (7.6 ± 5.7% for the green turtle and 10.4 ± 5.5% for the hawksbill turtle) respectively, while the average nest depth was 0.68 ± 0.15 m (0.68 ± 0.14m for the green turtle and 0.69 ± 0.15m for the hawksbill turtle).

Figure 2. *Pearson correlation between the hatching success and the maximum height of the tide and delay in the tide event (a, Eretmochelys imbricata, and b, Chelonia mydas). Differences in hatching success depending on the presence or otherwise of tides on the day of hatching and depending on the number of days with tides in the 15 days prior to hatching (c, Eretmochelys imbricata and d, Chelonia mydas).*



As can be observed in Figure 2, there was a negative correlation between the occurrence of tides with a relevant maximum height and hatching success for both sea turtle species. The hatching success of *Eretmochelys imbricata* was more affected by the occurrence of tide events on the same hatching day, while that of *Chelonia mydas* was more sensitive to tide phenomenon occurrences 15 days ahead. In the case of *E. imbricata*, the maximum absolute negative correlation was observed with maximum heights > than 3.1 m (r=-0.401, p=0.001), while in that of *Chelonia mydas,* the maximum effect was observed for days with a maximum height of the tide >2.8 m (r=0.225, p=0.042). We observed a difference in correlation as regards the nest depth in the case of *E. imbricata*, while no effect was observed for *C. mydas*.

Figure 3. *External validation of models predicting hatching success based on extreme tide event phenomenon.*

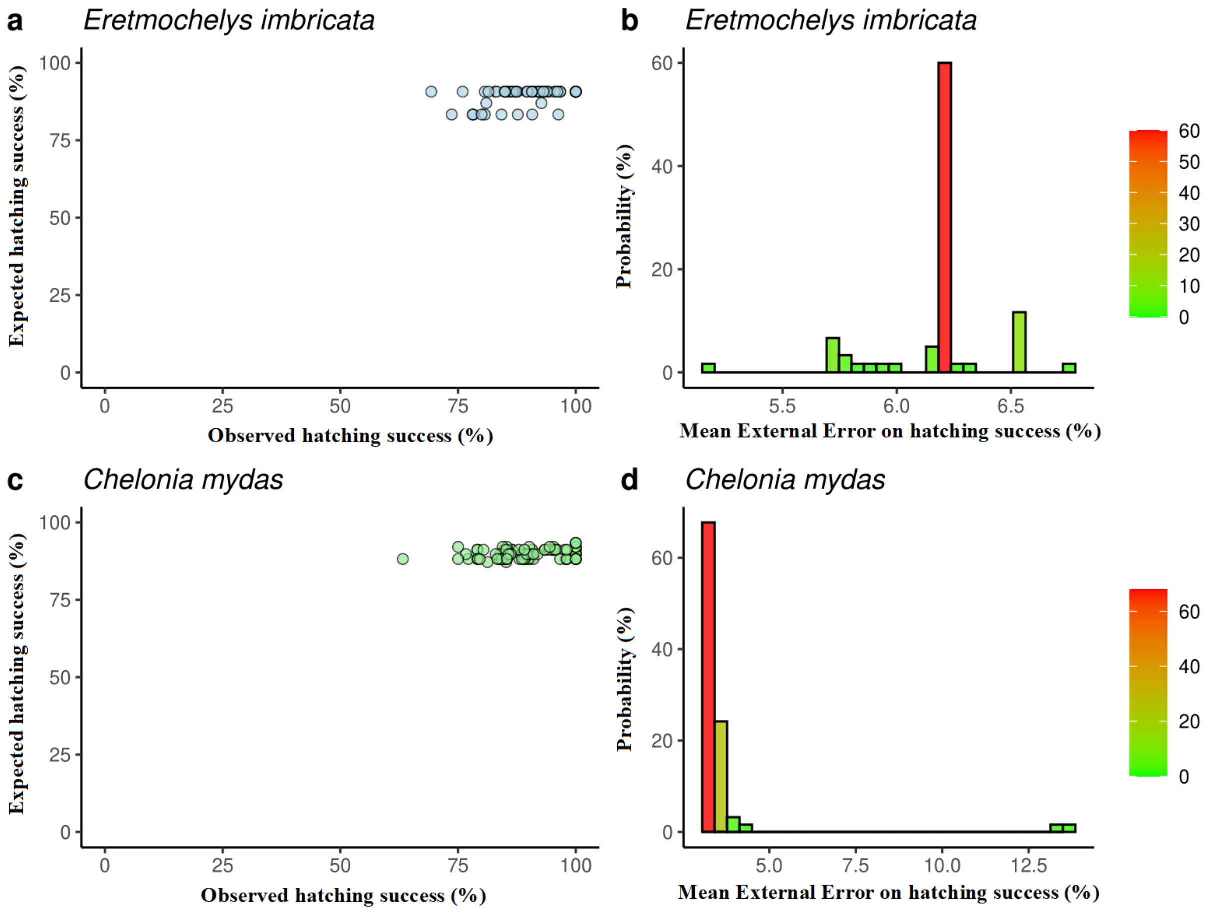
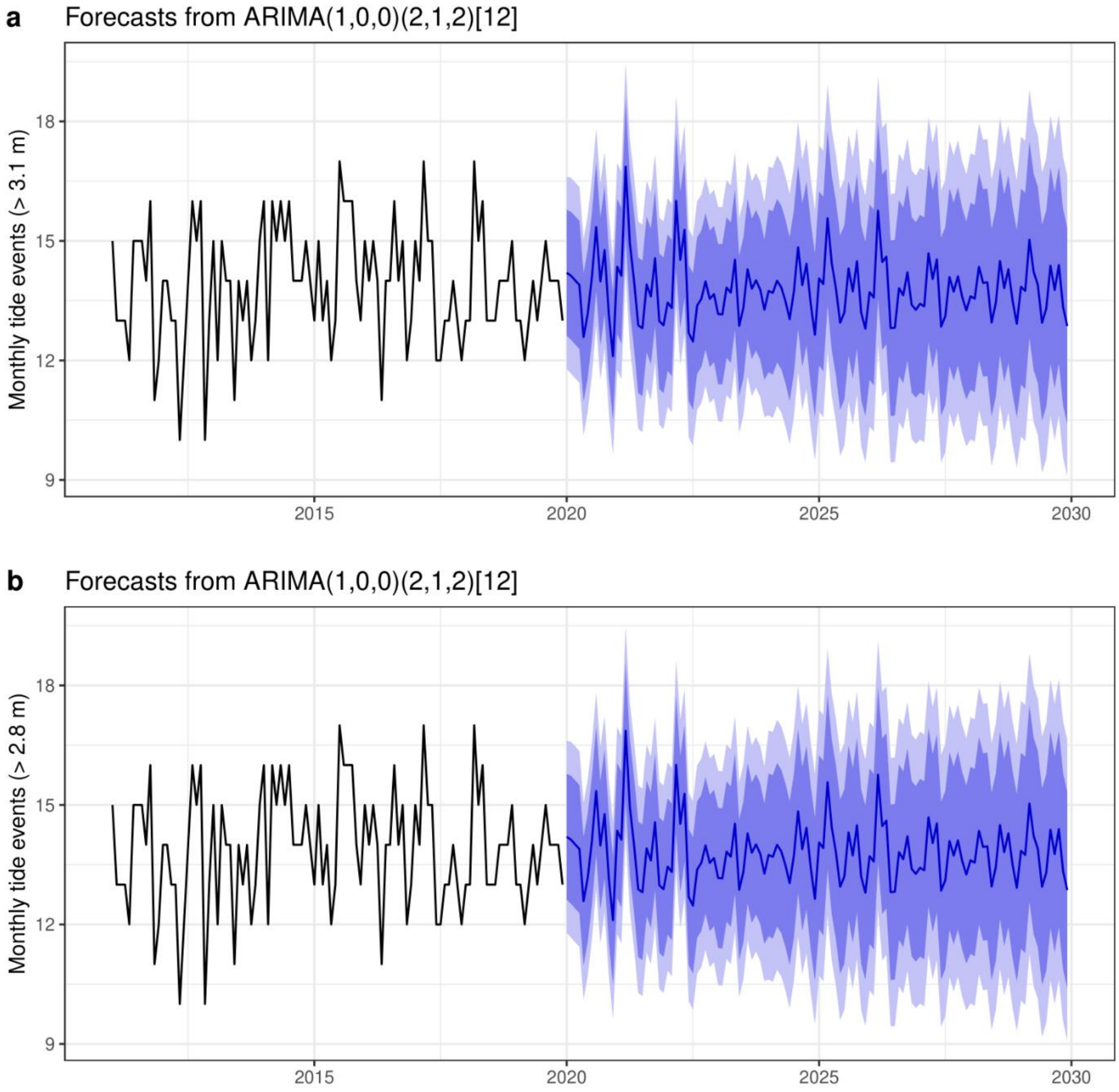


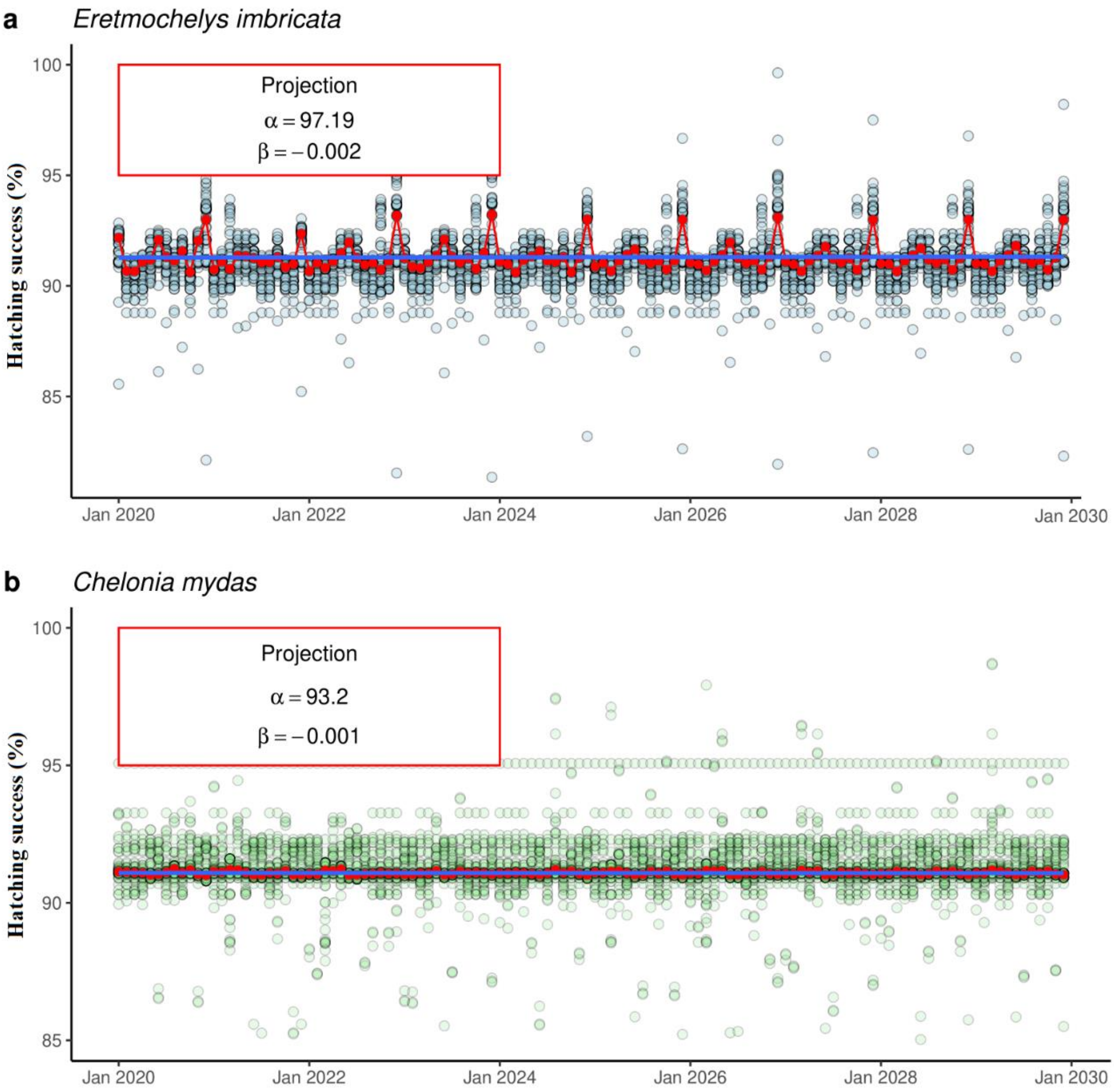
Figure 3 shows the performance of the models relating tide events to hatching success. With the external validation, a mean Absolute Error of about 6.2 % was expected for *E. imbricata*. >60% of models had an external error of 6.24%, and the EMAE was 6.18%. The EMAE was 5.5% for *C. mydas*. >60% of the models had an external error of 4.6%. Almost all the predictions made were correctly placed at >70% observed variability, with no false predictions in lower ranges.

