Universidade de Aveiro Departamento de Biologia
2018

Rita Sofia Santos Anastácio

UM CONTRIBUTO PARA A CONSERVAÇÃO DA BIODIVERSIDADE E PARA A GESTÃO DE RECURSOS NATURAIS

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Tese apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Doutor em Biologia, realizada sob a orientação científica do Doutor Mário Jorge Verde Pereira, Professor Auxiliar do Departamento de Biologia da Universidade de Aveiro

Este trabalho é dedicado a todas as crianças pequenas que fazem parte da minha vida que, tal como outras crianças neste planeta, esperam que lhes deixemos um património natural equilibrado e sustentável e que as ensinemos a estimar.

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o júri

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palavras-chave

Biodiversidade, conservação, gestão, futuro, conflito humano-animal, tartarugas marinhas, *Loxodonta africana*, gestão de ecossistemas, Microsistemas Eletromecânicos (*MEMS*), vedação virtual, livre circulação de vida selvagem, biologia reprodutiva de tartarugas marinhas, *Chelonia mydas*, *Eretmochelys imbricata*, áreas protegidas, alterações climáticas, metas para o desenvolvimento sustentável (*SDG's*), educação para a sustentabilidade, *curriculum* para educação em ciência.

resumo

A área da Conservação em Biologia tem como principais objetivos cuidar e encontrar meios de supervisão constante dos componentes dos ecossistemas. A eterna vigilância exige ao biólogo um olhar cada vez mais abrangente e interdisciplinar, não só dos processos específicos que ocorrem no mundo natural, mas também da procura de respostas para a gestão (dentro daquilo que é possível) desse mesmo mundo natural.

O presente estudo focou-se em pesquisar um conjunto de indicadores informativos sobre o *status* dos serviços dos ecossistemas e de elementos da diversidade biológica de uma área no norte de Moçambique, que compreendeu a "Messalo Wilderness Area" e as praias da Ilha de Vamizi. Aplicou-se, assim uma metodologia "bottom-up", em que o exercício de diagnóstico implicou o envolvimento dos "stakeholders" locais, *e.g.* na auscultação de carências, benefícios vivenciados, e de soluções para conflitos com a vida selvagem. O diagnóstico confirmou uma área de riqueza biológica considerável, pressionada pelo número crescente de habitantes no local, e de habitantes temporários oriundos, por exemplo, da Tanzânia. Como resposta à necessidade de gerir os recursos locais de forma mais eficaz, com vista à sua preservação mas também ao alívio da pobreza local, foi elaborado um plano de gestão para a "Messalo Wilderness Area".

Conta-se entre as espécies emblemáticas ameaçadas na região, as tartarugas marinhas, *Chelonia mydas* e *Eretmochelys imbricata*, assim como os seus habitats de nidificação; e o elefante africano, *Loxodonta africana*, que compete com o Homem diretamente por recursos naturais (água em períodos de estação seca, e alimentos com invasão e destruição de propriedade /campos de cultivo).

Como contributos para conservação da espécie emblemática em terra e por ser um problema grave identificado pelos locais desenvolveu-se e testou-se uma solução tecnológica de sinalização de elefantes. Os sensores mostraram resultados positivos para os objetivos estipulados: uma solução mais barata e não invasiva para a mitigação do conflito Homem-elefante.

Como contributos para conservação das espécies emblemáticas na costa, nos seus habitats de nidificação, realizou-se um estudo da biologia reprodutiva das tartarugas marinhas nidificantes na ilha de Vamizi, tendo-se gerado os indicadores de nidificação para esta região de Moçambique, e que permitiram comparações com outras regiões do Índico e do Globo. Das análises efetuadas chegou-se à conclusão que seria fundamental melhorar a monitorização das tartarugas marinhas, tendo-se desenvolvido uma aplicação tecnológica para o campo, o "software Turtles", que foi testada num estudo piloto com sucesso.

Trata-se de um contributo com implicações a nível global, e que altera a metodologia de campo.
Os dados recolhidos e analisados de Vamizi pré software mostram taxas de eclosão e de emergência de juvenis elevados (acima dos 80% para as green e para as hawksbill), conferindo à ilha um destaque/estatuto de boa incubadora de tartarugas marinhas.
A análise de ADN mitocondrial revelou, também, um considerável número de haplótipos para a região (11 para as green e 14 para as hawksbill), pelo que o estudo aprofundado de outras amostras de outros habitats próximos (de nidificação e de desenvolvimento) revelarão interconectividades e padrões de dispersão geográfica com relevância para a definição de uma “Regional Management Unit” mais sólida.
Os resultados demonstram a necessidade de alargar as medidas de conservação das tartarugas marinhas na região, com intensificação dos programas de monitorização nas praias nidificantes, de monitorização da atividade dos pescadores nos habitats de desenvolvimento dos juvenis, e na colheita de amostras para análises moleculares e cruzamento dessa informação com dados de outras partes do Índico Oeste.
Dado que a redistribuição de espécies marinhas em consequência da interferência das atividades antropogénicas com os ciclos biogeoquímicos, é uma constatação anunciada por estudos científicos, criar uma “consciência ecológica”, ou uma cultura do “cuidar” torna-se uma meta a atingir em termos globais. Assim, o desenho de um plano curricular para o ensino das Ciências, que colmatem essa necessidade de uma forma inequívoca é, também apresentado à comunidade, como base para debate.

keywords

Biodiversity, conservation, management, future, human-animal conflict, marine turtles, *Loxodonta africana*, ecosystem management, Micro-eletro-mechanical systems (*MEMS*), virtual fencing, free-ranging wildlife, reproductive biology of marine turtles, *Chelonia mydas*, *Eretmochelys imbricata*, protected areas, climate change, sustainable development goals (*SDG's*), education for sustainability, Science education *curriculum*.

abstract

Conservation biology has the main objective of caring and finding strategies for constant supervision of ecosystems components. This eternal vigilance mode demands an interdisciplinary and wider vision from biologists, not only concerning specific processes of the natural world, but also in searching for management answers (in what is possible) for that same natural world.
This study focused in searching a group of indicators about ecosystems services *status* and about biological diversity elements from an area in the North of Mozambique, which comprised the "Messalo Wilderness Area" and the beaches of Vamizi Island. A "bottom-up" approach was applied, using a diagnose exercise involving local stakeholders, *e.g.*, in documenting experienced needs and benefits, and inquiring for solutions to solve the human-wildlife conflicts. The results confirmed an area with considerable biological richness, pressured by the crescent number of local inhabitants, and of foreign people from, for example, Tanzania. As a response to the need of managing effectively local resources, aiming at preserving, but also alleviating local poverty, a management plan was designed for the "Messalo Wilderness Area". As emblematic species at risk in the area we list the marine turtles, *Chelonia mydas* and *Eretmochelys imbricata,* as well as their nesting habitats; and the African elephant, *Loxodonta africana*, which competes directly with man for natural resources (water in dry season periods, and food with invasion and destruction of crops and property).
As contributions for the conservation of emblematic species on land, and because it is a grave problem identified by local people, a technological solution to signal elephants was developed and tested. The sensors showed positive results for the stipulated objectives: an affordable and non-invasive solution to mitigate the human-elephant conflict.
As contributions for the conservation of emblematic species on the coast, at the nesting habitats, a reproductive biology study of the nesting marine turtles from the Vamizi Island was carried, that generated nesting indicators for that Mozambican region, and that enabled comparing it with other Indian Ocean and Globe regions. The analysis concluded that the monitoring program needs to be improved, hence the development of a field technological application, the "Turtles" software, which was tested with success in a pilot study. This is a contribution with global implications, that changes field methodology.
The data collected in Vamizi and analysed before the software development, showed high hatching and emergency successes (above 80% for the green

turtles and for the hawksbill turtles), conferring to the Island the status of good incubation spot for marine turtle's eggs.
The mitochondrial DNA analysis revealed, also, a considerable number of haplotypes for the region (11 for the green's, and 14 for the hawksbill's), hence an in-depth study of more samples from nearby habitats (nesting and development) will reveal relevant interconnectivities and geographic dispersal patterns for the definition of a more solid Regional Management unit.
The results show the need for extend the conservation strategies for the marine turtle's conservation in the region, with the intensification of the nesting beach monitoring programs, of the fisherman practices monitoring in the development habitats, and in collecting samples for molecular analysis to crosscheck information with other nesting/foraging/development spots in the Indian Ocean.
Because it is an announced scientific evidence that a redistribution of marine species is occurring due to the interference of Man on the biogeochemical cycles, to build up an "ecological conscience", or a "caring culture" is a goal to achieve globally. Hence, the design of a curriculum to teach Science to fulfil this need in an unambiguous way, is also shown to the scientific community, to start a debate.

Lista de publicações do presente trabalho

List of Publications from the present work

Artigos publicados

Anastácio, R.S.S., Azeiteiro, U.M.M., Pereira, M.J.V. (2012) Climatic Changes, Nutrient Imbalance and Primary Productivity in Aquatic Ecosystems. *Tropical Oceanography*, 40(1): 1-16. Doi: 10.5914/tropocean.v40i1.5189 http://dx.doi.org/10.5914/tropocean.v40i1.5189

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Anastácio, R., Santos, C., Lopes, C., Moreira, H., Souto, L., Ferrão, J., Garnier, J., Pereira, M.J.. (2014) Reproductive biology and genetic diversity of the green turtles (*Chelonia mydas*) in Vamizi Island, Mozambique. SpringerPLus 2014, 3: 540. Doi: 10.1186/2193-1801-3-540 http://dx.doi.org/10.1186/2193-1801-3-540

Anastacio, R., Pereira, M.J. (2017) A Piece of a Puzzle of Haplotypes for the Indian Ocean Hawksbill Turtle. Natural Resources, 8: 548-558. Doi: 10.4236/nr.2017.88034 https://dx.doi.org/10.4236/nr.2017.88034 http://www.scirp.org/journal/NR/

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Artigos a submeter ou em publicação

Anastácio, R., Cardoso, S. Pereira, M.J. Spy out to protect: a new generation of sensing devices for virtual fencing and sensing wildlife activity. *Submetido*. **Publicado a 29.03.2018 sob a forma**:

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Artigo em preparação

Anastácio, R., Ferrão, J. Pereira, M.J.. Protected Areas – A challenge for Land and Sea in Quirimbas arquipelago.
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Introdução

Atualmente, principalmente nos países que oferecem uma qualidade de vida satisfatória, é fácil esquecer que dependemos, direta e indiretamente, de serviços prestados pelos ecossistemas como água limpa, energia, alimentos, saúde, abrigo, etc. Em países menos desenvolvidos, a luta diária pelos bens essenciais torna mais real esta dependência, apesar de faltarem conhecimentos, organização e/ou recursos financeiros para lidar com os problemas impostos aos ecossistemas pelas mudanças climáticas e antropogénicas.

Proteger os ecossistemas assegurando os serviços que nos prestam, tornou-se altamente dependente da nossa capacidade de gestão, da nossa compreensão acerca do seu funcionamento, da nossa capacidade de persuasão. A pressão demográfica e o individualismo comprometem a sobrevivência de várias espécies, inclusive da nossa, e criam pressões sob os governos e a estabilidade de nações.

Os estudantes de geologia sabem que a Terra é um sistema altamente resiliente. Mesmo quando, no passado sofreu pressões catastróficas, como o impacto de meteoritos, mostrou a plasticidade dos seus ecossistemas, que se reorganizaram mantendo uma funcionalidade propícia à vida. Neste planeta dinâmico, as espécies podem evoluir ou extinguir-se. A nossa subespécie pertence a esta regra. Por muita capacidade e engenho que tenha, o *Homo sapiens sapiens* não consegue controlar as mudanças da Natureza. Podem-se, no entanto, com recurso à tecnologia e à ciência controlar algumas: o crescimento exponencial de algumas espécies, inclusive da nossa, a produção de alimentos, a disseminação de doenças, a exploração de recursos, o grau de poluição, entre outros.