Figure 4. *ARIMA statistics for time series models for monthly tide occurrences of >3.1 m of max height (a) and >2.8 m of max height (b).*



The ARIMA models for the monthly occurrences of tide events showed a performance of mean absolute error (MAE) of 0.95 (>3.1m) and 0.86 (>2.8m), both below 1 day of error each month. The root mean square error (RMSE) was 1.2 for threshold (>3.1m) and 1.1 for threshold (>2.8m). Overall, the projection to the end of the decade showed an increase in the prevalence of these events.

Figure 5. *Projection of hatching success based on an ensemble of tide-based models for E. imbricata (a) and C. mydas (b). Linear model of projected daily time series, where α shows y-axis cutting starting conditions and β shows the slope.*



The tide-based models had a negative slope for the projected hatching success of both species. In the case of *E. imbricata,* there was a negative slope of -0.01, signifying a decrease in hatching success of >1% every decade (0.01*120 months). In the case of *C. mydas,* a decrease in hatching success of 0.12% every decade (0.001*120) was projected (Figure 5b).

DISCUSSION

Climate change is expected to affect, and is already affecting, sea turtles in various ways, such as altering their sex ratios and decreasing reproductive output as a result of increasing sand temperatures (Hill et al., 2015), the flooding of beaches and nests owing to rises in sea levels (Fuentes et al., 2010) or the increasingly frequent erosion and loss of nests owing to extreme tidal events (Carpio et al., 2020; Palomino-González et al., 2020). This scenario predicted by climatic projections might, therefore, represent an additional obstacle to the survival of these species. In addition, many sea turtles had a high level of nest-site repeatability with a tendency to nest near previous nests, and maintained a preference for nesting in particular areas of the beach, even when the beach had changed (Heredero-Saura et al., 2022). This nest site fidelity also increases the risk of nest or egg loss as a result of flooding or other causes, such as changing beach conditions.

In order to address this issue, we analyzed the impact of high tides on nesting failure and which parameter (e.g height, moment in the incubation period) of the tides might impact on the hatching success of the nests. The correlation between hatching success and the maximum height of the tide and the delay in the tidal event was negative, particularly as regards the day of hatching in the case of hawksbills and the 15 days prior to hatching in the case of green turtles. The study carried out by Limpus et al. (2020) showed that freshly laid eggs and eggs on the verge of hatching exposed to any flooding suffered complete mortality, which coincides with what is shown here for the hawksbill sea turtle. The aforementioned authors also found that eggs exposed to prolonged periods of flooding (24 and 48 h) or eggs >80% developed underwent significant decreases in hatching success, which explains the decrease in the hatching success of green turtles when exposed to flooding in the last 15 days of the incubation period. Sea turtle eggs are, therefore, most sensitive to flooding at the beginning and end of the incubation period (Caut et al., 2010; Limpus et al., 2020). On the other hand, 40% of the nest sites underwent tidal inundation, which is consistent with previous studies (38.9% Foley et al., 2006; 30.3% Caut et al., 2010; 42.3% Ware et al., 2021). Even sex-ratio can be affected by tidal inundation, since the production of males was severely affected by the tidal inundation of nests (Martins et al., 2022).

Moreover, the hawksbill turtle was more sensitive to extreme events of greater intensity (>3.1m), while the green turtle was more sensitive to tidal events above 2.8m. This is because green turtles nest significantly closer to the mean high water line than hawksbill turtles (29.7±4.6m vs 36.7±7.5m) (t=5.23 p<0.001). The hawksbill turtle nests near or inside vegetation (Ditmer & Stapleton, 2012; Liles et al., 2015), while that the green turtle places its nests close to vegetation and open beach (Patricio et al., 2018; Heredero-Saura et al., 2022).

With regard to the depth of the nest, there were no differences between the two species (mean 69 cm) (similar to the 76 cm found by Varela et al. (2019) for the green turtle). However, it was observed that in the case of the hawksbill turtle, the deepest nests (>65 cm) have a greater risk of flooding and consequently less hatching success. This can be partially explained by the fact that the water table below the nest rises and falls depending on the tide, which may cause the flooding of eggs that are deposited at a greater depth (Thompson and Curran, 2015). However, in the case of the green turtle, since the nests are located at a lower height, it is likely that the risk of flooding is the same for all the nests (there are no differences between depths), with the number of overwashes being more critical for this species (Figure 2d). In addition to tidal events, these deeper nests are also more sensitive to precipitation (Rivas et al., 2018) and the inundation caused by rises in sea level (Pike et al., 2015).

Furthermore, the projections showed that these extreme events will be more and more frequent (Figure 4), similar to that shown in other projections (Lyons et al., 2020; Tomillo et al., 2020). However, these tidal models were projected only until 2030 owing to the great uncertainty associated with them. These extreme tides, along with other associated phenomena such as rises in sea level, are expected to cause shoreline erosion, saline intrusion into the water table and the inundation and flooding of beaches and coastal areas (Fuentes et al., 2010). Although there are many predictions regarding rises in sea level (Von Holle et al., 2019; Lyons et al., 2020; Veelennturf et al., 2020; Martins et al., 2022), there is very little information on the possible future effects of extreme tides (see Palomino-González et al., 2020). In the case of tides, they are caused by a combination of strong winds and astronomical high tides. These can produce high-frequency tide levels, which it is difficult to forecast, although new tools such as machine learning or neural networks are improving these projections (Chen et al., 2020). Despite this, our model showed a decrease of 1.2% (*E. imbricata*) and 0.12% (*C. mydas*) of hatching success in the next decade solely as a result of tides. These percentages, together with other phenomena such as the increase in sea level, biases in the sex-ratios, coastal narrowing or the loss of beaches, represent an additional risk as regards the survival of these species.

CONCLUSIONS

Many beaches at a global level might become unsuitable for nesting in future climate change scenarios, and those that exist or are newly established will consequently be critical habitats for the persistence of turtle populations.

Sandy beach habitats in which sea turtles nest will be affected by multiple climate change impacts, such as rises in sea levels and increasing storm frequency, which might increase beach erosion and the loss of available nesting areas. Before these impacts occur, knowledge of how nest-site selection and hatching success vary depending on local or regional conditions is required in order to highlight areas that are potentially at risk. This might allow managers to discover how to prioritize the protection of suitable habitats and implement mitigation measures in order to combat this threat to beaches around the world.

The use of strategies based on employing existing knowledge and bioclimatic modeling to improve the understanding of the likely effects of future climate on biodiversity is essential as regards assessing both current and future distributions of species. Recommendations to increase the conservation of sea turtle populations confronted by potential climate change effects should include the protection of nesting beaches. Increased research efforts with which to fill the critical knowledge gaps related to climate processes that influence population numbers should also be prioritized, since this could determine the future of many populations worldwide.

ANNEX 1. *Internal and external Root Mean Square Error (IRMSE and ERMSE) and internal and external Mean Absolute Error (IMAE and EMAE) of the 57 selected methods.*

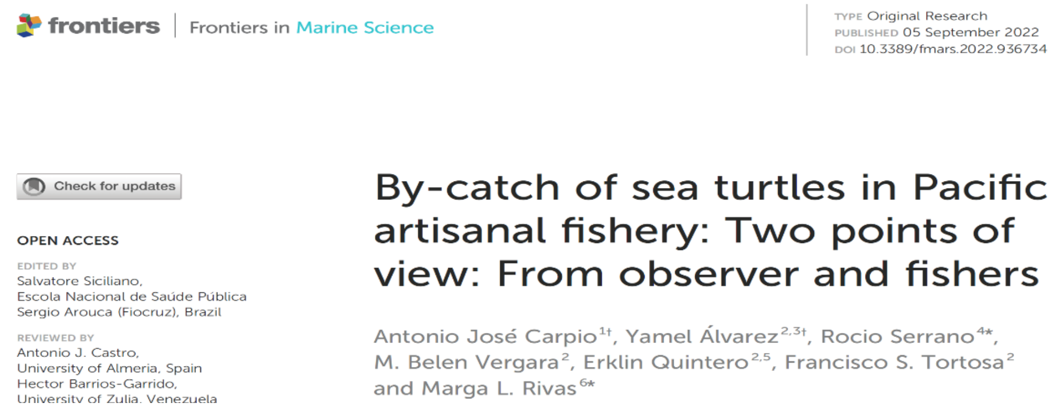
Model	IRMSE	IMAE	ERMSE	EMAE
ppr	4.01	3.13	5.54	5.01
qrf	4.75	3.23	4.24	4.06
extraTrees	3.97	3.24	4.86	4.40
gamboost	3.96	3.26	5.03	4.53
rvmRadial	3.97	3.26	4.86	4.41
bstSm	3.96	3.26	5.02	4.53
monmlp	4.15	3.28	5.99	5.43
rf	4.05	3.41	4.92	4.48
parRF	4.06	3.41	4.93	4.47
RRFglobal	4.07	3.43	4.88	4.42
svmRadialSigma	4.47	3.47	5.59	4.90
gaussprRadial	4.19	3.54	5.38	4.87

svmRadial	4.55	3.58	5.76	5.08
svmRadialCost	4.55	3.58	5.76	5.08
svmLinear	4.70	3.71	5.93	5.32
svmLinear2	4.70	3.71	5.93	5.32
krlsPoly	4.62	3.74	5.95	5.41
krlsRadial	4.55	3.74	5.89	5.37
svmPoly	4.78	3.77	5.97	5.35
BstLm	4.63	3.77	6.04	5.51
rpart	4.62	3.77	6.04	5.51
rpart1SE	4.62	3.77	6.04	5.51
rpart2	4.62	3.77	6.04	5.51
ctree	4.62	3.77	6.04	5.51
glmStepAIC	4.62	3.77	6.04	5.51
earth	4.62	3.77	6.04	5.51
gcvEarth	4.62	3.77	6.04	5.51
null	4.62	3.77	6.04	5.51
partDSA	4.62	3.77	6.04	5.51
lmStepAIC	4.62	3.77	6.04	5.51
M5Rules	4.62	3.77	6.04	5.51
M5	4.62	3.77	6.04	5.51
blackboost	4.62	3.77	6.04	5.51
neuralnet	4.62	3.77	6.04	5.51
gaussprPoly	4.62	3.78	6.04	5.51
lars	4.62	3.78	6.04	5.51
blasso	4.62	3.78	6.06	5.53
blassoAveraged	4.61	3.78	6.07	5.54
bridge	4.61	3.78	6.07	5.54
cubist	4.92	3.79	5.98	5.26
cforest	4.62	3.80	6.03	5.50
rlm	4.62	3.81	6.08	5.55
gaussprLinear	4.63	3.82	6.09	5.57
glmboost	4.63	3.82	6.09	5.57
msaenet	4.63	3.82	6.09	5.57
gamLoess	4.63	3.82	6.09	5.57
bam	4.63	3.82	6.09	5.57
gam	4.63	3.82	6.09	5.57
gamSpline	4.63	3.82	6.09	5.57
glm	4.63	3.82	6.09	5.57
spls	4.63	3.82	6.09	5.57
lars2	4.63	3.82	6.09	5.57
lm	4.63	3.82	6.09	5.57

glm.nb	4.63	3.82	6.09	5.57
bayesglm	4.63	3.82	6.09	5.57
bstTree	4.63	3.82	6.03	5.52
ctree2	4.64	3.83	6.04	5.55

BY-CATCH OF SEA TURTLES IN PACIFIC ARTISANAL FISHERY: TWO POINTS OF VIEW: FROM OBSERVER AND FISHERS

CAPÍTULO 4



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By-catch of sea turtles in Pacific artisanal fishery: Two points of view: From observer and fishers

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By-catch of sea turtles in Pacific artisanal fishery: Two points of view: from observer and fishers

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Running head: sea turtles by-catch

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ABSTRACT

Fisheries bycatch is a primary driver of population declines in marine megafauna. These captures not only have environmental impacts, they also have economic consequences for fishers such as direct losses when repairing fishing gear. Therefore, evaluating the fishers' perception of bycatch and comparing it with data from scientific fisheries observers might provide a broader view of the current situation these species face. To do this, we obtained data concerning the bycatch of 1,838 sea turtles between 2008-2018 in the Eastern Pacific Ocean as well as informative surveys from 421 artisanal fishers surveyed in 2020. There is a discrepancy between the bycatch observed and the fishers' perceptions of it. The observers' results identified that high rates of incidental capture of sea turtles are associated with the mahi mahi fishery that occurs during winter and is a shallow set fishery using fish as bait. The olive ridley turtle was the main species affected by bycatch. According to the fishers' perception, bycatch was higher with the use of J-hooks and a longline (compared to circle hooks and to gill nets and trawl nets) and when the target species are pelagic fish during the winter season. In addition, the fishers' perception showed that 39.4% considered incidental fishing as an environmental problem and 28.5% considered it as a nuisance, while 32.1% do not consider sea turtle bycatch as a problem. These findings suggest that 60% of fishers do not consider it a need to protect sea turtles. Given the different responses between fisheries observers and fishers' perception, it is clear that more dialogue is necessary to raise awareness about the effects of bycatch on worldwide sea turtle populations. Thus, there is an enormous potential to recruit/increase fishers' active participation for turtle protection. In this context, the idea of including the fishers' perception into any management strategy or conservation measure should be reinforced in order to effectively reduce the bycatch of these iconic species.

Keywords: fishing gear, fishing nets, longlines, marine turtles, surveys

INTRODUCTION

Bycatch resulting from fishing gear (in particular longlines and gillnets) is one of the most serious threats to marine megafauna such as seabirds, sea turtles, marine mammals, and elasmobranchs (Fiedler et al., 2012; Gilman & Huang, 2017; Lewison et al., 2004; López-Barrera et al., 2012; Wallace et al., 2013; Žydelis et al., 2009). This is particularly concerning in long-lived animals with low reproductive rates, such as is the case of sea turtles (Parga et al., 2015), cetaceans, pinnipeds and sirenians (Reeves et al., 2013) or elasmobranchs (Gallagher et al., 2014). Pelagic longline gear is commonly used throughout the world to catch large pelagic fish such as tuna, billfish, and sharks (Gilman et al., 2017; 2020; Martínez-Ortiz et al., 2015; Myers & Worm, 2003; Watson & Kerstetter, 2006). Although this gear is often considered to be more selective when compared with gillnetting and trawling (Berninsone et al., 2020; Lewison et al., 2004), it continues to catch large numbers of sea turtles and other non-target species (Carranza et al., 2006; Deflorio et al., 2005; Garrison & Stokes, 2017; Ovetz, 2007).

A conservative estimate of fisheries data suggest that bycatch represents 40.4% of global marine catches (Davies et al., 2009). Many studies have focused almost exclusively on industrial fishing in industrialised countries (Casale et al., 2017; Tagliolatto et al., 2020; Swimmer et al., 2020), given that in most countries there is little data on the artisanal fishing effort, catch, or bycatch of sea turtles, seabirds and marine mammals (Moore et al., 2010; Shester & Micheli, 2011). However, recent evidence has highlighted the potential for artisanal fishing to have significant negative impacts on sea turtles (e.g., the Caribbean: Blades et al., 2019; Rojas-Cañizales et al., 2020; Peru: Alfaro-Shigueto et al., 2011; Ayala et al., 2019; Kenya: Kakai, 2019 or Ecuador: Darquea et al., 2020), cetaceans (e.g., Ecuador: Alava et al., 2019; Peru: Bielli et al., 2020; Mangel et al., 2010), sharks or mobulids (Indonesia: Mustika et al., 2021) or seabirds (Western Mediterranean: Cortés & González-Solís, 2018). With artisanal fisheries comprising >95% of the world's fishers, this knowledge gap needs to be evaluated (Shester & Micheli, 2011). Previous assessments of sea turtle bycatch due to industrial longline fishing indicate significantly higher catch rates with narrower J and tuna hooks and with squid bait compared to wider and large circle hooks (18/0) equivalent to ≈4.9 cm and fish as bait (Gilman & Huang, 2017; Gilman et al., 2020; Swimmer et al., 2017). However, the target species for most artisanal fishing are medium and small-sized fish which are usually caught in medium-sized hooks (Gilman et al., 2018, Alfaro-Shigueto et al., 2010).

The largest small-scale artisanal fishing fleets of the Eastern Pacific Ocean (EPO) are in Ecuador (Alava et al., 2015), with an estimated annual sea turtle bycatch of 40 480 individuals, which represents approximately 5.3 sea turtles per 1000 hooks (Maunder et al., 2021); and account for 87% of the total bycatch from Chile to Ecuador (Alfaro-Shigueto et al., 2018). These fleets mainly use longlines and gillnets to catch several species (tuna, billfish, sharks and mahi-mahi; Coryphaena hippurus) (Martínez-Ortiz et al., 2015). Even in the Galapagos, where marine megafauna is protected since 1998, these protected species are still being caught (Cerutti-Pereyra et al., 2020). In addition to the ecological impact, this incurs an economic cost for the fishers due to the damage or repair of the fishing gear (repaired by themselves) and loss of hooks (between 10-20$ per year/own data) due to the interaction with the turtles (Hall et al., 2000).

To gain insights into the impact of bycatch and the other financial, behavioural and environmental challenges faced by small-scale fishers, we initiated a questionnaire survey to assess fishers' perception of the problem (Gaibor, 2016; Panagopoulou et al., 2017; Mustika et al., 2021). Most previous studies have been based on observers obtaining large-scale data on bycatch and then evaluating fishing gears separately and not in an integrated way by considering all the fishing gears affecting sea turtle populations individually (Marco et al., 2020). In this context, knowledge about the difference of perceptions of bycatch is essential to reach a global overview of this current threat in order to reduce its impact (Wallace et al., 2011). In addition, both approaches (the fishers' replies to questionnaires and the data from observers) should provide a more accurate assessment than the current limited sea turtle bycatch estimates (Carreras et al., 2004; Barrios-Garrido et al., 2020).

There are many socio-cultural constraints related to the culture of fishing, such as values of conservation, family relationships and hierarchies, fishing knowledge and beliefs (Teh et al., 2015), all of which hamper effective knowledge transfer or implementation, thereby necessitating a multidisciplinary conservation approach (Komoroske & Lewison, 2015). Alexander et al. (2017) found that sea turtle conservation strategies succeed when the cultural and social traditions of local communities are integrated with management activities. Therefore, it is essential to evaluate whether there is a difference or discrepancy between the fishers' perception of the phenomenon and the observers' data concerning the incidental catch of turtles, since each stakeholder group may have an unique perspective towards these conflicts (Barrios-Garrido et al., 2019). Understanding how fishers perceive the problem has significant implications for management and policies (Mason et al., 2020; Moore et al., 2010; Awabdi et al., 2021). Although, perceptions and attitudes are difficult to change (de Carvalho et al., 2016), raising awareness robustly should help this conceptual change and, consequently, lead to a change in behaviours (Fu et al., 2020). There is a necessity to assess both approaches (fishers' perception and observer data) at global and regional scales simultaneously, such as in the EPO fisheries, as it might determine the future of these populations (Alfaro-Shigueto et al., 2018; Darquea et al., 2020 and Gaidor, 2016). Using the largest small-scale fleets in the EPO as a case study will highlight the differences between the fishers' perception of the problem and the data provided by on-board observers.

In this paper, we aim to: i) estimate and characterise the bycatch of sea turtles in the EPO according to the fisheries observer data; ii) identify the fishers' perceptions concerning bycatch; iii) compare the results obtained from both approaches, and iv) propose concrete recommendations for conservation management to reduce this worldwide phenomenon and at a local level.

MATERIAL AND METHODS

Observer data

A monitoring programme using fisheries observers was implemented from August 2008 to June 2018 regarding small-scale longline fishing (a "mother ship" fleet) from the fishing ports of Manta (Ecuador). This programme represents a small percentage of the Ecuadorian fishing fleet (10% for 2022; ACUERDO Nro. MPCEIP-SRP-2021-0208-A https://vlex.ec/vid/mpceip-srp-2021-0208-876693938). The observer data were provided by PAT – Ec, which is part of the National Plan for the Fisheries Control of Ecuador (PNCP – Ec). Observers were trained in biological and fishing data collection by the undersecretary of Fishery Resources (SRP); using the "Programa Nacional de Observadores Pesqueros de Ecuador" (PROBECUADOR). The information recorded in 160 boats included: target fish, hook type, number and size, type of bait, number and species of turtle caught, coordinates and date (Manual para el observador a bordo, Ministerio de acuacultura y pesca). These 160 boats each made between 1 and 29 fishing trips per year (mean ± SE = 5.5 ± 5), and between 1 to 20 sets (the action and result of releasing the longline) per trip (mean 4.3 ± 3). Therefore, we analysed 1,363 sets, representing 17,965 of fishing hours. The soaking time (number of hours of the set in the water) (between 5 and 45; mean ± SE= 13.2 ± 7) and the number of hooks per set (between 8 and 1,680; mean ± SE= 322 ± 263) were used to estimate the Catch Per Unit of Effort (CPUE) = (number of catches / hour / 1,000 hooks).