A noção de se estar perante um desafio global despertou na comunidade científica a necessidade de se centrar em desenvolver estratégias globais que mudem mentalidades de decisores, industriais, governos e mercados. Estão-se a construir redes de conhecimento e especialistas para mitigar os problemas à escala global. Estes problemas relacionam-se com a perda de biodiversidade, a fome (devido à baixa produtividade de bens alimentares e à depleção dos recursos marinhos), falta de água potável e a necessidade de confiscar mais área à natureza.

O relatório “Roads to Dignity by 2030” propõe, no tópico 125, que “se estabeleça uma plataforma global, *online*, construída a partir das iniciativas já existentes que se complementam, com a participação de todos os decisores relevantes” (UN 2014) para resolver estes problemas globais.

No que concerne aos ecossistemas, iniciativas ou ideias para gerir globalmente os seus componentes têm surgido, como por exemplo a rede global para a supervisão das práticas agrícolas (Sachs *et al.*, 2010, 2012); a discussão das “Essential Biodiversity Variables” (EBVs) para o projeto GEOBON (http://geobon.org) (Scholes *et al.*, 2008; Pereira *et al.*, 2013); o “Global Ocean Observing System” (GOOS) (Gray 1997; http://www.goosocean.org/); as “Essential Climate Variables” (ECV) definidas pelo “Global Climate Observing System” (GCOS – UNFCCC); o “mapping and assessment of ecosysems and their services” (MAES) desenvolvido sobre a supervisão de especialistas do “MAES working group” para os ecossistemas da União Europeia (Maes *et al.*, 2016), entre outras. E estas iniciativas dão resultados como prova o seguinte testemunho:

"There is *high agreement* and *much evidence* that notable achievements of the UNFCCC and its Kyoto Protocol are the establishment of a global response to the climate change problem, stimulation of an array of national policies, the creation of an international carbon market and the establishment of new institutional mechanisms that may provide the foundation for future mitigation efforts" (IPCC, 2007).

Em 2010, Rands *et al*. propuseram o estabelecimento de uma plataforma científico-política intergovernamental sobre biodiversidade e serviços de ecossistemas. Esta plataforma é defendida como fundamental para eliminar lacunas de conhecimento sobre *status*, tendências, importância funcional de microrganismos, grupos de plantas e vertebrados, sobre diversidade genética e como diferentes componentes da biodiversidade contribuem e se relacionam para providenciar serviços ou criar resiliência à mudança do ecossistema, ligando conhecimentos científico e económico segundo uma regulamentação global para a gestão da biodiversidade (Rands *et al.*, 2010). Os mesmos autores apresentam o modelo de três patamares para desacelerar e impedir a perda de biodiversidade: o "Foundational" Nº1, o "Enabling" Nº2 e o "Instrumental" Nº3 (ver Rands *et al.*, 2010), que se montam de forma contínua e dependente a partir da base do conhecimento sobre as causas da perda de diversidade biológica.

Uma forma de obter conhecimento sobre o *status* dos ecossistemas (avaliação do estado dos ecossistemas, das suas características e estado e qualidade dos seus serviços), que permita uma gestão adaptada dos mesmos ao longo do tempo, é aplicando estruturas como a "Ecosystem Services Profile" (EPS) (Paetzold *et al.*, 2010). Estas ferramentas permitem uma planificação da função das grandes áreas, à semelhança do que o projeto ARIES faz para a "Conservation International", e constituem-se como exemplos de futuro (de Groot *et al.*, 2010). Na União Europeia adotou-se o "conceptual framework for ecosystem assessment" que estabelece um conjunto de indicadores para o estudo do *status* de vários ecossistemas, e que, apesar de apresentar algumas lacunas, dá uma resposta bastante satisfatória ao que se pretende: desenvolver e implementar princípios sólidos (políticas) na gestão dos recursos hídricos, clima, e na gestão dos sistemas agrícolas, florestais, marinhos e regionais (ver Maes *et al.*, 2016).

Estas perspectivas integradas são inclusivas, mais autoexplicativas, tecnológicas e nelas consegue-se perceber um propósito comum. Esta poderá ser a resposta humana mais sábia, otimista, com potencial para ultrapassar as mudanças que ameaçam a nossa qualidade de vida.

Porém, anotações pessimistas persistem e não devem ser esquecidas: «Humanity's ability to marshal the earth's resources, along with the economic and political competition that drives governments, corporations, and individuals, has meant that there have been few—if any—constraining factors on human actions. This lack of constraint may be the biggest threat to human survival» (SOTW, 2015).

Enquadramento teórico da tese

O desafio inicial da tese de doutoramento implicou a pesquisa das causas atuais da perda da biodiversidade. Como ponto de partida sabia-se que após a década de 2000-2010 a biodiversidade continuaria a diminuir, afetando os ecossistemas, os seus bens e serviços. A meta global de reduzir significativamente a taxa de perda de biodiversidade até 2010 também não foi cumprida (Mace *et al.*, 2010). Como ponto de chegada pretende-se contribuir para a visão seguinte: "By 2050, biodiversity is valued, conserved, restored and wisely used, maintaining ecosystem services, sustaining a healthy planet and delivering benefits essential for all people" (UNEP/CBD/COP, 2010). O objetivo (o desejo) expresso na frase anterior deixa à comunidade global uma nobre e árdua tarefa. Confere uma magra janela de tempo (pouco mais de 30 anos) para resolver um conjunto de problemas complexos. Os obstáculos avolumam-se, estando entre os maiores o modo de utilização dos ecossistemas e a dificuldade de cooperação entre países, no concreto, para o cumprimento dos acordos globais (como o do clima), e dos "sustainable development goals" (SDG).

Pensar em sustentabilidade e conservação dos ecossistemas implica gerir uma paz global, balizada por acordos internacionais. Sem isso, não se consegue preservar os bens mais essenciais da Natureza. A montante torna-se fundamental estabelecer as prioridades de ação, que se enraízam na compreensão dos fatores que afetam as pessoas. O "Working Group II" do "IPCC's Fifth Assessment Report" referia que a gestão dos novos conflitos intergovernamentais carece de uma avaliação completa e rigorosa dos diversos fatores sociais, económicos e culturais (IPCC, 2014) para uma atuação concertada sobre as mudanças globais.

O conhecimento angariado da aplicação dos "Millennium Development Goals" (MDGs) das Nações Unidas (aqui chamadas de metas) constituiu-se como a grande tentativa para atingir uma "paz global", em torno de valores humanitários e ambientais globalmente apreciados (tabela 1).

Tabela 1. Millennium Development Goals (MDGs) http://www.un.org/millenniumgoals/

Meta Nº	Descrição
1	Erradicar a pobreza extrema e a fome
2	Atingir a educação primária universalmente
3	Promover a igualdade de género e a capacitação das mulheres
4	Reduzir a mortalidade infantil
5	Melhorar a saúde materna
6	Combater o HIV/SIDA, malária e outras doenças
7	Assegurar a sustentabilidade ambiental
8	Desenvolver parcerias globais para o desenvolvimento

Em 2015, os MDGs e os "six essential elements for delivering on the sustainable development goals (6EE)" constituíram a base de criação dos 17 SDGs (figura 1), publicitados desta forma: "the Millennium Development Goals show that targets work. They have helped end poverty for some, but not all. The United Nations has lately defined Sustainable Goals as part of a new sustainable development agenda that must finish the job and leave no one behind" (www.un.org/sustainabledevelopment/development-agenda/).

Figura 1. As oito metas antigas (MDGs) dão lugar às 17 novas metas globais (SDGs) para um desenvolvimento global sustentável. Consultar o "Transforming our World: the 2030 Agenda for Sustainable Development" (https://sustainabledevelopment.un.org/post2015/transformingourworld).

O sétimo MDG (tabela 1) incidia claramente no campo da conservação; porém, a preocupação com os ecossistemas aumentou na definição dos SDG (vide o 6, 7, 11, 12, 13, 14, 15, 16). Pergunte-se então: por que é que o Mundo necessita desta agenda global? Porque só ela garantirá uma humanidade mais justa, mais pacífica, mais culta, mais equilibrada na sua relação inter-humana e entre humanos e ecossistemas (mais humilde); tudo para alcançar o "desenvolvimento sustentável", conceito apresentado pelo Brudtland Report (1987): "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts: the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs." (http://www.un-documents.net/our-common-future.pdf).

Outras iniciativas de auscultação global que extravasam a esfera científica desenvolveram-se, mostrando uma sociedade empenhada em debater problemas e em definir caminhos da paz global. O "Global Risks Report" (GRR), construído todos os anos pela comunidade do "World Economic Forum's" (WEF), é um exemplo desse esforço centrado na antecipação de estratégias dado que procura definir riscos globais. Risco global é definido como "an uncertain event or condition that, if it occurs, can cause significant negative impact for several countries or industries within the next 10 years*"* (GRR/WEF, 2016)". A listagem anual dos principais riscos a nível global por intermédio de inquérito a um conjunto de participantes, e a sua categorização (em "nível de preocupação", "probabilidade e impacto", e "interconectividade") permitem identificar aspetos que

direcionam planos de ação gerais. Mas a Cimeira do Clima de 2015 e os ajustes feitos *a posteriori*, revelam a dificuldade de gerir ideias globais: “Climate negotiations have failed to deliver anything close to the breakthrough agreement that the world desperately needs” (SOTW 2015).

Apesar do otimismo das Nações Unidas com os SDGs, o GRR de 2015 e o de 2016, mostram uma visão constituída por ameaças à paz global (crises fiscais, falta de emprego e a dificuldade em mitigar catástrofes naturais climáticas) e, por conseguinte ao desenvolvimento sustentável e aos planos de reduzir as causas de perda de biodiversidade. Então, como fazer acontecer com sucesso os SDGs, e os “tratados climáticos”, com poucas garantias de uma paz global coesa e duradoura? Será possível atingir os SDG até 2050?

O relatório “Roads from Rio+20, Pathways to achieve global sustainability goals by 2050” (van Vuuren *et al.*, 2012), concentrando-se na biodiversidade, reforça a necessidade de novas políticas relativas à gestão de duas áreas, que definem simplesmente como “alimento, terra (e mar) e biodiversidade”, e “energia e clima”. O mesmo relatório mostra a redução significativa da biodiversidade dos últimos anos e que essa tendência se manterá no futuro, comprometendo, assim, todos os objetivos que rondam o conceito de sustentabilidade. Ceballos *et al*., (2015) corrobora a visão de van Vuuren *et al*., (2012).

«The 1992 Earth Summit in Rio de Janeiro was a milestone in global environmental consciousness. Yet in the two decades since then, the pressures on the planet’s natural resources and ecological systems have only increased, and the second Rio conference—“Rio+20” in 2012—was far less of an environmental milestone» (SOTW, 2015).

van Vuuren *et al*., (2012) refere a necessidade de criar um “consenso internacional” em torno destas prioridades e da criação de políticas e sua aplicação. Uma certeza persiste: não necessitamos de mais relatórios que nos alertem para o que devemos fazer; não necessitamos de mais definições novas, que apelem à “consciência ecológica” (Lourenço, 2005). Necessitamos de testar, de fazer acontecer. É nisso que esta tese se centra: no pouco que pode resolver, vai tentar concretizar.

> "People want decent jobs, social protection, robust agricultural systems and rural prosperity, sustainable cities, inclusive and sustainable industrialization, resilient infrastructure and sustainable energy for all" (UN, 2014).