Observers recorded the catch composition (target and bycatch species) per set. The fish species were categorised for the statistical analysis, such as: tunas (Thunus obesus, T. albacaren or T. alalunga), billfish (Xiphias gladius, Makaira nigricans or Istiophorus platypterus) and mahi-mahi (Coryphaena hippurus) (this clustering is similar to Parga et al., 2015). The hooks were grouped into two categories, circle (C14, C15 and C16) and J (J1, 2, 3, 4, 5, 7, 8, 34, 36, 38 and 40) (see Mituhasi & Hall, 2011 for more details). The baits were grouped into: fish, squid and small scombrids (Auxis spp.). The seasons of the year were grouped into: winter (from December to May) and summer (from June to November) (Table 1). The setting depth depends on the season and varies between 12-16 metres in winter (mahi-mahi) and between 20 and 30 metres in summer (tuna and billfish). The characterization of the study longline fishing is detailed in table S1.

Table 1. *Percentage of catches of the target species according to the type of hook, type of bait and season*

Target species	Hook Type	Bait type	Season	Average hook per set (nº)	Average hour set in water
Tuna (*Thunnus*)	J38 78% J36 10% C16 9%	Squid 46% Auxis 33% Fish 21%	Summer 59% Winter 41%	248±182	14±7.1
Billfish (Istiophoridae and Xiphiidae)	J38 79% J36 10% C16 9%	Squid 49% Auxis 34% Fish 17%	Summer 75% Winter 25%	295±336	13.7±6.9
Mahi mahi (*Coryphaena hippurus*)	J4 66% J5 13% J3 11%	Squid 45% Auxis 43 % Fish 12%	Winter 62%, Summer 38%	480±272	11.2±6.1

Fishers’ survey

The total population of artisanal fishers is made up from 63,972 Ecuadorian fishers (Alava et al., 2015). Therefore, the minimum number of fishermen required to survey for the sample to be representative according to the population was 382 (Singh & Masuku, 2014). In total, 421 fishers participated in the survey: 51 answered the online version of the questionnaire and 370 the in-person questionnaire (Table S2). Age and years of experience were also registered since previous studies have showed that the fishers’ perception may change according to these variables (Bender et al., 2014).

Fishers’ perceptions

The questionnaire was divided into two parts (i) the fishers’ experience, type of fishing gear, bait and boat used, and sociodemographic variables (Annex 1), and (ii) the fishers' perceptions about the problem of sea turtle bycatch. In the first part, questions were included about: whether they had experienced the bycatch of sea turtles and its frequency; their perceptions of trends in sea turtle bycatch in the last ten years; what gear, types of baits, season, or hooks they think cause the most bycatch. In the second part of the questionnaire, we asked questions such us: Is such bycatch a nuisance? Do they have a major environmental impact? Or, are they not relevant?

The development of the questionnaire follows three differentiated steps that provide it with precision and reliability (Gracia et al., 2021):

1. Selection and formulation of the items. Firstly, a review of the literature was carried out in order to identify the different variables that may influence sea turtle bycatch.
2. Content validation by the panel of scientific experts. Secondly, a panel of experts judged the instrument's clarity, pertinence and relevance using a Likert-scale (Annex 2). Then, the validation of the items in terms of content led to include some adaptations.
3. Comprehension validation. Thirdly, after modifying the instrument considering the experts' suggestions, it was carried out on to 30 fishers (face-to-face) following the recommendation of Beaton et al. (2000) and Serrano et al. (2020) to analyse its comprehension.

After these validation processes (content and comprehension), the questionnaire was composed of 16 sociodemographic questions and 13 closed questions about bycatch. The average time taken to fill in the questionnaire was 15 minutes per fisher. The results of the content validation are shown in Annex 2.

Questionnaire implementation

The sampling technique applied was convenience sampling (Emerson, 2015) as fishers were selected based on availability and willingness to take part. Fishers were previously informed about the purpose of the present study and research ethical principles were applied to protect their anonymity, dignity, rights and welfare throughout the whole research project. Collecting the information from the fishers took place from June 2020 to November 2020 in ports of the province of Manabí and Esmeraldas. Two strategies were used to recruit participants for the study. First, in-person surveys were conducted in the ports of P. Lopez, P. Cayo, Machalilla, Jaramijó, Salango, S. Lorenzo, Pampanal, Tambillo and Manta (see Annex 3). These ports include the main points of artisanal and industrial fishing catches in Manabí and Esmeraldas (Ecuador). The questionnaires were completed in the presence of the fishers (n=370), by the interviewer. Simultaneously, we conducted an online questionnaire during the same period using the

Google Forms tool (n=51). The online questionnaire was also promoted by the fishers' cooperatives and guilds of Manabí and Esmeraldas.

To account for any uncertainty and potential bias in this convenient sampling method, we took some precautions and applied controls before the data analyses (Maas et al., 2021), for example: (i) distributing the survey online and on paper; (ii) distributing the survey at 9 ports to achieve higher levels of diversity and sample size in our survey (annex 3); (iii) controlling demographic representativeness by comparing our survey sample to census data concerning the fishers, showing a high level of representativeness for age and a higher representation of artisanal groups compared to the overall fishing populations. In addition, sampling bias was avoided through; (iv) the participants' self-identification with the type of fishing that the fishers practice, type of boat, and type of fishing gear used, (v) reliability analyses of scale (Cronbach's Alpha for internal validity). Cronbach's Alpha was above 0.70 for our scale, representing a good level of fit (e.g., Cortina, 1993).

Data analysis

With respect to observer logbook data, one GLM (observer model) was carried out where the Catch Per Unit of Effort (CPUE) was included as response variable. In the case of fishers' perception one GLMM (fishers' model) was performed where number of turtles bycatch by fishers was included as response variable (frequency of the fishers' perception of bycatch). In the observer model, the target species (3 levels), hook type (2 levels, circle vs J-hook), bait type (3 levels), turtle species (5 levels), and season (2 levels) were included as factors. The year was included as a random factor (ten levels). In the fishers' model, the target species (2 levels), fishing gear (3 levels), hook type (2 levels), bait type (3 levels), turtle species (4 levels), and time of year (2 levels) were included as factors. The port was included as a random factor (six levels). For the observer model, a normal distribution with an identity link function was used, while for the fisher's survey model, Poisson distribution with a log link function was used. Fisher's Least Significant Difference (LSD) post-hoc test was also applied to check for response differences among different levels of categorical variables. The most plausible models were selected by comparing Akaike's information criterion (AIC) (Burnham & Anderson, 2002) following a backward procedure (Zuur et al., 2009). The statistical analyses were performed using InfoStats software.

RESULTS

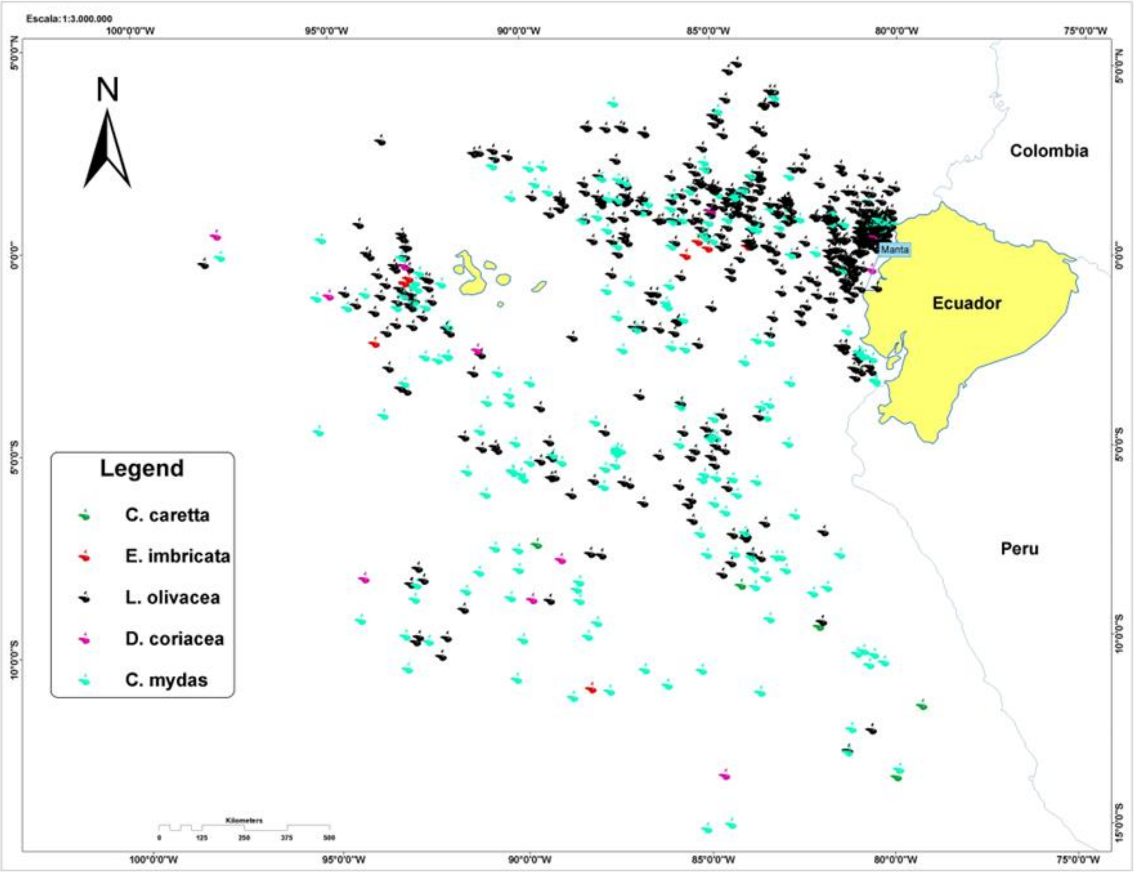
Survey respondents

There were more men (n = 417) than women (n = 4) among the respondents, as well as a predominance of the intermediate age-class (30-45). The participation of older people and artisanal fishers was lower for the online questionnaire than the in-person questionnaire. The specialised fishing gear most commonly used were the gillnet (51%), followed by the longline (44%) and trawl net (5%). Artisanal fishers represented 94% of the responders, while professional fishers (working for a company for a salary) represented only 6% of the questionnaire's respondents.

Sea turtle bycatch data from observers

According to the observers' data, 1,838 sea turtles were captured incidentally during the study period (figure 1), of which 72.3% were olive ridley (Lepidochelys olivacea), 23.7% green (Chelonia mydas), 1.5% leatherback (Dermochelys coriacea), 1.3% hawksbill (Eretmochelys imbricata), 0.8% loggerhead (Caretta caretta) and 0.4% undetermined sea turtles. In contrast, fishers identified that the green turtle was the most frequently caught species (46%), whereas they stated the olive ridley and hawksbill turtles to be caught at a lower rate, 27% and 24.7% respectively (Table S3). The mean number of turtles caught incidentally per set was 1.3 ± 1 (range between 1 and 13), with an average of 4.2 sea turtles caught incidentally per 1,000 hooks.