O conceito ecológico de "carrying capacity" (Sadava *et al.*, 2011) pode ser, em teoria, aplicado à espécie humana. Enquanto aplicada a outras espécies, os recursos disponíveis condicionam o crescimento de uma população para uma dada área ocupada por essa população – o valor de K consiste no número de indivíduos numa população que os recursos do seu meio suportam (Sadava *et al*. 2011). Para os seres humanos é mais difícil estimar o valor de "carrying capacity". Isto acontece porque a nossa espécie tem a capacidade de ocupar diferentes áreas e de modificar tecnologicamente o seu meio para obter mais eficazmente determinados recursos. A noção de que o planeta possui recursos finitos para a nossa espécie, não podendo mantê-la em crescimento indefinidamente, ou seja, a noção de que existe um "carrying capacity value" para a nossa espécie (mesmo que flutuante, ou difícil de estimar) é fundamental para percebermos o "problema demográfico".

Concentremo-nos no patamar do "human well-being" (tabela 2) apresentado no Millenium Ecosystem Assessment (MEA, 2005). Esse patamar está dependente do funcionamento dos ecossistemas, que por sua vez dependem da biodiversidade, mas será tanto mais reduzido quanto mais pessoas existirem, pois serão mais necessidades a satisfazer (MEA, 2005, Díaz *et al*., 2006).

Tabela 2. Categorias de mal-estar (ill-being) e de bem-estar (well-being) humanos (http://pdf.wri.org/ecosystems_human_wellbeing.pdf).

Mal-estar (ill-being)	Bem-estar (well-being)
Sem liberdade, impotência	Liberdade de escolha e ação
Insegurança, conflito	Segurança
Sem cuidados básicos de saúde, sem saúde (completo bem-estar físico, mental e social e não somente a ausência de doença, segundo a Organização Mundial de Saúde).	Saúde (fisica, mental e social)
Relações inter-sociais fracas	Boas relações sociais
Sem (ou deficitários) materiais básicos	Materiais básicos

Só para o continente Africano, o IPCC (2007) projeta que em 2020 entre 75 a 250 milhões de pessoas experimentarão "ill-being" por: stress hídrico ("water stress") devido às alterações climáticas, e fome, insegurança alimentar e malnutrição devido à redução em mais de 50% da produtividade agrícola. Estes fenómenos são já sentidos e promotores do êxodo de pessoas de países que exibem as categorias "ill-being", como a Colômbia, a Ucrânia, a Síria, o Iraque, o Afeganistão, o Paquistão, o Butão, o Myanmar, as Filipinas, o Yémen, a Somália, a Líbia, o Sudão, a Nigéria, a República Centro Africana, a República Democrática do Congo, e o Sudão do Sul (GRR/WEF, 2016). As pessoas destes países vêm-se, fora dos seus países em crise, na condição de refugiados.

Quais os números do problema demográfico? As projeções mostram que os países menos desenvolvidos contribuirão em 69% para o crescimento humano (os países subdesenvolvidos contribuirão em 249% para a mudança da população entre 2010-2100) (tabela 3).

Tabela 3. População total mundial e por continentes, em 2010 e em 2100 (estimativa), retirada do Relatório das Nações Unidas (Andreev *et al.*, 2013).

	População total (milhões)		Mudança populacional 2010 – 2100	
Grandes Áreas	**2010**	**2100**	**Absoluta (milhões)**	**Relativa a 2010 (em %)**
Mundial	6916	10854	3938	57
África	1031	4185	3153	306
Ásia	4165	4712	546	13
Europa	740	639	-101	-14
América Latina e Caraíbas	596	736	140	23
América do Norte	347	513	167	48
Oceania	37	70	33	90

Se em 2010 existiam 6,9 mil milhões de seres humanos, em 2100 existirão 10,9 mil milhões (Andreev *et al.*, 2013; veja-se também *Current World Population*: http://www.worldometers.info/world-population/). Este crescimento esperado para o período 2010-2100 foi estimado com base no aumento da fertilidade (13,8%), no declínio da mortalidade (16,3%) e no "momentum" do crescimento populacional (26,9%). O crescimento traduz-se, no imediato, no aumento de dificuldades para as pessoas e aumento das pressões sobre os ecossistemas. Quais são essas dificuldades e pressões?

O decréscimo do rendimento agrícola e da produtividade primária

A agricultura e a pesca foram-se desenvolvendo ao longo de milénios, tendo evoluído em termos tecnológicos e em escala. Mas, pode o grau de conhecimento atual permitir produzir comida para toda a população mundial? E o que implica isso para o esforço dos ecossistemas? Os ecossistemas agrícolas são construções humanas, que tentam dominar espécies que, antes selvagens, são agora domesticadas. A agricultura desenvolveu-se num mundo com, aproximadamente, 5 milhões de pessoas (Raven *et al.*, 1992), porém sob tecnologia rudimentar.

"As our numbers were exploding, the homogenising influence of globalisation saw us turn for sustenance to fewer and fewer domesticated food providers. Indeed, we came to rely, in the 20th Century, on fewer than 20 crop plants to provide more than 90% of our global vegetable intake. Of these, just three – wheat, maize, and rice – now account for more than half of humanity's global harvest. This compares with the roughly 6,000 food crops our forebears are known to have raised at one time or another throughout history" (Boy e Witt, 2013).

Os avanços no conhecimento técnico e as ferramentas tecnológicas permitiram o aumento significativo da produtividade agrícola, não implicando isso que os produtos estejam disponíveis com a mesma qualidade em todas as partes do mundo, um dos principais problemas de insegurança alimentar (FAO, IFAD, WFP, 2014). O que se sabe, é que as exigências de mais consumidores poderão implicar dificuldades na segurança alimentar (Alexandratos e Bruinsma, 2012). Na atualidade, alguns autores defendem que existe alimento suficiente para a população

existente (ver opinião de Eric Holt-Gimenez no jornal Público, 16/11/2015). Porém, o manual de indicadores da FAO (2014) lembra que apesar dos progressos das últimas duas décadas, cerca de 840 milhões de pessoas sofrem de fome crónica, e 2 mil milhões de pessoas carecem de micronutrients na sua alimentação.

A pobreza, a prática da agricultura precária e o débil acesso aos mercados por parte dos pobres rurais contribuem como fatores que potenciam a fome em várias regiões do globo (Alexandratos e Bruinsma, 2012). A revista *Nature* aborda a problemática no artigo "The Growing Problem" (Nature, 466, 2010), revelando que é na Ásia, no Pacífico e na África Subsaariana que se encontram os valores mais elevados de subnutrição (oscilantes entre 26-63%). Em muitas regiões, os ecossistemas são incapazes de fornecer os recursos necessários, levando as populações a destruir os habitats à sua volta. Essa exploração descontrolada agrava o contexto em termos ecológicos e socioeconómicos. A agravar a situação estão outros fatores biológicos que interferem com o rendimento agrícola: o aparecimento de pragas, devido à baixa variabilidade genética em determinadas culturas que são a base da alimentação mundial (milho e arroz), e à dispersão rápida de espécies exóticas que interferem com a funcionalidade dos ecossistemas (Boy e Witt, 2013). Raven *et al.*, (1992) refere mesmo que nem os avanços tecnológicos permitirão superar os desafios impostos pelo crescimento populacional.

Para contornar o problema das baixas produtividades, a ciência recorreu à engenharia genética. Mas também esta comporta riscos, como nos lembra Wilson (2004): "de 1996 a 1999, o número de terras agrícolas americanas consagradas à produção de plantas geneticamente modificadas explodiu (…)" enquanto "nunca as espécies híbridas conseguiram contaminar outras espécies não domésticas: os transgénicos podem agora modificar este estado das coisas" (Wilson, 2004). Porém, é nelas que reside alguma esperança para a produção de bens de consumo alimentares como o "golden rice" (ver opinião em Nature 466, 2010).

A biologia também é pragmática nos números. A produtividade primária em determinadas áreas (por exemplo nas zonas costeiras) pode estar a alterar-se, devido às alterações da temperatura da água que acarretam alterações na distribuição de espécies marinhas, muitas delas exploradas economicamente (Perry *et al.,* 2005; Poloczanska *et al.,* 2016) com consequências para as espécies exploradas economicamente (o caso do *Gadus morhua* e outras espécies, em resultado do desfasamento nos picos de produção entre fitoplâncton/zooplâncton e outros níveis tróficos).

Poluição

Nunca a Terra foi tão poluída como no dia "hoje", a menos que consideremos a Terra primeva, após a desgaseificação da crosta terrestre. Caso não se comecem a explorar energias renováveis em massa, diminuindo a dependência dos combustíveis fósseis, será difícil controlar a emissão de gases de estufa (greenhouse gases, GHG) com consequências para o clima. As perspetivas para o futuro do planeta em termos de alterações do clima não são nada positivas, com agravamento de fenómenos climáticos (mais frequentes e de maior intensidade), imparável aumento da temperatura média do planeta, e alteração do pH dos meios (Saina *et al.,* 2013).

Para aumentar a produção de bens alimentares serão utilizados mais fertilizantes e pesticidas (Nature 466, 2010). A disseminação dos constituintes destes químicos pelo solo, águas superficiais e aquíferos, lagos, rios e oceanos também aumentará em consequência (Rands *et al.*,

2010). Muitos poluentes funcionam como disruptores endócrinos, para além de interferirem nos ciclos biogeoquímicos (Sadava *et al*., 2011). Sem dúvida, que os seres humanos fazem parte do mesmo cosmos, logo das consequências. De que forma irá o organismo humano reagir ao aumento de químicos perigosos nos seus bens alimentares e no meio? Quais as respostas que irão emergir destas tendências futuras?

Para além da degradação do ambiente (com perda das espécies mais vulneráveis), e a diminuição da qualidade do ar, solo e água, os poluentes diminuirão a qualidade dos bens alimentares (Kern *et al.*, 2016).

O acordo de Paris de 2016 (http://unfccc.int/paris_agreement/items/9444.php) foi fundamental para definir estratégias de redução das emissões de GHGs. A atmosfera e os Oceanos não têm fronteiras visíveis que estanquem a disseminação de poluentes, pelo que o não assumir uma agenda global sobre o clima é sinal de grande irresponsabilidade.

A instabilidade do clima é um desafio à resistência das espécies. É por isso que são um motor da alteração das interações entre espécies, da sua redistribuição geográfica e até extinção (IPCC, 2007).

A Diminuição da quantidade e da qualidade de água doce para consumo

"All life — terrestrial and aquatic, ranging from microbes to vertebrates — depends on and is shaped by water and watershed dynamics" Palmer (2010). Palmer (2010) alerta para o facto do possível desaparecimento de determinadas espécies, algumas das quais ainda nem saberemos o quão importantes são, poder implicar a perda da qualidade da água. Impressionada com o estudo de Vörösmarty *et al.,* (2010) reforça a ideia daqueles autores de que a deterioração da água doce é um problema real dos países pobres e ricos.

Num artigo mais recente de avaliação de escassez de água, Veldkamp *et al.,* (2015) têm em consideração parâmetros como a variabilidade hidroclimática e as condições socioeconómicas. Mostraram que a população global sofreu de escassez de água ("water shortage") de um valor de 17% em 1960, para um valor de 45% correspondente ao ano de 2000. A mesma população experimentou um aumento de stress hídrico ("water stress"), indo de um valor de 11,7% em 1960, para um de 33,6% em 2000. No mesmo período de tempo, subiu de 8,9 para 28,6% a fatia de população que experimentou escassez de água e stress hídrico em simultâneo (Veldkamp *et al.,* 2015).

Este estudo demonstra que as mudanças socioeconómicas globais, nomeadamente o contínuo aumento populacional, contribuíram para o aumento dos indicadores anteriores (0%, em 1960, para 76,2% (2000) no "water shortage", e de 82,5% no "water stress"), pois exigiram um maior fornecimento de água. Acrescenta ainda que "future climate change, projected population growth, and the continuing increase in water demand, are expected to aggravate these water scarcity conditions world-wide" (*vide* Veldkamp *et al.,* 2015).

O Aumento de doenças

O aumento de doenças degenerativas e de formas de cancro é apenas uma suspeita, perante uma tão elevada prevalência de químicos no ambiente e nos alimentos, com os quais contactamos diariamente (Kern *et al.*, 2016).

A resistência de muitos agentes patogénicos aos fármacos que as combatem (*e.g.* aos antibióticos), poderá significar o aparecimento de superorganismos patogénicos (SOTW, 2015). Um dos efeitos do aquecimento global é a redução do período de frio dos invernos que exercia um efeito "bottleneck" sobre agentes patogénicos; assim, estima-se que agentes de propagação de doenças como o dengue e a malária progridam para latitudes mais elevadas (Sadava *et al*., 2011).

A fragmentação de território que cria habitats cada vez mais reduzidos, ampliando a área de "edge" em relação ao core dos "patches" (fragmentos) reservados às espécies, amplia a possibilidade de encontro das espécies selvagens com os seres humanos e os seus animais domésticos. Doenças confinadas em seres antes confinados em florestas, nas zonas tropicais ou mais remotas, podem começar a surgir e a disseminar-se: as chamadas doenças emergentes (EID), (figura 2).

Figura 2. Dado que a disseminação de agentes patogénicos pode verificar-se entre espécies não humanas ⇆ humanas; entre espécies selvagens ⇆ domésticas; e entre espécies exóticas ⇆ nativas, considera-se, ainda a sequência de causas/efeitos que potenciam o contacto entre as espécies e agentes patogénicos das EIDs (adaptado de Daszak *et al.*, 2001).

Estas representam uma ameaça séria à saúde pública, porque os agentes patogénicos que as transmitem não são conhecidos, e os animais selvagens que as transmitem já não estão inclusos nos seus habitats (Daszak *et al.,* 2001, SOTW, 2015).

O Aumento de populações migrantes

"30. (…) we are a mobile world, with more than 232 million international migrants, and almost 1 billion when internal migrants are counted (...)" (UN, 2014).

Nos últimos anos tem-se verificado a migração descontrolada e aflitiva de pessoas em busca de melhores condições de vida. Principalmente dos países da África central e do norte assolados por conflitos políticos e religiosos, que minimizam as hipóteses de paz e criação de alguma riqueza de sustento (GRR/WEF, 2016). As pessoas que procuram uma oportunidade encontram dificuldades que comprometem o seu bem-estar em vários domínios. As mulheres, crianças, idosos e pessoas com necessidades especiais são os mais vulneráveis nestas situações (FAO, IFAD e WFP, 2015). As mulheres que em tantos locais são as responsáveis pela agricultura que sustenta as famílias, vêm-se obrigadas a abandonar as práticas de sustento para proteger a família, abdicando do seu direito à terra. Pobres e vulneráveis nestas migrações, com baixo nível de alfabetização, desprotegidas, sem poder económico mergulham em situações de profunda vulnerabilidade, incerteza e mal-estar (FAO, IFAD e WFP, 2015).

Mas não serão só as pessoas a deslocar-se. Outras espécies reagem às alterações dos seus habitats e adaptam-se migrando para novos locais. As tartarugas marinhas demonstram essa

capacidade e essa resiliência, como nos lembra Fuentes *et al.*, (2010) por exemplo escolhendo novos locais de nidificação; também Poloczanska *et al.,* (2016) refere alterações na abundância de espécies (de fitoplâncton e de krill por exemplo) e de como essa evidência é indicador de alterações na distribuição de muitas outras espécies (efeito cascata de uma rede trófica).

"The redistribution of zooplankton has implications for marine food webs; warm-water species tend to be smaller and less energy-rich than polar/subpolar species (…) changes in plankton communities (…) are a strong driver of cod, *G. morhua*, abundance in the North Sea" (Beaugrand e Kirby, 2010 *in* Poloczanska *et al.,* 2016).

As Alterações Climáticas

> "Anthropogenic warming over the last three decades has *likely* had a discernible influence at the global scale on observed changes in many physical and biological systems" (IPCC, 2007).

Ouvir sobre alterações climáticas nos media não é novidade. Todos somos espectadores do debate entre cientistas que mostram os efeitos dessas alterações e as cedências e ceticismo de outras entidades que detêm o poder sobre os mercados. Será que para o cidadão comum é importante assistir e participar neste debate? Não é a Terra um planeta instável na sua essência?

Adota-se aqui a definição de alterações climáticas ("climate change") do IPCC; a alteração "refere-se a uma mudança no estado do clima que pode ser identificada (*e.g.* usando testes estatísticos), por mudanças na média e/ou variabilidade das suas propriedades, e que persiste por um período grande, geralmente décadas ou mais" (IPCC, 2007, 2014). A conjugação dos termos "climate change" inclui "qualquer alteração no clima ao longo do tempo, seja devido à variabilidade natural ou causada pelo ser humano" (IPCC, 2007, 2014).

Na Ciência é importante perceber os motores do "climate change", e, nomeadamente, quais os contributos antropogénicos para o agravamento do fenómeno. É consensual entre a comunidade científica que as ações poluentes de gases de estufa (GHG) são um dos motores inequívocos (Oreskes, 2005). A aceitação da responsabilidade humana na degradação do clima é o primeiro passo para a solução. O estudo das alterações da atmosfera do passado da Terra podem trazer alguns esclarecimentos sobre que efeitos podem trazer as alterações climáticas, sobre a atmosfera e o oceano e permitir atuar num sentido inverso. Se nos concentrarmos no período Pérmico da Era Paleozóica (542,0-251,0 milhões de anos), a primeira do nosso Éon, verificaremos um aumento da temperatura média do planeta com consequências devastadoras para os ecossistemas existentes (Levin, 2013; Campi, 2012).

À primeira vista, sob um olhar de alguém não-especialista, há semelhanças assustadoras com os índices apresentados no Pérmico: o aumento significativo da quantidade de CO_2 e CH_4 atmosféricos (que em 2005 excediam os valores dos últimos 650,000 anos (IPCC 2007); o valor de "significant mínima" da pCO_2 atmosférica tem valores similares aos do Pérmico (Levin, 2013).

No que concerne aos oceanos e às zonas costeiras muitos autores citados por Tribbia e Moser (2008), referem que o "climate change" será responsável por efeitos como o aumento do nível médio das águas do mar de forma acelerada, a alteração das tempestades costeiras (frequência e intensidade), a alteração da pluviosidade e escorrência de águas superficiais que arrastam quantidades significativas de sedimentos para a costa, o aumento da temperatura superficial

média da água (SST) levando à redistribuição de espécies, o aumento das temperaturas do ar, e o aumento de episódios de inundação, de erosão costeira e de meteorização de arribas, com alteração das linhas de costa.

As emissões globais de GHG derivam essencialmente da indústria, da desflorestação e do sector agrícola (IPCC, 2007). Uma alteração significativa seria conseguida caso se deixasse de explorar combustíveis fósseis, e se se investisse numa agricultura sustentável (IPCC, 2007; Godfray *et al*., 2010).

O GRR/WEF (2013) mostra que a maior preocupação entre os decisores é o "climate change". A figura 3, retirada do referido relatório, mostra os impactos estimados da subida da temperatura nas categorias clima, água, alimento, ecossistemas, e sociedade, entre 2030 e 2080 (GRR/WEF, 2013).

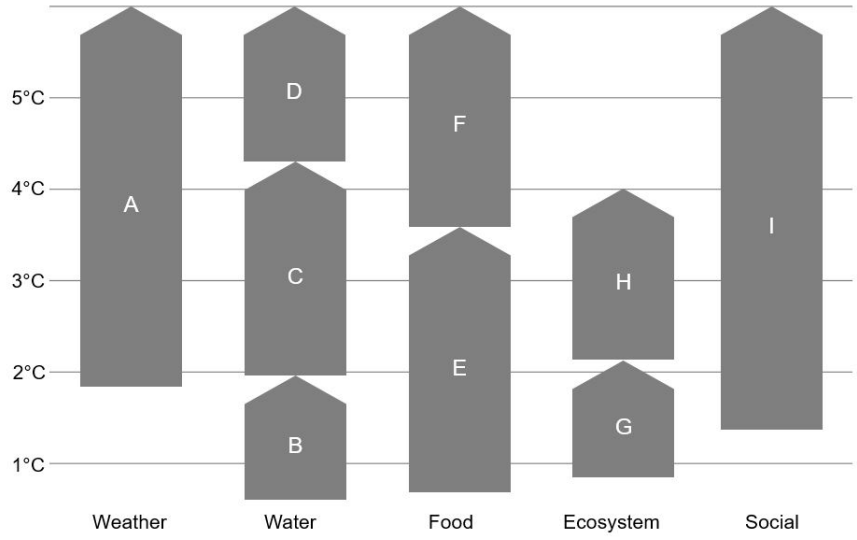

Figura 3. Imagem com os possíveis impactos do aquecimento global em diferentes sectores (clima, água, alimento, ecossistema, social): A. Tempestades mais intensas, incêndios florestais, seca, inundações e vagas de calor; B. Ameaças às reservas de água locais, como resultado do degelo de glaciares; C. Alterações na disponibilidade de água, ameaçando mais de mil milhões de pessoas; D. A subida do nível médio das águas do mar afetará grandes cidades costeiras a nível global; E. Diminuição do rendimento agrícola em muitas regiões em desenvolvimento; F. Diminuição de rendimento em muitas regiões desenvolvidas; G. Ecossistemas intensa e irreversivelmente danificados; H. Perigo de extinção de muitas espécies; I. Mais de mil milhões de pessoas serão migrantes, aumentando o risco de conflitos (GRR/WEF, 2013).

Tem-se debatido se serão pertinentes estratégias para atenuar o aumento de temperatura, dado que não se conseguirá inverter a tendência ascendente da temperatura. Assim, muitos autores falam em "adaptação" como estratégia para as gerações futuras desacelerarem o fenómeno e as suas consequências, implicando isso, também, mais formação das pessoas (Tribbia e Moser, 2008). O IPCC (2014) apresenta medidas objetivas respeitantes à adaptação (ver páginas 21-25). A figura 4 pretende resumir esquematicamente o debate supra apresentado.

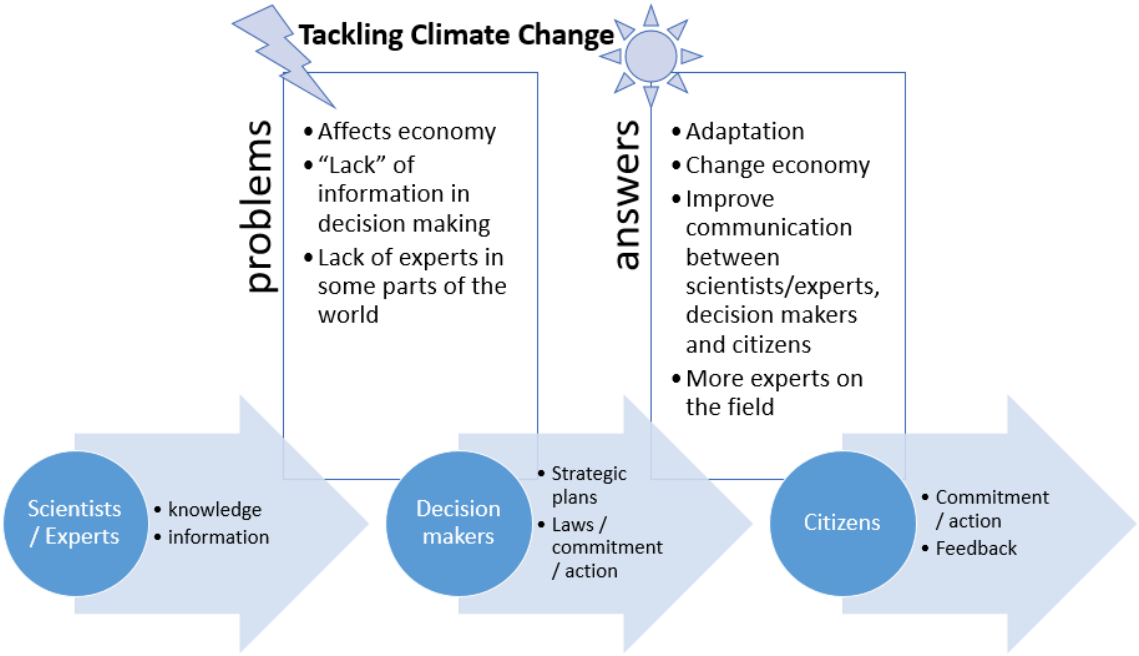

Figura 4. Resumo dos problemas e das medidas para combater as alterações climáticas.