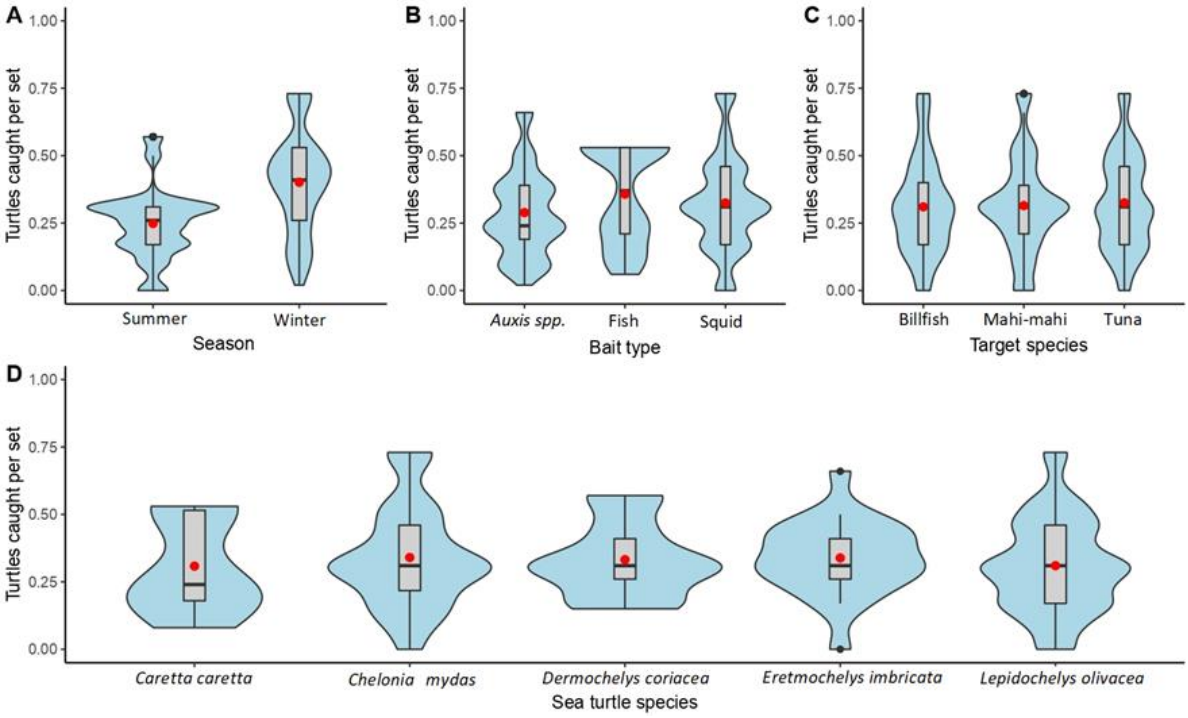
Figure 1. *Location of sea turtles captured incidentally on longlines*



Observers' model

Regarding the factors that influence the incidental catch of sea turtles, according to the observers' data (model 1), the results show the effect of the target species, the season, the type of bait and the turtle species (Table 2). The results show significantly more bycatch in winter (Figure 2a) and when squid is used as bait (Figure 2b). As for the target species, results show significant differences between when the intended catch was mahi-mahi and when it was other species (tuna or billfish), with a higher bycatch percentage of sea turtles when mahi-mahi was the target species (Figure 2c). Finally, there are significant differences between the proportions of turtles captured, with a particular predominance of the olive ridley turtle (Figure 2d).

Figure 2. *Violin plots of predicted values of the catch per unit effort according to: a) season b) bait type c) target species and d) sea turtle species, according to the observers' data (model 1). The thick grey bar in the centre represents the interquartile range and the width of the violin represents the sample size. Red point and horizontal black line represent mean and median respectively.*



Fishers' model

Regarding the factors that, according to the fishers, influence bycatch (model 2), the results show the effect of the type of hook, the season, the target species, the turtle species and the fishing gear (Figure 3). The highest incidental catch rates occur with the J-hook (figure 3a), in winter (figure 3b) and on a longline (figure 3c). The results also show that the highest rates of bycatch occur when the target species are pelagic fish (Figure 3d). Finally, there are significant differences between the proportions of turtles captured, with a particular predominance of the hawksbill turtle (Figure 3e).

Figure 3. *Violin plots of the predicted values of the number of sea turtle by-catch according to: a) hook type b) season c) fishing gear d) target species and e) sea turtle species, according to the fishers' data (model 2). The thick grey bar in the centre represents the interquartile range and the width of the violin represents the sample size. Red point and horizontal black line represent mean and median respectively.*

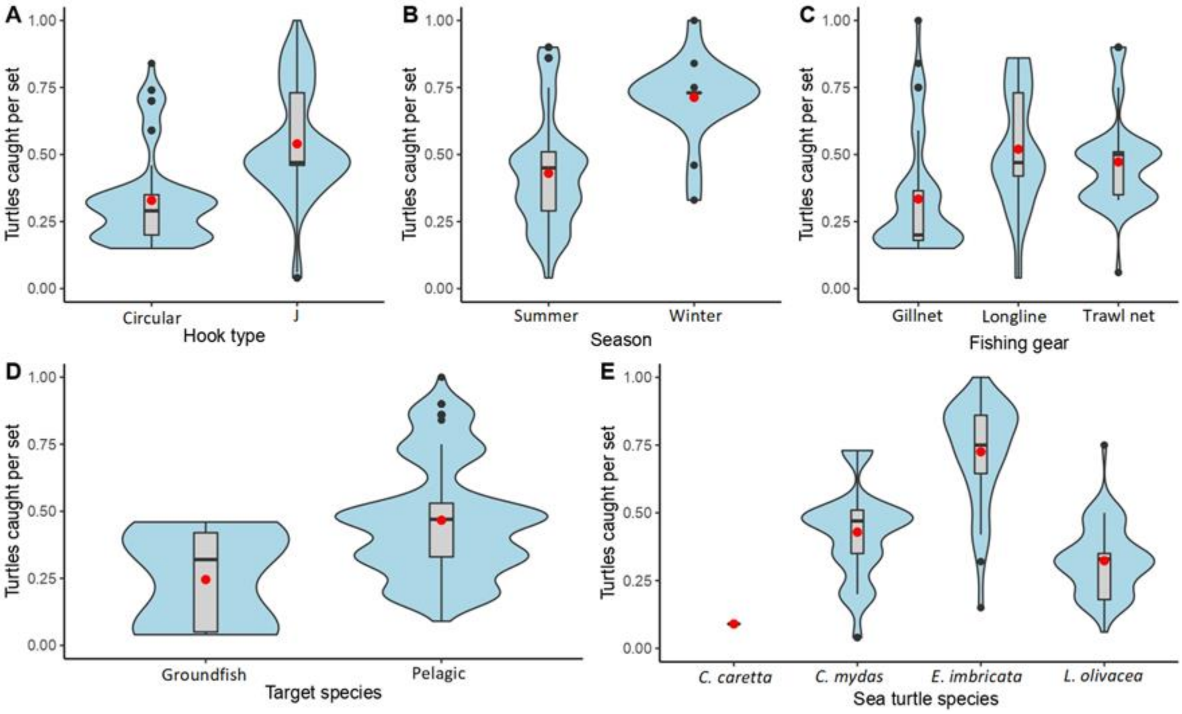


Table 2. *F, p-values and coefficients of the variables included in the mixed linear model to explain the by-catch of sea turtles according to the observers' data (Model 1) and fishers' perception (Model 2). The coefficients for the level of fixed factors were calculated according to the reference value of 'tuna' (in model 1) and 'groundfish' (in model 2) for the variable 'target species', 'loggerhead' for the variable 'sea turtle', 'winter for the variable 'season', 'Auxis spp' for the variable 'bait type' (model 1) and 'gillnet' for the variable 'fishing gear' (model 2).*

Model 1: Observed data			
Variables	**F-value**	**p-value**	**Estimate ± SE**
Target species	11.03	<0.001	Mahi-mahi = 0.29 ± 0.08 Billfish = -0.16 ± 0.07
Turtle species	5.17	<0.01	Olive ridley = 0.56 ± 0.29 Hawksbill = 0.47 ± 0.33 Green = 0.25 ± 0.17 Leatherback = 0.12 ± 0.25
Season	10.44	<0.001	Summer = -0.17 ± 0.09
Bait type	7.46	<0.01	Squid = 0.09 ± 0.07 Fish = -0.12 ± 0.07
Model 2: Fishers' perception			
Hook type	12.2	<0.001	J-hook = 0.4 ± 0.21
Season	4.43	<0.01	Summer = -0.21 ± 0.10
Target species	4.05	<0.01	Pelagic = 0.36 ± 0.07
Turtle species	3.33	<0.05	Hawksbill = 0.42 ± 0.14 Green = 0.33 ± 0.24 Olive ridley = 0.29 ± 0.27
Fishing gear	2.64	<0.05	Longline = 0.28 ± 0.07 Trawl net = 0.05 ± 0.02

Data from observers vs the fishers' perception

The fishers' perception of bycatch was heterogeneous throughout the participants sampled, highlighting that age and years of experience influence the perception of bycatch (Annex 4). According to our results, 39% of the fishers answered that bycatch is an important environmental problem, while 32% and 29% answered that it is not relevant or is a nuisance, respectively. Their perception of the temporal trends in the last ten years of bycatch is that it remains constant, which is similar to data reported by the observers. Concerning the question of what fishing gear was associated with more accidental catches of turtles, 43% point to the longline; followed by the gillnet 31% and the trawl net 26%. With respect to the bait, squid was the bait most indicated by the observers as responsible for bycatch (60%), followed by fish (35%), which coincides with what is reported by fishers (Table 3), where squid represented 57% and fish 40%. Both the data from the observers and the perception of the fishers show that winter is the season with the most bycatch. For the target species, 78% of fishers highlight that bycatch occurs when pelagic species (included mahi-mahi, tuna or billfish) are selected, while in the case of observers, mahi mahi was involved in 53% of the captures. As for the moment at which the bycatch occurs, 60% of the respondents stated that it occurs when the fishing gear is already set versus 14% hauling or 26% setting fishing gear (Annex 4). In addition, 70% indicated that the bycatch was due to entanglement with fishing gear. Finally, 63% said the J-hook was responsible for the bycatch.

DISCUSSION

This study found that sea turtle bycatch is associated with factors such as hook type, bait type, fishing gear, season, fishing effort and target species. However, we also found differences between observer data and fishers' perceptions. It is noteworthy that 61% of fishers perceive incidental fishing as a nuisance (economic loss or damage to fishing gear) or not relevant and only 39% as an environmental problem, which represents that 61% of fishers are not aware of the conservation needs for the protection of sea turtles.