O caso particular do Este Africano

> "One region of the world where the effects of climate change are being felt particularly hard is Africa. (...), African countries are likely among the most vulnerable to the impacts of climate change" (IPCC, 2001 *in* Case, 2006).

África apresenta um conjunto de países com dificuldades a vários níveis para dar resposta às alterações climáticas, sendo também um dos continentes onde o crescimento demográfico será acentuado (Andreev *et al.*, 2013), tal como as pressões sobre os recursos da natureza (Ceballos *et al*., 2015; 2017). A vulnerabilidade dos ecossistemas e biodiversidade africanos torna-se, assim, uma preocupação de toda a comunidade científica. Para o Este Africano são apontados, em concreto, os problemas esquematizados na figura 5, derivados de alterações climáticas (Case, 2006).

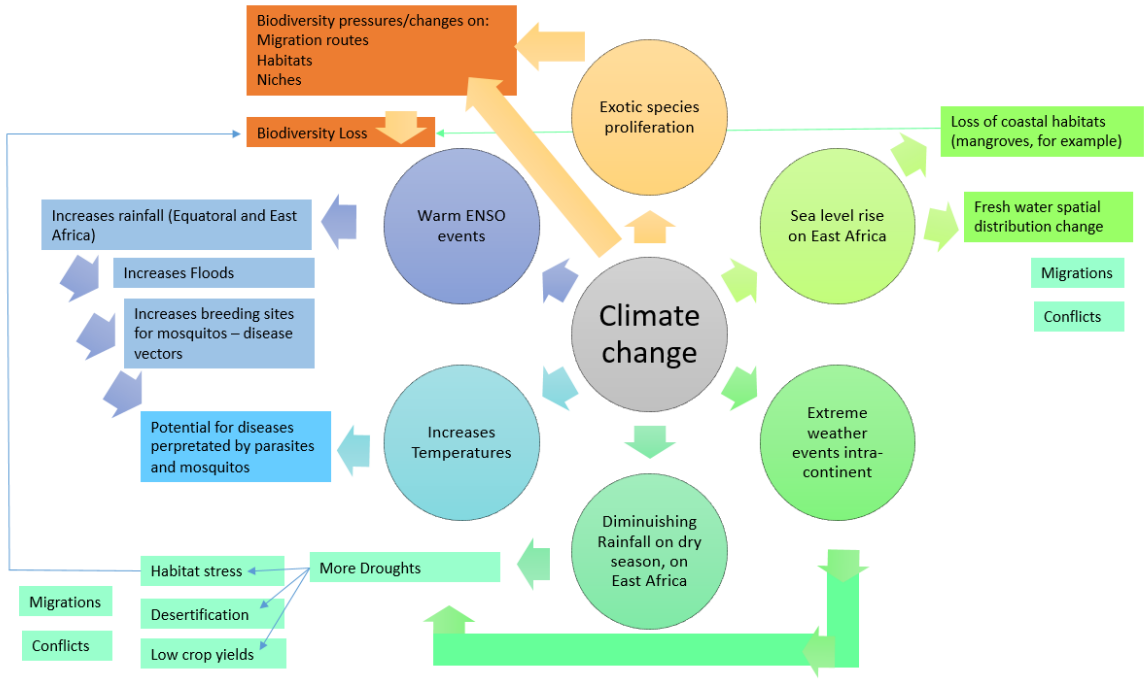

Figura 5. Adaptação das previsões de Case (2006) e do IPCC (2007) para o Este Africano, derivadas das alterações climáticas, para os próximos anos.

Cabo Delgado, Moçambique

Moçambique é um país do Este Africano, substancialmente diferente de Portugal: 10,4 milhões de portugueses residentes em Portugal (2015) contrastam com os 26,4 milhões de Moçambicanos (2016) (AE, 2017) distribuídos pelas 11 províncias, num país de 799 380 km^2 de área total. O crescimento anual da população é de 2,6%, sendo a maioria do sexo feminino (51,8% do censo 2007), tendo aumentado uma décima percentual segundo o anuário de 2016 (AE, 2017).

Moçambique é incrivelmente jovem, retendo um potencial de desenvolvimento incrível à espera de oportunidades. Segundo o plano estratégico de educação de 2012-2016 (PEE/MZ, 2012), 52% da população está no grupo etário dos 0-18 anos, dos quais 20% pertence ao grupo etário dos 6-12 anos.

Cabo Delgado é uma das províncias moçambicanas, situada no extremo nordeste do País, banhada pelo Oceano Índico e limitada a Norte pelo rio Rovuma. A província apresenta uma superfície total de 82,625 km² (AE, 2017). Apesar da riqueza geográfica de Cabo Delgado, destacam-se as muitas pequenas ilhas de coral junto à orla continental, os muitos rios que possui, entre os quais o Rovuma, o Messalo e o Lúrio, e um litoral recortado, com cabos e baías. Apresenta, também um património biológico considerável quer em terra, quer em mar, onde se destacam os 27,836 ha de Mangal (CDB Mz, 2003), corais pristinos e em bom estado, como os de Vamizi (com 46 géneros de corais) e cujas águas circundantes albergam cerca de 4 centenas de espécies de peixes (Hill *et al.,* 2009).

A cidade capital desta província denomina-se Pemba, estando situada precisamente no litoral, em tempos chamada de “Porto Amélia” (ver carta 1: 6,000,000 da região litoral norte de Moçambique na figura 6).

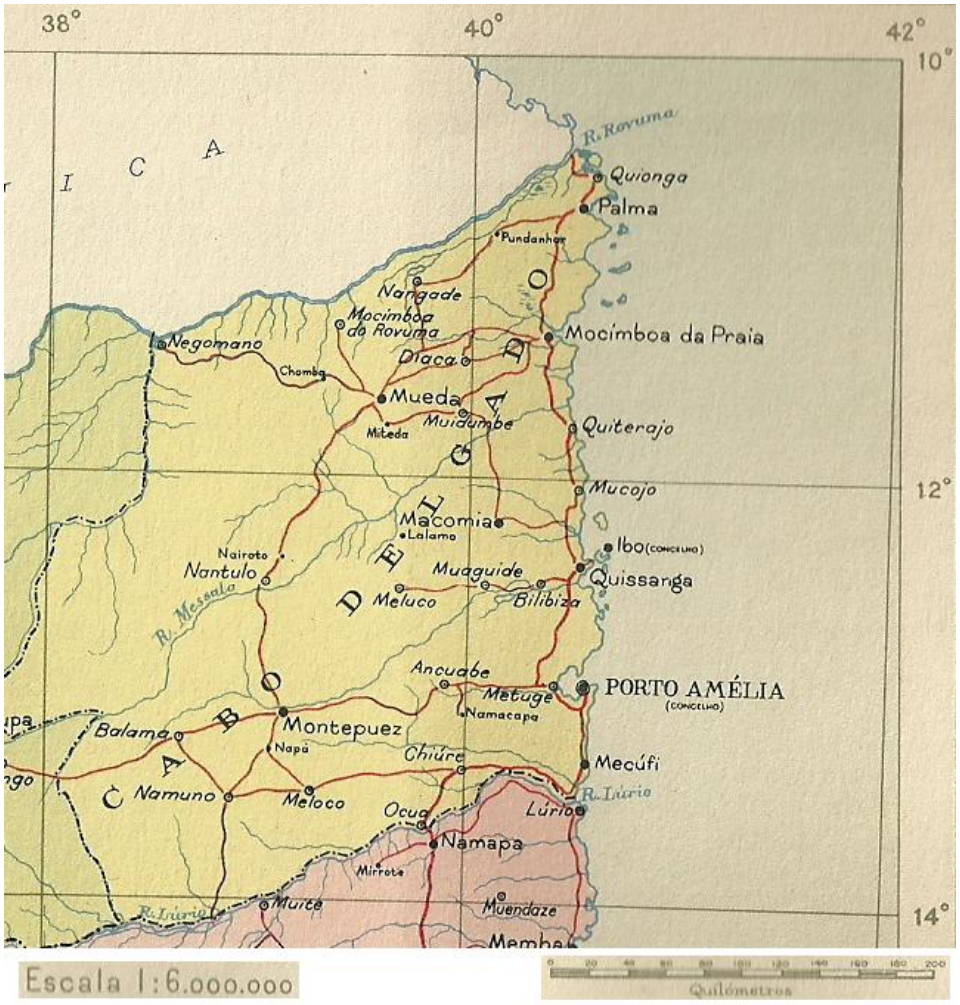

Figura 6. Digitalização da carta original do Atlas de Moçambique (DAS, 1960).

Cabo Delgado, com uma densidade populacional de 23 habitantes/km^2 (a média de Moçambique é de 33, AE, 2017), apresenta 1,923,264 habitantes, 931957 homens e 991307 mulheres (AE, 2017), dos quais uma grande parte vive em áreas rurais, onde praticam a pesca e a agricultura de subsistência (Garnier, 2003; Mabunda, 2005; Anastácio *et al*., 2014a). Projecta-se que esta mesma província tenha 2,761,986 habitantes em 2030 (www.ine.gov.mz/), sendo que o aumento de residentes se prenda com os recursos energéticos descobertos e com o elevado potencial turístico da região, explorado já em alguma medida (*e.g.*, Mozambique Anchor Investment Program, Projeto Arco Norte). Vamizi, um dos pontos turísticos de luxo da região, é uma das 32 ilhas (figura 7) de constituição biogénica pertencentes ao Arquipélago das Quirimbas (Hill *et al*., 2009). Este arquipélago forma um cordão que não dista mais de 15 km da costa, estendendo-se desde a baía de Pemba até Palma.

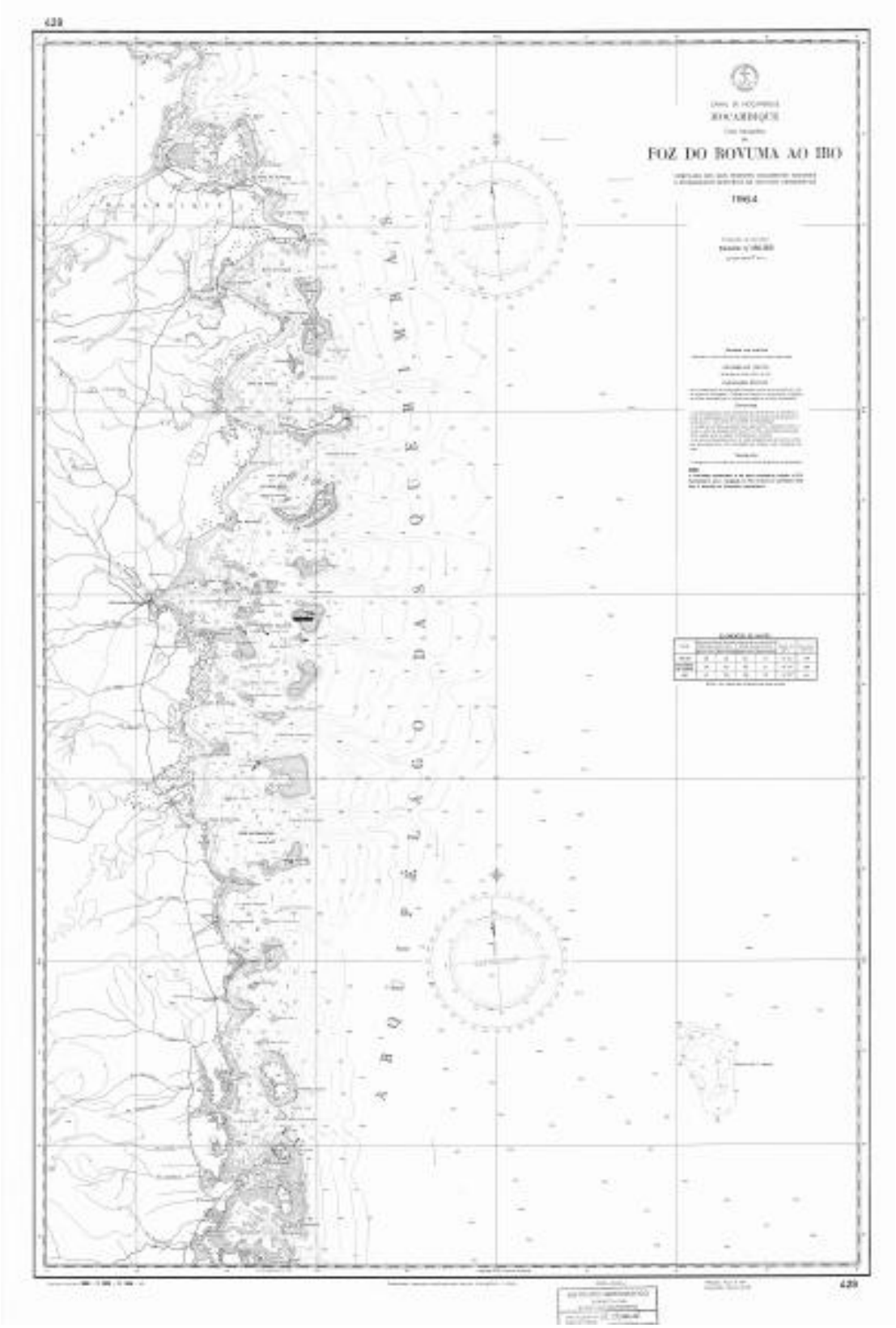

Figura 7. Canal de Moçambique: Carta hidrográfica da foz do Rovuma ao IBO. Carta nº429. Instituto Hidrográfico, Lisboa (IH, 1965, reimpressão de 1986).

Cabo Delgado apresenta recursos naturais biológicos, hídricos e geológicos de interesse relevante, muito embora a pobreza da população seja ainda considerável. Devido à elevada taxa de desemprego a exploração de gás natural descoberto na bacia do Rovuma é também uma esperança para o desenvolvimento da região. Aliás, o gás natural é o 4º principal produto de exportação de Moçambique (AE, 2017). Tem atraído um grande investimento estrangeiro para a região, ao ponto de não haver resposta hoteleira suficiente para albergar o influxo de pessoas (note-se que existem apenas 6 unidades hoteleiras, 5 pensões e 4 pousadas na região AE 2017). Mas é, também, uma preocupação (ver reportagem de Carvalho e Roberto 2014, no jornal Público). Alguns desses recursos encontram-se protegidos, como por exemplo em Vamizi, no Messalo (Anastácio *et al*., 2014a, b) ou pelo Parque Nacional das Quirimbas, QNP, uma área protegida da região que apresenta uma elevada riqueza faunística, mas sob grande pressão devido à quantidade crescente de pessoas a habitar o seu interior (Mabunda, 2005, Ntumi *et al.,* 2009, Craig, 2013). Este fenómeno cria constrangimentos e pressões sobre a biodiversidade local (Rosendo *et al.,* 2011; da Silva *et al.,* 2015; Craig, 2013).

> "The greatest levels of marine biodiversity are found in tropical countries which are developing. Being poorer (…) they have less facilities, equipment, trained staff and resources to devote to (…) biodiversity conservation" (…) "their priorities focus on food production and development (…)" (Gray, 1997).

Moçambique precisa de um plano de desenvolvimento eficaz para Cabo Delgado (segundo o Plano de Ação para a Redução da Pobreza II, ou PARPA II, a pobreza em Cabo Delgado aumentou, com uma estimativa de 63,2% de pobres, PARPAII, 2006) que inclua benefícios para os residentes locais e que garanta a proteção do património natural. As atividades que exploram a riqueza natural e geológica da região, com as devidas "precauções", devem contribuir para a melhoria das condições de vida das pessoas, com criação de infrastruturas e serviços, assim como de postos de trabalho. A região deve zelar por fugir à síndrome "Rich Forests, Poor people" (Naughton-Treves *et al*., 2005). As pessoas podem ser alavancadas da pobreza, não só com oportunidades de crescimento económico (FAO, IFAD e WFP, 2015), mas também, com informação sobre a importância dos ecossistemas e da sua funcionalidade. Informadas as pessoas serão mais conscientes dos desígnios do seu futuro.

Biodiversidade em risco

Sendo um facto que as pressões sobre a biodiversidade continuam a aumentar (Rands *et al*., 2010; Mace *et al*., 2010) o crescimento demográfico agravará a procura dos serviços de provisionamento dos ecossistemas marinhos e terrestres (Mace *et al*., 2010). Contam-se como as causas gerais da perda de biodiversidade: a degradação, destruição, conversão e fragmentação de habitats; a sobre-exploração de espécies; a presença e disseminação de predadores, competidores e agentes patogénicos; as mudanças rápidas do clima (Sadava *et al*., 2011). Rands *et al*., (2010) e Mace *et al*., (2010) acrescentam ainda a poluição, e Mace *et al*., (2010) acrescenta a produção de biocombustível como "drivers" de perda de biodiversidade. Há ainda as ameaças bizarras, como a poluição relacionada com microplásticos, entre outras (ver Rands *et al*., 2010). Ceballos *et al.,* (2017) fala em aumento da toxicidade nos meios como fator potenciador da extinção.

No que diz respeito a zonas terrestres, o ser humano tentará extrair recursos a uma velocidade maior (na indústria madeireira, agravando a desflorestação). Irá ter necessidade de áreas agrícolas maiores ou mais produtivas (para biocombustíveis e produção de alimento para gado e sua alimentação) aumentando o grau de conversão de habitats. Perspectiva-se uma maior fragmentação de habitats naturais, aumento do "patchiness" e uma maior pressão sobre as áreas protegidas, quer terrestres, quer marinhas (Rands *et al.,* 2010). A fragmentação de habitats será aprofundada adiante.

No contexto marinho as ameaças fazem-se sentir com mais proeminência nas zonas costeiras, dado que é nestes locais que as populações e as atividades industriais se concentram (Gray, 1997; Anastácio *et al*., 2012).

O IPCC (2007) refere que o aumento da temperatura, as alterações das calotes polares, as alterações dos níveis de salinidade e oxigénio e das correntes têm sido responsáveis por alterações nos sistemas biológicos marinhos e dulçaquícolas (corroborado por Poloczanska *et al.*, 2016, ainda que incida na necessidade de aprofundar o conhecimento sobre a acidificação dos oceanos e de estudos que combinem efeitos de vários fatores abióticos e não só temperatura). Estas alterações traduzem-se em variações na diversidade (e abundância) de plâncton e de peixes nas zonas de elevada latitude; alteração na abundância de fitoplâncton e de zooplâncton em lagos de elevada latitude e elevada altitude; e variação das migrações de peixes em rios, como por exemplo, a sua antecipação (IPCC, 2007). Boyce *et al.*, (2010) referem que a produtividade primária dos oceanos diminuirá, trazendo consequências para os restantes níveis tróficos. A falta de recursos pesqueiros irá provocar uma procura ainda maior das espécies marinhas (não só as do topo das cadeias alimentares), tanto nas zonas costeiras, como no alto mar (Rands *et al*., 2010).

Degradação, destruição e fragmentação de habitat

" (…) "islands" of natural habitat scattered across a "sea" of human-transformed habitat" (Haddad *et al*., 2015).

A alteração antropogénica dos habitats é a maior ameaça à riqueza da vida (Meffe e Carroll, 1997). Talvez seja por isso, e por outras pressões antropogénicas, que o ser humano seja responsável pela extinção em massa (Ceballos *et al*., 2015, 2017) mais acelerada (Olff e Ritchie, 2002) do nosso planeta.

A fragmentação de habitat (a separação de uma área em porções de composição abiótica diferente) compreende (1) a redução da quantidade de um habitat-tipo, ou de todos os habitats naturais dentro da paisagem, e (2) a criação de porções do habitat restante em "patches" (fragmentos, manchas) mais pequenos e isolados (Harris, 1984; Wilcove *et al*., 1986; Saunders *et al*., 1991, *in* Meffe e Carroll, 1997).

Apesar de a maior parte dos estudos se focarem na fragmentação de habitats, este conceito pode também ser aplicado aos recursos explorados pelas espécies, como por exemplo o alimento (Olff e Ritchie, 2002). A análise dos diferentes componentes de uma área, pode mostrar o grau de fragmentação da mesma (por vezes um fragmento grande pode apresentar o mesmo grau de fragmentação que uma paisagem fragmentada) (Olff e Ritchie, 2002). Há, pois, muitos graus e escalas de fragmentação (Haddad *et al*., 2015) que definem o grão de uma paisagem-área (Meffe e Carroll, 1997). A fragmentação não afeta só as populações e as suas interações bióticas; interfere também com funções dos ecossistemas como, por exemplo, a polinização, a produtividade e os ciclos biogeoquímicos ao nível da captação de carbono, ou a retenção de azoto (Haddad *et al*., 2015).

O conceito de fragmentação que é aplicado a meios terrestres é aplicado, também a meios aquáticos, apesar do número de estudos sobre este fenómeno nos ambientes salinos como os oceanos e ecossistemas afins, como pântanos, estuários, pradarias marinhas, corais e mangais serem ainda poucos (Gray, 1997), por serem também muito complexos de estudar (ver Crowder e Norse, 2008). É precisamente nestes sistemas específicos junto às costas, nas plataformas continentais e/ou em ilhas, que se verifica uma atividade humana exacerbada, e que explora inexoravelmente a área, poluindo e pressionando a biodiversidade lá existente (Gray, 1997).

Nenhum habitat é homogéneo a 100%, principalmente porque também está sujeito a um padrão de perturbações naturais. Porém essas mesmas perturbações criam um "naturally patchy landscape" à qual as espécies se adaptaram ao longo do tempo, algo que não acontece numa "fragmented landscape" por ação antropogénica, que experimentou alterações drásticas, resultando numa heterogeneidade alienígena.

A fragmentação atua segundo estes cinco mecanismos, que acarretam perda de biodiversidade:

- exclusão inicial ("initial exclusion"), *i.e.*, é o nome dado ao mecanismo que torna vulneráveis ao desaparecimento aquelas populações que dependem de áreas com condições muito próprias e que se encontram em pontos específicos da paisagem; ao fragmentar a paisagem, podem eliminar-se essas áreas específicas, ou diminuir-se a sua extensão, e os indivíduos não conseguindo migrar para outras áreas são os primeiros a sofrer/desaparecer;

- barreiras e isolamento, *i.e.*, os fragmentos podem preservar partes do habitat original nefastas para algumas espécies e isolam-nas nestas ditas áreas menos propícias, principalmente se estas não tiverem capacidade de executar as suas movimentações naturais ou de se dispersarem;

- efeito espécie-área ("crowding effects"), *i.e.*, quanto mais pequeno o fragmento, menor a variedade de habitats que exibe, menor capacidade de suporte de populações que nele vivam, menor a probabilidade de ser intercetado por outras espécies nos seus caminhos de dispersão, logo, mais suscetibilidade à extinção das espécies que permanecem no fragmento;

- efeito de limite ("edge effect"), *i.e.*, as espécies bem adaptadas aos limites de um fragmento (predadores e competidores oportunistas), terão maior propensão em penetrar no fragmentos com núcleos ("core areas") reduzidos, também suscetíveis às perturbações rápidas dos fatores abióticos;

- as paisagens com um grão grosseiro de fragmentação (na paisagem ocorrem áreas perturbadas com uma vasta extensão) estão menos capazes de gerar/suportar padrões de perturbação naturais, o que interfere com a comunidade (Meffe e Carroll, 1997).