Factors that determine the bycatch of sea turtles

According to the observers' reports, the main factors associated with turtle bycatch detected in this study were bait type, target species and season. However, the hook type was not found to be a significant factor, possibly because most J-hooks used in the EPO are slightly smaller than circle hooks, which possibly cause the same probability of being swallowed (Parga et al., 2015) but J-hooks cause much more damage and deaths (Parga, 2012). Previous studies such as Foster et al. (2012) in North Atlantic Ocean, Yokota et al. (2009) in Western North Pacific or Coelho et al. (2015) in Tropical Northeast Atlantic Ocean have already shown that squid increases bycatch as it is difficult to separate from the hook and it is swallowed whole (Serafy et al., 2012; Stokes et al., 2011). In the case of the target species, mahi-mahi is the main species linked to the capture of sea turtles, especially for the olive ridley turtle (Whoriskey et al., 2011, Costa Rica's Pacific; Bugoni et al., 2008, Southern Brazil). The results also showed winter as the maximum catch period, which coincides with the peak of mahi-mahi catches as well as when fishing occurs (Andraka et al., 2013; Whoriskey et al., 2011). However, this may be related to the depth of the set, since the mahi-mahi fishing terminal gear is set at between 12-16 m deep in winter, while in summer tuna and billfish are deeper, at 20-30 m. Previous studies in Madeiran Waters (Dellinger & Ferreira, 2005), Mediterranean Sea (Alessandro & Antonello, 2010) or Atlantic and North Pacific (Swimmer et al., 2017) have shown that the main interaction depth with longlines is in the upper 20 m of the water column, especially when hooks are set between 10 and 15 m deep, which coincides with the mahi-mahi relatively shallow fishing strategy.

Data from the observers vs fishers

Data from fishers were collected in 2020 and from fishery observers from 2008 to 2018. Data from observers and fishers coincide in that winter is the period of most bycatch and that pelagic species are the target catch when the bycatch occurs but differ in those fishers highlight the role of longlines as the most harmful fishing gear for turtles compared to trawl nets and gill nets (Annex 4). This was also identified at other locations such as in the Equatorial Eastern Atlantic (Carranza et al., 2006) or US North Atlantic (Watson et al., 2005). With this gear, the turtle ingests the hook with the bait, up to 40% deep in the throat with the highest probability of mortality (Parga, 2012; Stokes et al., 2011; 2012; Swimmer et al., 2014). According to the fishers' perception, nets rank second in the causes of bycatch and the mortality of sea turtles, as in Pacific or Atlantic fisheries, especially at the highest levels by gillnets and trawl nets (Awabdi et al., 2021; Pingo et al., 2017; Wallace et al., 2010; 2013). Regarding the type of hook, fishers do indicate that the J-hook is responsible for a higher bycatch rate compared to circle hook (Annex 4), up to 19.3 turtles per 1000 hooks for longlines (eastern Pacific Ocean) (Wallace et al., 2010), with the dimensions (length) of between 41 to 60 mm and 20 to 30 mm having the greatest rates of turtle bycatch (Caracappa et al., 2018).

The bycatch rates obtained in this study (4.3 turtles per 1,000 hooks) are comparable to those extrapolated from the results of Barragan et al. (2009) in Machalilla National Parks (Ecuador), which are approximately 4.8 turtles per 1,000 hooks, or those reported by Whoriskey et al. (2011) in Costa Rica's Pacific, where bycatch rates were 9.05 per 1000 hooks for olive ridley turtle and 0.35 per 1000 hooks for green turtles. On the other hand, they are relatively higher than those reported by Wang et al. (2021) in the Pacific Ocean, Gilman et al. (2007) in Hawaii longline fleet or Jaiteh et al. (2021) in the western Pacific Ocean (Caroline Islands) with sea turtle bycatch rates ranging from 0 to 0.024/1000 hooks, 0.094/1000 hooks and 0.29/1000 hooks, respectively.

In this study, the observer data indicated higher frequency of catch of green and olive ridley turtles, while the fishers' data identified hawksbill turtles to be most frequently captured. In this sense, it is important to train fishers in species identification to improve accuracy of fisheries data collection (Fulton et al., 2019). Awabdi et al. (2021) in southeastern Brazil also found that green turtle was the most-captured species with all fishing gear (gillnet, trawl net and longline) according to the fishers' perception, and Huang & Liu (2010) highlighted the capture of the olive ridley turtle by tuna longline fleets in the Indian Ocean.

Quantitative inclusion of the human element can increase our understanding of marine conservation issues (Awabdi et al., 2021; Primack et al., 2021). Our results highlight the fact that age and years of experience modify the perception of bycatch, as Bender et al. (2014) observed. Additionally, other parameters such as educational or socioeconomic level also have an effect on perception (Pont et al., 2016). For instance, a more negative perception towards South American sea lions was found among less educated fishers who had no other source of income besides fishing. Sanguinetti et al. (2021) found that older fishers with less formal education have a high focus on maximizing fishing yield, while younger fishers have a more sustainable and conservationist view of fishing. Similarly, Liu et al. (2019), found that artisanal fishers' perceptions of marine mammals were predicted by fishing experience and education level. Therefore, it is relevant to include these parameters in studies of this type.

This study has showed that only 39% of fishers perceive incidental catch as an environmental problem, 60.6% consider it as a nuisance or not relevant. This coincides with the results of Aguilar-González et al. (2014) in the Gulf of California, where individual fishers do not see themselves as part of the problem. Although data concerning perception could be biased, since fishers may consider bycatch to be a larger problem than they indicated in the questionnaires because of concerns regarding their livelihoods or negative previous experiences such as damaging nets, spoiling catch, removing bait, or the endangered status of the species (Godley et al., 1998). However, validating the fishers' answers with data collected directly by observers on the fishing vessels could help to minimise this bias (Carreras et al., 2004). Finally, understanding how worldwide fishers perceive and use resources has significant management and policy implications (Awabdi et al., 2021), which would allow the development of robust management models for sustainable fishing, as pointed out by Karnad et al. (2014).

National and international interpretation of the results

At the national level, the results showed the high-level impact that the artisanal fleet has on sea turtles, which was similar to previous studies (Alfaro-Shigueto et al., 2011; 2018); highlighting that the season (winter) and type of hooks used with mahi-mahi are associated with bycatch of sea turtles (Andraka et al., 2013). Although Ecuador is implementing measures to reduce the bycatch of sea turtles and other megafauna (such as adoption of circle hooks, distribution of tools and training to unhook turtles from hooks or fisheries observer programs (https://www.iattc.org/GetAttachment/), these policies are still insufficient or not implemented by fishers (Alava et al., 2019). For this reason, empowering fishers' governance is crucial to mitigate megafauna bycatch. At an international level, the results coincide with other studies in the EPO region, which highlight that in order to expand the use of circle hooks in the EPO region, governments should guarantee the availability of circle hooks at competitive prices in each country, and fishery authorities should implement regulatory measures in the use of tools to handle and release turtles (Parga et al., 2015). Therefore, the certification of the implementation of sustainable practices should be presented to fishers as a chance to access international, environmentally sensitive markets. Likely, measures at the international level should invest on scientific data collecting, training, support for the role of women, access to new technologies (by-catch reduction technologies) and promote more sustainable fishing practices (similar to https://oceans-and-fisheries.ec.europa.eu/fisheries/rules/small-scale-fisheries_en)

Limitations

Despite the large amount of information generated by the "Ecuador National Fisheries Observer Program", it only represents a small percentage of the Ecuadorian fishing fleet (10% for 2022; ACUERDO Nro. MPCEIP-SRP-2021-0208-A). Onboard observers can only be efficiently placed on one of the two decks, and information is provided by the crew to complement it, underestimating bycatch estimates (Luck et al., 2020), especially when bycatch estimation is of a lower priority (Forget et al., 2021). The longline fleet is the only one monitored by fisheries observers, while other fishing gears (such as gillnets or trawls) are absent. Another limitation is the possible bias of the fishers when answering the questions due to the fact that their perceptions depends on their memory and bycatch numbers could not be accurate (Mustika et al., 2021). To avoid this, it is relevant to include educational or socioeconomic variables in this type of studies (Pont et al., 2016); and to carry out studies with holistic approaches, where research integrates insights from local fisher communities with large-scale, long-term monitoring programs (Vásquez-Carrillo & Peláez-Ossa, 2021). Natural sciences are increasingly recognizing the value of social science methods for conducting conservation research, through interdisciplinary collaboration (Lowe et al., 2009). In this sense, there is also a growing foray by ecologists into social science realms (Awabdi et al., 2021; Lowe et al., 2009; Moore et al., 2010). For this study, we found several obstacles to achieve our research objectives, which were solved by collaboration with social scientists.

Management implications and recommendations to reduce bycatch

In summary, based on our results and previous studies, we propose a series of management measures and recommendations that could contribute to minimising the current bycatch rates (see Annex Table S4). Firstly, we recommend (i) evaluating and using the knowledge of the fishers as a tool to diagnose the situation in a time efficient manner (Vásquez-Carrillo & Peláez-Ossa, 2021), (ii) implementing the most turtle friendly type and size of hook and/or type of bait (larger, circular hooks and fish as bait) (see Swimmer et al., 2020), (iii) evaluating the fishers' willingness to adopt bycatch reduction technologies (e.g. LEDs; Bielli et al., 2020; Darquea et al., 2020; Allman et al., 2021), (iv) implementing economic compensation, such as ecological labels or subsidies that would provide added value or incentives for fishers carrying out sustainable practices (Leduc & Hussey, 2019). Finally, (v) the implementation of education and awareness campaigns is also essential, since 32% of fishers do not see this situation as a problem. Legislative changes and political measures must include the fishers' perception (hook, bait, fishing bans) and monitoring programmes (both scientific and citizen science) in any management plans since any action without their active participation and cooperation might fail (Mason et al., 2020). This may be of help to researchers and policy makers to achieve a better managed, sustainable fishery (Panagopoulou et al., 2017). In this sense, we recommend addressing the gap between the fishers' perceptions and behaviour as part of the development of environmental policies at the local, regional and national level which, in turn, should then contribute to reducing the significant global impact of bycatch on sea turtles and other species caused by artisanal fishing.