A fragmentação de habitats afeta a diversidade de forma distinta, diminuindo por exemplo a riqueza de espécies (Haddad *et al*., 2015) de uma área, pois interfere com diferentes processos ecológicos determinantes da biodiversidade que governam a composição das populações (Olff e Ritchie, 2002). A competição, a interação entre níveis tróficos, o grau de preenchimento espacial são processos determinantes de biodiversidade de "escala local"; a dinâmica entre metapopulações, as condições abióticas do meio são exemplos de determinantes que atuam a uma escala intermédia no "pool" da espécie; a especiação, a extinção e a história biogeográfica são determinantes que atuam/se verificam a uma escala maior (Olff e Ritchie, 2002).

Existem conjuntos de espécies mais vulneráveis à fragmentação de habitat, sendo elas as: "naturally rare species", as "wide-ranging species", as espécies com taxas baixas de fecundidade, com ciclos de vida curtos, as espécies dependentes de recursos dispersos ("patchy or unpredictable resources"), as que nidificam no solo, as espécies dependentes de núcleos grandes ("large-patch"), e as espécies exploradas e perseguidas pelos seres humanos (Meffe e Carroll, 1997).

No caso dos elefantes africanos, objeto de estudo desta dissertação, pode-se dizer que são vulneráveis à fragmentação por serem "wide-ranging" (Douglas-Hamilton *et al.,* 2005), apresentam uma taxa baixa de fecundidade com período de gestação de 22 meses (van Aarde *et al.,* 2008), dependem de recursos dispersos (van Aarde *et al.,* 2008), e são perseguidos pelo ser humano. Entram ainda, em conflito por recursos e área com o ser humano, entre outras características que os levam a ser perseguidos (IUCN/SSC African Elephant Specialist Group, 1999) (*vide* capítulo II).

As tartarugas marinhas foram também alvo de estudo e, segundo a teoria, são vulneráveis à extinção por serem "wide-ranging species", sendo exploradas pelo ser humano para diversos fins (IUCN/SSC Marine Turtle Specialist Group, s/d; Hamann *et al.*, 2010) (*vide* capítulo III).

Conflito "humanos-vida selvagem"/ "human-wildlife conflict"

A fragmentação de habitats está intimamente relacionada com a necessidade de exploração de recursos naturais pelo ser humano. Quanto maior o número de pessoas, maior será a tendência a ocuparem e a fragmentarem a paisagem. Claro que dependerá da forma como o ser humano se organiza em relação ao seu meio ambiente, o que está relacionado com a cultura dos povos e os modelos de governação de ocupação de território (Evans e Adams, 2016).

O conflito "human-wildlife" é um fenómeno no qual a espécie selvagem entra em conflito com o ser humano, por ataque às culturas, ao gado, pela depredação de materiais e área ocupada pelo ser humano, pela predação de espécies selvagens geridas (por exemplo, em áreas protegidas), e/ou por morte de pessoas (Woodroffe *et al*., 2005). Este conflito resulta de uma relação de competição - uma "competitive exclusion" (Parker e Graham, 1989 *in* Lee e Graham, 2006).

A relação entre os elefantes africanos e as pessoas personifica bem este fenómeno. Os elefantes selvagens ao explorarem as mesmas fontes de água e de alimento encontram, com facilidade, pessoas desencadeando uma relação conflituosa (Pinter-Wollman, 2012). Também podem invadir áreas convertidas (em campos agrícolas, ou de pasto e resguardo de gado, aldeias, etc.) e até causar a morte de pessoas (Pinter-Wollman, 2012; Lee e Graham, 2006). Todos esses fatores condicionam a ação humana em relação a esta espécie selvagem. Na literatura o conflito é denominado por "human-elephant conflict" ou HEC (Hoare, 2012; Pinter-Wollman, 2012), e tem precisado da criatividade da comunidade científica para encontrar soluções, sob pena da exclusão total de elefantes dos ecossistemas (ver capítulo II). As respostas, porém, nem sempre são isentas de interesses políticos e privados (ver o artigo de Evans e Adams, 2016, e a construção de vedações elétricas para afastar elefantes), que evidenciam o egoísmo humano em partilhar espaço com esta espécie e, também a falta de tolerância (a designação dada aos indivíduos varia consoante o local onde estão: "wildlife" se confinados na área protegida e de preferência vedada, ou "dangerous pests" se fora dos limites da área protegida) (Wels, 2000 *in* Evans e Adams, 2016).

Uma das respostas mais importantes para resolver o HEC, ou para minimizar os efeitos da fragmentação de habitats, é a criação de áreas protegidas, quer em terra, quer em mar. Esta resposta global tem evoluído no sentido de conservar áreas cada vez maiores, abarcando o mosaico integral formado por diversos habitats que se interconectam por corredores, que têm sido também preservados (Gray, 1997; Gaines *et al*., 2010; Lausche, 2011).

Respostas para a proteção da biodiversidade

> "But over the past centuries humans have increased the extinction rate by as much as 1,000 times the "natural" rate typical of Earth's long history" (MEA, 2007).
>
> "The most recent Living Planet Index (LPI) has estimated that wildlife abundance on the planet decreased by as much as 58% between 1970 and 2014" (WWF, 2016 *in* Ceballos *et al.,* 2017).

O MEA (2005; 2007) refere-se à biodiversidade como "uma característica importante dos ecossistemas saudáveis, pois aumenta a sua felixibilidade e resiliência". A palavra resiliência é entendida neste contexto como "a capacidade dos ecossistemas em responder e lidar com a mutabilidade das condições, mantendo-se capazes de proporcionar serviços valoráveis" (MEA, 2007).

A diversidade biológica é definida pela Convenção da Biodiversidade Ecológica (Convention on Biological Diversity, CBD) como "a variabilidade existente entre os organismos vivos de todas as fontes, *inter alia*, terrestre, marinha e de outros ecossistemas aquáticos e os complexos ecológicos dos quais fazem parte: incluindo a diversidade intra-espécie, entre espécies e entre ecossistemas" (CBD, 1992). A biodiversidade é definida por Rands *et al.,* (2010) simplesmente como "a variedade de genes, espécies e ecossistemas que constituem a vida na Terra – proporciona numerosos serviços essenciais à sociedade".

Pode abordar-se a biodiversidade ao nível dos seus componentes, como o número de espécies, a abundância relativa, composição, extensão/alcance ("range"), aptidões funcionais ("functional traits"), distribuição espacial (padrões de…), interconexões verticais (tróficas) (Díaz *et al*., 2006); ou nas suas vertentes (níveis de organização): diversidade genética (o nível intraespecífico; o mais básico de todos), diversidade de espécies (*i.e.* o número de espécies numa dada área; o uso mais comum do conceito, chamado de "species richness"); diversidade filética (número de filos endémicos, ou não, num domínio, *e.g.* marinho ou terrestre); diversidade funcional (extensão de funções demonstradas pelos organismos num ecossistema); diversidade da comunidade ou do ecossistema, que aqui é tomado como a unidade de área (medida com índices de diversidade e/ou quantidade de espécies para uma comunidade); diversidade de habitat (o "template" da ecologia, dado que é uma unidade de área menos ambígua que o ecossistema), que pode ser medida também com índices de diversidade – Shannon diversity índex; Sorenson's índex – dependendo da escala utilizada (podem ser três): diversidade intra-habitat (*alpha*); entre-habitat (*beta*); ou regional (*gamma* ou "landscape diversity") (ver Gray, 1997 e Sadava *et al.,* 2011). Para além do valor de riqueza de espécies de uma dada área, pode determinar-se a "species evenness" (equidade), ou seja, as comunidades com a distribuição mais simétrica entre espécies ("more evenness") são mais diversas que comunidades com o mesmo índice de riqueza, mas uma distribuição assimétrica entre o número de indivíduos de cada espécie (Sadava *et al.,* 2011).

Em resumo, biodiversidade significa variedade, proporciona serviços essenciais, é um indicador do estado de equilíbrio do meio ambiente, da sua riqueza, e, quando elevado, aumenta a robustez dos ecossistemas. A biodiversidade encerra uma dimensão temporal (varia com o tempo) e uma dimensão espacial (varia com a dimensão da área considerada); varia com fatores como a latitude, a longitude, a altitude e a profundidade (Sadava *et al*., 2011).

Ao longo de milénios, os ecossistemas têm-se mostrado como sistemas de notável capacidade de resiliência às atividades humanas. Talvez pela primeira vez a uma escala global sejam postos à prova pelo aumento populacional disseminado, que funciona como uma sobrecarga sobre os recursos e serviços naturais. Para além da pressão derivada do crescimento populacional, as ações humanas foram tornando os ambientes do planeta "mais uniformes e menos resistentes" (MEA, 2007; Boy e Witt, 2013). O mundo estandardizado acarreta riscos, pois torna-se mais vulnerável e incapaz de resistir às transformações climáticas e geológicas repentinas.

Pensando nas transformações que exercemos ao longo de milénios, podemos concluir que, como espécie temos sido terríveis: dominamos espécies para nos proporcionarem alimento e fibras; somos agentes de disseminação de espécies que se convertem em exóticas e pragas; manipulamos solos, paisagens, genes para satisfazer a nossa curiosidade e aumentar lucros; estressamos, poluímos e extinguimos ecossistemas. Seremos sempre uma espécie com responsabilidade na extinção de outras, mas ao contrário de outros mecanismos naturais de extinção, somos também capazes de desenhar soluções criativas que podem diminuir os impactos negativos sobre o mundo natural ao qual pertencemos.

Estamos conscientes que "não é possível alterar um único elemento de um ecossistema sem correr o risco de destruir o equilíbrio sobre o qual a estabilidade do ecossistema depende" (Raven *et al*., 1992) e é por isso que os ecossistemas são entendidos como estruturas em equilíbrio dinâmico (Odum, 1993). O dinamismo aliado às incontáveis variáveis que operam num ecossistema aumentam a complexidade para a avaliação do status ou "saúde" do mesmo (Paetzold *et al.,* 2010) e para a previsão de consequências (de Groot *et al*., 2010; Maes *et al*., 2016), mas é graças a esse dinamismo que os ecossistemas "encontram" um novo equilíbrio. Odum (1993) lembra que a Terra (e os seus ecossistemas) é biorregenerativa em contraste com os "sistemas-armazém" (como por exemplo, uma nave espacial com recursos finitos que vai para o Espaço), devido à interconectividade das formas de vida encaixadas em três domínios e nos cinco Reinos, regenerando-se, reciclando e autocontrolando-se. Esta realidade intrínseca à Terra emana a esperança para o nosso futuro: se aliarmos ao nosso conhecimento tecnológico a capacidade regenerativa da Terra, talvez possamos superar alguns estragos infligidos aos ecossistemas e melhorar a forma como os utilizamos.

Mas, o que acontecerá se a biodiversidade diminuir drasticamente? A manifestação mais entendível da perda de biodiversidade é a extinção de uma espécie (Sadava *et al*., 2011). Por isso medimo-la usando contagens, métricas e índices que estimam a riqueza (número de espécies diferentes) e a uniformidade de espécies, e permitem comparar duas ou mais comunidades (Meffe e Carroll, 1997; Sadava *et al*., 2011). Apesar de existirem exemplos recentes do impacto da perda de espécies nos ecossistemas, com consequências para uma cadeia alimentar e para a paisagem (ver Díaz *et al*., 2006), os exemplos de extinção em massa do passado da Terra criam o pior cenário e evidenciam a fragilidade dos sistemas. Um paleontólogo sabe que a Terra é imprevisível, conseguindo exibir alterações naturais bruscas e mortais.