DISCUSIÓN GENERAL

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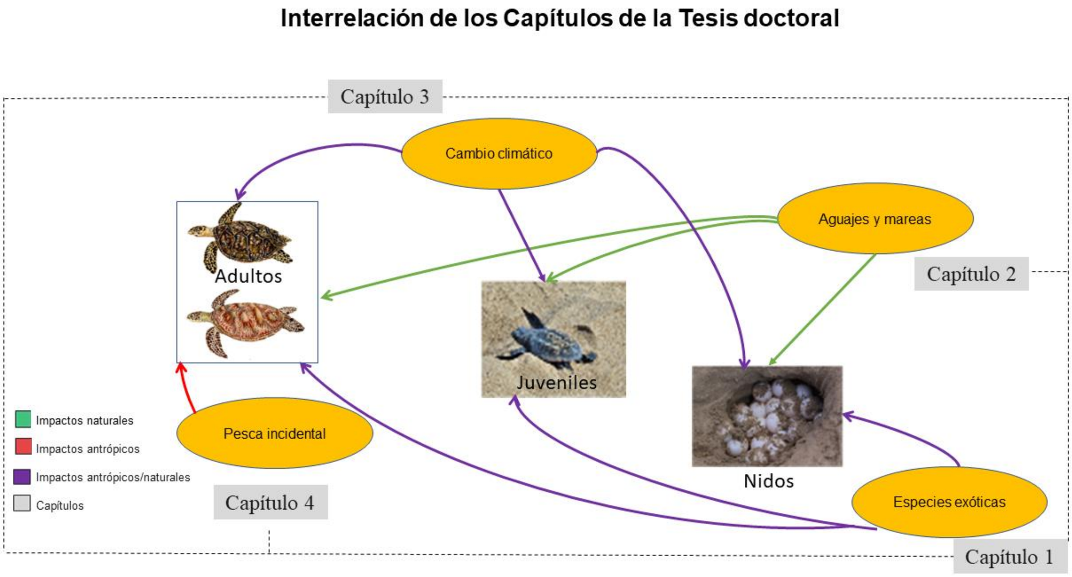
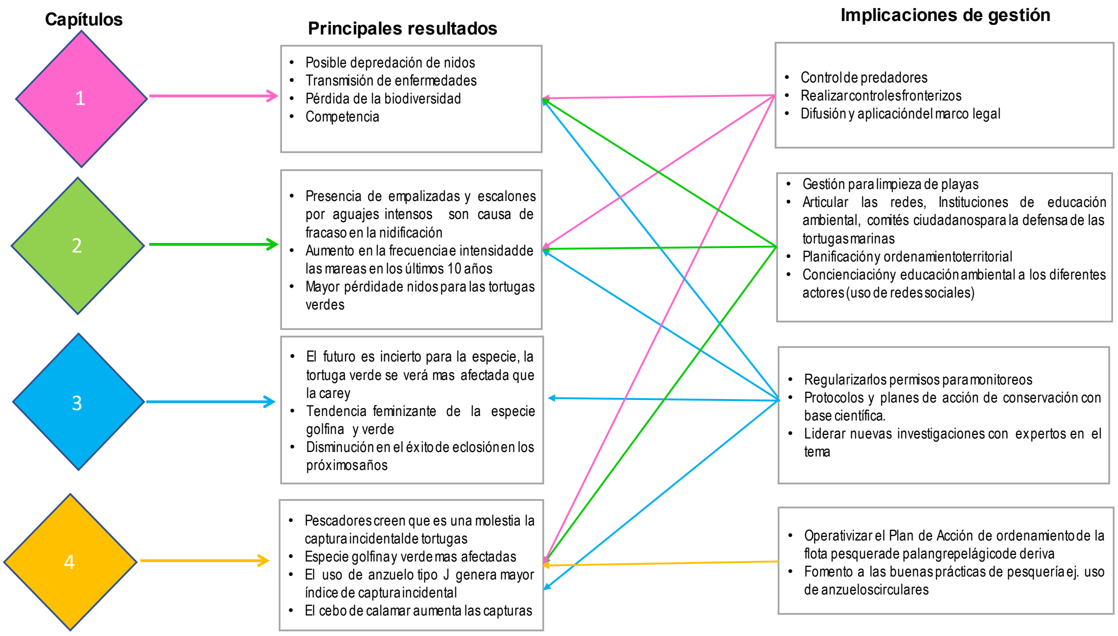
Este apartado expone los contenidos más relevantes de la presente *Tesis Doctoral*, poniendo especial atención en resaltar los resultados más destacados, interacciones e implicaciones de diversa índole entre los diferentes elementos de las amenazas de las poblaciones de las tortugas marinas estudiadas (Figura 5).

Figura 5. *Interrelación entre capítulos de la Tesis doctoral.*



Esta sección se centra en los aspectos relativos a la interrelación de los resultados de los diferentes capítulos de la tesis, ya que las discusiones individuales han sido ampliamente presentadas en cada capítulo. En la tabla 2 se observan las conexiones establecidas entre los principales resultados derivados de cada capítulo y las principales estrategias de gestión derivadas de esta tesis doctoral. Esta tabla muestra la importancia y complementariedad de realizar estudios que incluyan ambas amenazas para las poblaciones de tortugas marinas (pérdida de sitios de nidificación y mortalidad adulta). Además, cabe destacar el papel que tiene la introducción de especies exóticas, como un elemento sinérgico de estas amenazas.

Tabla 2. *Interrelación de los principales resultados de los diferentes capítulos de la Tesis e implicaciones de gestión para las poblaciones de tortugas marinas*.



Principales resultados

- Posible depredación de nidos
- Transmisión de enfermedades
- Pérdida de la biodiversidad
- Competencia

- Presencia de empalizadas y escalones por aguajes intensos son causa de fracaso en la nidificación
- Aumento en la frecuencia e intensidad de las mareas en los últimos 10 años
- Mayor pérdida de nidos para las tortugas verdes

- El futuro es incierto para la especie, la tortuga verde se verá mas afectada que la carey
- Tendencia feminizante de la especie golfina y verde
- Disminución en el éxito de eclosión en los próximos años

- Pescadores creen que es una molestia la captura incidental de tortugas
- Especie golfina y verde mas afectadas
- El uso de anzuelo tipo J genera mayor índice de captura incidental
- El cebo de calamar aumenta las capturas

Implicaciones de gestión

- Control de predadores
- Realizar controles fronterizos
- Difusión y aplicación del marco legal

- Gestión para limpieza de playas
- Articular las redes, Instituciones de educación ambiental, comités ciudadanos para la defensa de las tortugas marinas
- Planificación y ordenamiento territorial
- Concienciación y educación ambiental a los diferentes actores (uso de redes sociales)

- Regularizar los permisos para monitoreos
- Protocolos y planes de acción de conservación con base científica.
- Liderar nuevas investigaciones con expertos en el tema

- Operativizar el Plan de Acción de ordenamiento de la flota pesquera de palangre pelágico de deriva
- Fomento a las buenas prácticas de pesquería ej. uso de anzuelos circulares

La tesis doctoral presentada pretende completar algunos vacíos de conocimiento relacionados con el estado de conservación de las poblaciones de tortugas marinas y sus amenazas en la costa continental de Ecuador. Estas especies se enfrentan a desafíos derivados de las actividades humanas (pesca incidental, pérdida de sitios de nidificación) y del cambio climático (aumento del nivel del mar, aumento de la frecuencia e intensidad de eventos de mareas extremos y de la temperatura), que ponen en riesgo la viabilidad de sus poblaciones a medio y largo plazo (Pike et al., 2013; Maurer et al., 2021; Tomillo et al., 2021). Estos trabajos, muestran como las predicciones de la resiliencia de las tortugas marinas al cambio climático a menudo se centran en como el sesgo en los sex-ratios hacia la feminización de la población o la producción reducida de crías (debido a la alta mortalidad por las elevadas temperaturas), pueden afectar sus poblaciones. A esto se suma la subida del nivel del mar, Rivas et al. (2023) pronostican que en algunos hábitats de anidación de tortugas marinas se inundará el 100%, y en un escenario extremo muchas colonias de tortugas marinas podrían desaparecer.

En este contexto de cambio (tanto en las condiciones naturales como en la presión antrópica), esta tesis se enfoca en América Latina ya que es uno de los lugares con mayor biodiversidad del mundo (Myers et al., 2000). Sin embargo, la introducción de especies exóticas en la región se ha convertido en una preocupación creciente debido a su impacto negativo en el medio ambiente según la Plataforma Intergubernamental de Ciencia y Política sobre Biodiversidad y Servicios Ecosistémicos (IPBES). En ese sentido los resultados del **primer capítulo** de la tesis mostraron que la principal razón para la introducción de las especies en América Latina es el comercio de especies exóticas, las cuales son en su mayoría introducidas intencionalmente (69 especies de mamíferos y 62 de aves exóticas). Esto ha provocado un impacto significativo en la biodiversidad de los ecosistemas de la región, con muchas especies en peligro de extinción, entre las que se incluyen las tortugas marinas.

De acuerdo a los informes de la *Convención Internacional de Especies Amenazadas de Fauna y Flora Silvestre* (CITES), la introducción de especies exóticas en Latinoamérica se da principalmente por el comercio de mascotas (representa el 70,9% de las introducciones). Lo anterior concuerda con los resultados de la investigación, que concluyen que, el tráfico de mascotas y la caza fueron los dos elementos de introducción más importantes en las aves (44 y 12 especies, respectivamente) y los mamíferos (27 y 26 especies).

Estudios similares mencionan que la introducción de especies es un factor importante y creciente para la pérdida de la biodiversidad (Capdevila et al., 2013). Además, el Informe del IPCC 2022 menciona que las especies introducidas pueden reemplazar a las especies nativas y/o competir con ellas además de alterar el ecosistema. En este sentido, estudios realizados por Buitrago et al. (2015) han demostrado que la depredación de huevos y neonatos de tortugas marinas se da por especies introducidas como perros, gatos y ratas. En las playas de República Dominicana las tortugas marinas han registrado depredación total o parcial de nidos por parte del cangrejo fantasma, larvas de insectos, perros y cerdos salvajes (Tomás et al., 2006). En una de las zonas de estudio, “Refugio de Vida Silvestre de Pacoche”, Pincay et. al (2021) explican que una de las amenazas que generó mayor impacto negativo en la nidificación de tortugas marinas, fue la presencia de perros que afectaron a las nidadas por la excavación y/o consumo de huevos. Esta depredación ha sido una de las razones que históricamente han provocado la reducción en el tamaño de las poblaciones (Amorocho, Rodríguez-Zuluaga et al., 2015). Por otra parte, Marcos et al. (2020) en los estudios realizados en Argentina, menciona que los impactos negativos de la introducción de jabalí o cerdo silvestre están asociados a las alteraciones que provocan en los suelos, la vegetación y la fauna, así como la transmisión de enfermedades incluidas las zoonóticas, lo que incrementa el riesgo en el proceso de incubación, eclosión y emergencia de los neonatos (Butler et. al, 2020).

No solo los factores naturales (tratados en los capítulo 2 y 3) causan el deterioro de los sitios de anidación (formación de escalones de arena, inundación de nidos, aumento de la temperatura), también los factores antrópicos como estrechamiento costero, las perturbaciones humanas o la propia pesca incidental tratada en el capítulo cuatro tienen un impacto negativo. En este contexto, el desarrollo costero y la destrucción del hábitat (zonas de nidificación) también son amenazas antropogénicas importantes para las tortugas marinas (Mazaris et al., 2017). La destrucción o el daño físico causado por las actividades de desarrollo costero pueden afectar la existencia y recuperación de las especies y su hábitat, que son importantes para la supervivencia de las tortugas marinas (Frieler et al., 2013). Esto es tratado en el capítulo dos de la tesis donde se compró que el aumento en la frecuencia e intensidad de eventos de mareas extremas asociados al estrechamiento costero y la pérdida del hábitat suponen un riesgo para la nidificación de las tortugas.

A medida que las zonas costeras se urbanizan las tortugas marinas están perdiendo sus zonas de anidación. Las playas que alguna vez fueron utilizadas por las tortugas para poner sus huevos ahora están siendo destruidas por el desarrollo costero (Pincay et al., 2021). Esto es importante en especies con filopatría como las tortugas, las cuales presentan tendencia a volver al mismo sitio en el que nacieron para reproducirse o nidificar (Feldheim et al., 2014). Por consiguiente, hay menos lugares para nidificar, mayor concentración de nidos y a su vez un incremento de la actividad depredadora por especies exóticas tratado en el capítulo uno.

Muchos estudios demuestran que los huevos de las tortugas marinas requieren de varias condiciones de incubación para el desarrollo embrionario, que incluye temperatura, humedad e intercambio de gases. En ese sentido los resultados obtenidos revelaron que existe un porcentaje decreciente del éxito en la anidación de las tortugas marinas asociado al incremento del nivel del mar, al inundarse los nidos e impedir el intercambio de oxígeno para los embriones, perdiéndose un 35,9% de los nidos estudiados. Cheng et al. (2015), mencionan que el éxito de la eclosión disminuía por la inundación de los nidos. Cabe resaltar que la elección del sitio de anidación es otro factor determinante en el éxito de las eclosiones, de acuerdo a los resultados obtenidos, el grado de la pendiente tiene un efecto favorable para la tortuga carey que anida cerca de la vegetación por lo tanto tiene menor riesgo de inundación, mientras que la tortuga verde corre mayor riesgo de pérdida de nidos por anidar más cerca al mar, lo que fue analizado por Pike et al. (2015) en Raine Island donde obtuvo una pérdida de huevos del 45% en tortugas verdes. Por otra parte, Cuevas et al. (2007), mencionan que el éxito de la eclosión está asociado a las condiciones del microhábitat dentro del nido, influyendo el riesgo de inundación de nidos, facilidades de acceso de las crías al mar, así como el riesgo de depredación de crías y huevos (Mazaris et al., 2006), por lo que la selección de hábitat tiene implicaciones en la viabilidad y éxito reproductivo de las tortugas marinas. En relación con este tema, estudios previos concluyen que las tortugas carey prefieren playas con pendientes pronunciadas y con poco oleaje (Horrocks et al., 1991), con poca presencia de rocas y alta cobertura vegetal (Ficetola, 2007).

Los resultados obtenidos muestran que la pérdida de hábitat se da principalmente por la formación de montículos o escalones de arena por el efecto del incremento e intensidad de las mareas, como consecuencia del cambio climático. Este elemento puede ser condicionante para las tortugas ya que afectan el desove, al encontrarse con estos montículos regresan al mar y buscan otro sitio para depositar sus huevos. Un ejemplo de estas preferencias de los lugares de nidificación para cada especie fue descrito por Santos et al. (2016), quienes encontraron que las tortugas carey tienen preferencias por la zona de vegetación (Medina-Cruz et al., 2010) para la elección de sitios de anidación, afirmando que las disminuciones están relacionadas a cambios en el paisaje en las playas de anidación. Se ha visto que el aguaje es otro elemento condicional, pues incrementa la tasa de humedad de la arena en zonas cercanas a la línea máxima de pleamar; esta condición provoca que las nidadas cercanas en estas franjas de playa se vean interrumpido el desarrollo embrionario debido a la proliferación de hongos (Pincay et al., 2020).

Otros estudios realizados por investigadores de la ONG OCEANA mencionan que el cambio climático y el aumento del nivel del mar representan otra amenaza significativa para las tortugas marinas y sus hábitats (abordado en el capítulo tres de la tesis**)**. En este escenario, las temperaturas más altas provocadas por el cambio climático podrían hacer que la arena se caliente, lo que provocaría una disminución en el número de crías que sobreviven (Gutiérrez et al., 2023). Esto es de particular preocupación, ya que el 40% de los sitios de anidación investigados sufrieron inundaciones por mareas, lo cual es consistente con estudios previos (38,9% según Foley et al. (2006) y 42,3% según Ware et al. (2021). Incluso la proporción de sexos puede verse afectada por la inundación de las mareas, ya que la producción de machos se vio gravemente afectada por la inundación de los nidos por las mareas (Martins et al., 2022).

Numerosos estudios han advertido sobre la potencial “feminización” de las poblaciones bajo el cambio climático (Jensen et al., 2018; Tanner et al., 2019). Por lo tanto, el paradigma predominante en la investigación del cambio climático en tortugas marinas es que están amenazadas porque la determinación del sexo depende de la temperatura (Santidrián & Spotila, 2020), con los resultados obtenidos en la investigación, se espera que las poblaciones muestreadas tengan una tendencia hacia la feminización de las crías, con un alto porcentaje de hembras. Tomando en cuenta que la temperatura pivotal garantiza la supervivencia de las tortugas marinas, existe un límite térmico donde temperaturas de incubación mayores a los

36 °C pueden ser letales para los embriones y temperaturas de incubación menores a los 23 °C impiden su desarrollo embrionario. Una incubación exitosa de los huevos sucede en un intervalo de temperatura de aproximadamente 25˚C a 35˚C (Bustard & Greenham, 1968; Mrosovsky & Yntema, 1980; Miller & Limpus, 1981; Dimond, 1985; Ugalde, 1986 y Ackerman 1997). Estos resultados concuerdan con los estudios previos de Torre-Robles et al. (2017) quienes en su investigación concluyen que las temperaturas promedio en nidos de tres especies de tortugas marinas que anidan en un Área Natural Protegida de Oaxaca, México mostraron una tendencia feminizante en el segundo tercio del periodo de incubación, con temperaturas promedios entre 30,1°C y 32,1°C y con temperaturas promedios altas (*D. coriácea* = 34,2 °C, *L. olivacea* = 36,1 °C y *C. mydas* = 32,5 °C), e incluso en este estudio se demuestra que ocurre un mayor porcentaje de mortalidad embrionaria en estas condiciones.

Por otro lado, otros estudios han considerado adicionalmente que las temperaturas altas durante la incubación pueden dar lugar a la producción de crías con anomalías morfológicas, fisiológicas y a nivel celular (Zimm et al., 2017). Por ejemplo, Fleming et al. (2020) detectó a través de análisis de sangre un cambio en el equilibrio hemodinámico (deshidratación) y una posible inflamación y/o estrés en las crías que emergen de nidos que se incubaron a temperaturas elevadas.

Sin embargo, los efectos de la temperatura y otros factores ambientales, en aspectos de la fisiología y morfología de las tortugas marinas, muestran escenarios desfavorables debido al aumento del nivel del mar (Patricio, 2019) de 20 a 30 cm para el 2050 (Kulp et al., 2019). Estudios recientes realizados por Rivas et al. (2023) muestran un futuro incierto debido al incremento del nivel del mar para el caso de Costa Rica y Ecuador ya que las proyecciones afirman que un porcentaje alto de los nidos resultarán inundados para el 2050. En concordancia con estos datos, el sexto informe del IPCC 2022 estima una pérdida de hábitats marinos del 51% paras las especies estudiadas, las que se atribuyen a eventos extremos del cambio climático. Por lo que es necesario realizar una gestión de la biodiversidad de los sitios de anidación de las tortugas marinas en las playas de Manabí, puesto que cada microhábitat varía entre playa y playa.

Por otro lado, la pesca incidental es otra de las principales causas de muerte de las tortugas marinas (adultos), según los resultados del capítulo cuatro de la tesis. Los datos obtenidos por parte de los observadores pesqueros muestran que el 72,3% de las capturas se corresponden con la especie golfina, mientras que para los pescadores artesanales entrevistados identifican una mayor frecuencia de pesca incidental con la tortuga verde. En parte estas diferencias pueden deberse a la zona de faena, ya que los observadores operan en embarcaciones que se alejan más de la costa. La especie objetivo, el tipo de anzuelo, el cebo empleado, así como la temporada son variables que inciden en la captura incidental. Según el Fondo Mundial para la Naturaleza (WWF por sus siglas en inglés), en su informe del 2014, indicó que 300 000 tortugas marinas mueren al año, como resultado de la pesca incidental. Además, Alfaro-Shigueto et al. (2018) realizó una estimación de 46.478 tortugas resultante de la captura incidental anual, solo en Ecuador fue de 40.480, con una mortalidad del 32.5%.

Pincay et. al (2021) en cuyo estudio realizado en el año 2019 hace referencia a 333 tortugas marinas varadas en la costa continental del Ecuador, de ellas 234 se encontraron muertas y 99 se encontraron con vida (Ministerio del Ambiente y Agua, 2020). Sin dudas, estas cifras denotan el alto impacto al que se encuentran sometidas sus poblaciones a causa de los factores descritos, destacando la interacción con pesquerías. Estos resultados se asemejan a los obtenidos en este estudio puesto que la tasa de captura incidental se da por el enredo con las redes de pesca, la interacción del anzuelo tipo J, y cuando la especie objetivo es el dorado, afectando a la tortuga carey y verde. Alfaro-Shigueto et al. (2018) describen una tasa de captura de 5.4 tortugas por cada 1000 anzuelos, comparable a los resultados obtenidos de 4.3 tortugas por cada 1000 anzuelos, aún siendo datos bajos son comparables con estudio realizados por Savacova et al. (2020).

Estudios realizados por Rosales (2010), hacen mención del 77,8% de ejemplares de tortugas capturadas incidentalmente y que fueron sacrificadas para la comercialización de su carne, y en algunas ocasiones de su caparazón, lo que evidenció la falta de concienciación de los pescadores. Esto se corrobora con las investigaciones de Richard (2019) en cuyo análisis determina que, para los pescadores, un anzuelo o una red vale más que una tortuga, por su parte los resultados obtenidos también denotan que para los pescadores el encontrarse con tortugas en sus redes es una molestia. Por lo que es necesario tener en cuenta la actitud de los pescadores frente a las especies marinas con las que interactúan (Cueva, 2020). Desde esta perspectiva, la actitud hacia el medio ambiente puede ser proambiental y responder favorablemente a la conservación o pueden ser de indiferencia, lo que se ve influenciado por las acciones de los individuos (Gattig y Hendrickx, 2007). Estas actitudes y comportamientos son un elemento común en todos los capítulos, ya que es necesario la concienciación y educación ambiental hacia estos problemas (introducción de especies exóticas, cambio climático, pesca incidental). Esta conexión con la naturaleza es de gran relevancia para la sociedad (Cuadrado et al., 2022) y de gran importancia para la sostenibilidad (Sobko, Jia y Brown, 2018) de las especies en peligro de extinción.

CONCLUSIONES

CONCLUSIONES

1. 69 especies de mamíferos y 62 especies de aves fueron introducidas en América Latina intencionalmente. Las principales vías de introducción fueron el comercio de mascotas/ ornamentales (70,9%) para aves, y la caza (39,1%) y el comercio de mascotas / fines ornamentales (37,7%) para mamíferos.
2. Una de las principales causas de la pérdida de nidos en las tortugas marinas está relacionada con el cambio climático, debido al aumento en la frecuencia e intensidad de las mareas durante los últimos diez años, que generaron un 35,9% de pérdida de nidos como consecuencia de la inundación de estos.
3. La intensidad y la frecuencia de los eventos extremos asociados a la altura de las mareas y sus consecuencias (formación de escalones) tienen un gran impacto en el éxito de anidación de las tortugas marinas, especialmente en la tortuga verde.
4. El éxito de la anidación de la tortuga carey se ve más afectada por la ocurrencia de eventos de marea alta en el mismo día de la eclosión; mientras que la tortuga verde es más sensible a la ocurrencia de fenómenos de mareas 15 días antes.
5. Los modelos predictivos indican una tendencia en el aumento de la frecuencia e intensidad de los aguajes, lo que podría causar una reducción en la tasa de éxito de eclosión en varias especies de tortugas marinas
6. La pesca incidental se da en mayor proporción en invierno, coincidiendo con la pesca de especies pelágicas como el dorado, atún, y picudo. El calamar fue el cebo empleado en un 60% por los pescadores, quienes le atribuyen como responsable de la pesca incidental.
7. El arte de pesca que más capturas incidentales causa es el palangre, en un 43%, seguido por las redes de enmalle en un 31% y redes de arrastre en un 26%. El anzuelo tipo J es el principal responsable de la captura incidental en un 63%.
8. Para enfrentar las diversas causas de muertes de las tortugas marinas, es necesaria la sensibilización y educación ambiental de tres agentes: 1) los pescadores para minimizar el efecto de la pesca incidental, 2) las políticas oficiales para la protección de las playas de anidación y 3) la población local que tome conciencia de la necesidad de proteger nidos y evitar la presencia de perros divagantes.

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