Para o ser humano tanto a noção de posse como a de perda de algo é importante. Usando a definição de Rands *et al.,* (2010), sabemos que a perda de biodiversidade implicará a perda de genes, espécies, o que poderá comprometer em primeira instância a qualidade dos ecossistemas, isto é, aumenta o risco de transmissão de doenças, os danos causados por insetos, diminuição da produtividade em meio terrestre e marinho (Klenner *et al*., 2009) – mas, em último lugar, poderá representar a perda do próprio ecossistema em si. Como pode um ecossistema regenerar-se com

a nossa intervenção, de forma a que os seus serviços sejam restabelecidos e oferecidos com qualidade?

Um caminho é a recuperação das populações existentes no ecossistema, ou seja, restabelecendo os valores de diversidade do mesmo. A disciplina da Conservação Biológica ("Conservation Biology") é uma resposta desenvolvida para combater a perda da biodiversidade. Semanticamente, conservação é: "o ato de conservar, de manter intacto ou não deixar deteriorar; preservação; estado do que é conservado ou preservado" (DPE, 2005). O conservacionista tem de dominar a arte do "cuidar", o que sugere a aplicação de um conjunto de medidas bem definidas, continuadas ou pautadas no tempo. Esse é o "good management" de algo a preservar. Também em biologia conservar implica cuidar, mesmo que não se tenham todas as respostas sobre: "De que forma a biodiversidade alicerça o "Human Well-Being"?, "Quais as funções e serviços do ecossistema mais diretamente dependentes da biodiversidade?", "To what extent are all those species essential fo the maintenance of different ecosystem processes and services? (Díaz *et al*., 2006; de Groot *et al*., 2010; Maes *et al*., 2016), "Como se avalia o "ecological status"? E o "biological integrity"? (Paetzold *et al*., 2010; de Groot *et al*., 2010; Maes *et al*., 2016).

Meffe e Carroll (1997) definem a "Conservation Biology" como um "campo sintético recente que aplica os princípios da ecologia, da biogeografia, da genética das populações, da economia, da sociologia, da antropologia, da filosofia e de outras disciplinas teóricas para manter a diversidade biológica em qualquer parte do mundo". É uma disciplina em "crise" multifacetada, "value-laden" (pressupõe a aceitação de um conjunto de valores), com evolução temporal, exercida em modo de eterna vigilância, regendo-se especialmente pelo valor da biodiversidade (Meffe e Carroll, 1997). Como área multidisciplinar está a evoluir para uma "modern conservation biology" (MCB), que procura uma abordagem mais equilibrada, sob uma ética de gestão como guia filosófico, e sob uma fusão entre ciências sociais e exatas como base teórica e prática de desenvolvimento (Meffe e Carroll, 1997; Bradshaw e Bekoff 2001). Sendo complexa, a MCB implementa e desenvolve os processos de *gestão da conservação* (Conservation Management), e de gestão dos ecossistemas (Ecosystems management). O primeiro é definido como "um conjunto de ferramentas e abordagens cuja utilidade e adequação são medíveis pelo grau de contributos para a conservação a longo-prazo dos padrões e processos naturais" (Meffe e Carroll, 1997). A gestão de ecossistemas é definida como "uma abordagem à manutenção e restauro da composição, da estrutura e do funcionamento dos ecossistemas naturais e dos modificados com o intuito de os tornar sustentáveis a longo prazo" (Meffe e Carroll, 1997).

A biodiversidade é preservada através da criação de áreas protegidas, do restauro dos ecossistemas degradados, do restauro dos padrões de perturbação natural, mitigando o tráfico e a caça furtiva, controlando o crescimento de espécies exóticas, prevenindo que se convertam em pragas, publicitando o valor económico dos bens naturais (economia ecológica), aumentando os efetivos das espécies mais ameaçadas, entre outras medidas/estratégias (Sadava *et al*., 2011).

Mace *et al*., (2010, 2013) em resposta à ambiguidade das metas da década de 2000-2010 propõem que as metas sejam distinguidas pelo grau de urgência segundo uma escala de cores: os "red" (mais urgentes), "blue", e os "green targets".

As metas da biodiversidade de Aichi ("Aichi Biodiversity Targets") resultam do compromisso global que pretende conservar os ecossistemas e o seu conteúdo. Desenhadas para serem alcançadas em 2020 (como primeiro patamar) (ver documentos UNEP/CBD/COP, 2010, UNEP/CBD/COP, s/d; e Mace *et al*., 2013), representam a ambição e o desejo de descontinuar as

ações que contribuem para a perda de todas as formas de biodiversidade. São apresentadas sobre a forma de cinco metas estratégicas (de A a E), que se desdobram em grupos de submetas (20 no total). Estas metas estratégicas (ou "strategic goals", SG) compreendem: abordar as causas que contribuem para a perda de biodiversidade, integrando o conceito de biodiversidade em todas as secções da sociedade, inclusive nos governos (SG A); reduzir as pressões diretas sobre a biodiversidade e promover a utilização sustentável (SG B); melhorar o *status* da biodiversidade, salvaguardando os ecossistemas, as espécies e a diversidade genética (SG C); Potenciar os benefícios derivados da biodiversidade e dos serviços dos ecossistemas para todos (SG D); Melhorar a implementação, através da planificação participada, da gestão do conhecimento e da capacitação das pessoas envolvidas (SG E) (SPB, 2010; UNEP/CBD/COP, 2010).

É com estas medidas que se espera cumprir a missão ambiciosa proposta pela CBD de "take effective and urgent action to halt the loss of biodiversity in order to ensure that by 2020 ecosystems are resilient and continue to provide essential services, thereby securing the planet's variety of life, and contributing to human well-being, and poverty eradication" (UNEP/CBD/COP 2010).

A base de trabalho dependerá do governo de cada país e dos seus centros académicos, pois através das suas escolhas e do debate/divulgação dessas escolhas poderão permitir a difusão de uma cultura nova para a conservação da biodiversidade (figura 8). Esta difusão cultural certamente promoverá um "empoderamento" ou capacitação das pessoas, ideia defendida no relatório "Strategy for the Celebration of the United Nations Decade on Biodiversity 2011-2020" (UNEP/CBD/COP, s/d), e por autores como Fraser *et al*., (2006). Assim, apela-se à criação de uma campanha messiânica que atinja todas as partes do mundo (UNEP/CBD/COP, s/d). Rands *et al*., (2010) propõem combater a perda de biodiversidade segundo três prioridades básicas interconectadas: gerindo-a como um bem público; integrando-a nos domínios de decisão pública e privada; e criando condições para a implementação de políticas que promovam a sua proteção.

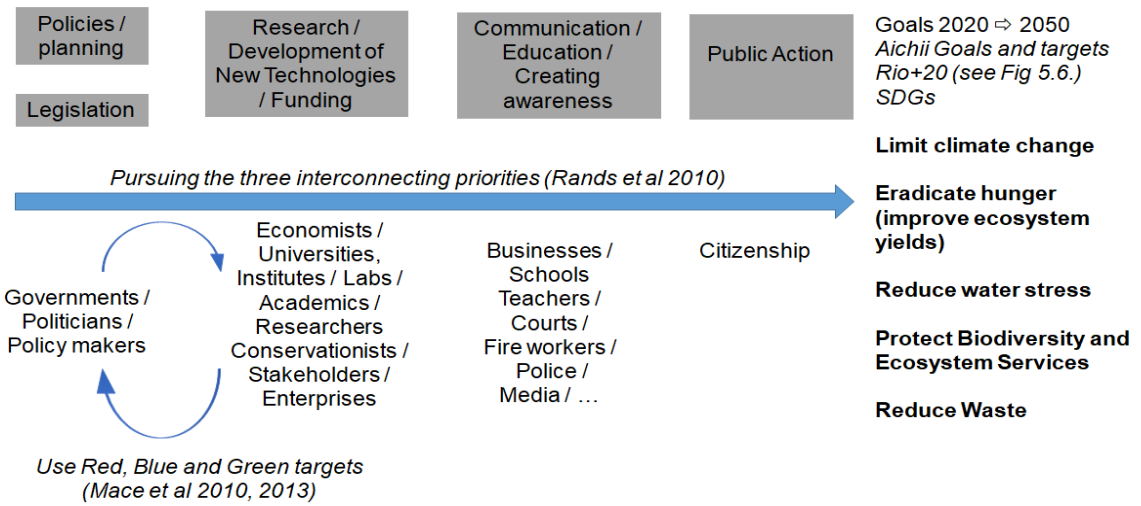

Figura 8. Visão de ação global integrada para gestão global da biodiversidade, adaptada dos trabalhos de Rands *et al*., (2010), Godfray *et al*., (2010), van Vuuren *et al*., (2012), Mace *et al*., (2013) e dos SDGs.

Preocupados com a perda de biodiversidade e mostrando futuros cenários van Vuuren *et al*. 2012 centrando-se em dois núcleos de ação (erradicar a fome, coincidente com os MDG1 e SDG2; e proteger a biodiversidade, como o MDG7 e o SDG14) afirmam que são prioridades políticas: acelerar a implementação de práticas agrícolas sustentáveis, com a criação das devidas condições; reduzir a fome das populações, melhorando os sistemas de produção e distribuição de alimento; integrar as preocupações sobre biodiversidade no planeamento do uso das áreas terrestres e aquáticas; e promover mudanças nos padrões de consumo das populações. Mesmo que alguns destes pontos contenham alguma ambiguidade, vão ao encontro das ideias de outros autores (Mace *et al*., 2013; Foley, 2014; Godfray *et al.,* 2010).

A capacitação dos agricultores mais pobres no uso de práticas agrícolas sustentáveis tem sido uma meta de entidades como a FAO, com a ideologia do "family farming". Mas existem soluções altamente tecnológicas, ambiciosas e que encerram em si um potencial estrondoso e exequível como o "Vertical Farming" (Despommier, 2010).

O MEA toolkit (2007) referia que se deveria incluir nas decisões políticas e planos de gestão a nível regional ações que permitissem a definição de áreas protegidas, ou uma proteção mais determinada das já existentes. Jackson (2011) defende que "a nova macroeconomia necessitará de uma maior literacia ecológica e social, terminando de uma vez por todas com a separação contraproducente entre economia, sociedade e ambiente".

Ceballos *et al*., (2015) demonstrou recentemente, utilizando o que chamaram de "background rate" de 2 E/MSY (BR), *i.e.* 2 extinções de mamíferos por 10000 espécies por 100 anos, que a taxa atual de extinção de vertebrados é 100 vezes maior que esta "background rate". Mais, as espécies de vertebrados que se extinguiram nos últimos 100 anos, caso o tivessem feito à BR demorariam entre 800 e 10000 anos (e não 100 anos) a desaparecer (Ceballos et al., 2015). Focando-se *a posteriori* na perda de populações de uma amostra de 177 espécies de mamíferos (entre 1900 e 2015), demonstra que assistimos à sexta extinção em massa (Ceballos *et al*., 2017).

Popper na sua palestra dada em Zurique em Agosto de 1985 lembrava que "só existem problemas quando existem valores"; ensinar os valores da natureza aos seres humanos implica que estes venham a pensar nos problemas que causam ao mundo natural (Popper, 1985 *in* Popper, 1999). No mundo científico são necessárias mudanças que facultem uma nova forma de olhar para os problemas: ser original, criativo, participativo e – o mais importante de tudo – colaborativo. Ser conservacionista será tão importante como ser professor, ou corretor de bolsa, ou CEO de um grande empresa.

Os artigos que integram esta tese derivam desta necessidade. Foi necessário olhar para a conservação dos elefantes de Quiterajo e para as tartarugas de Vamizi de forma criativa, após analisar os resultados, no primeiro caso, dos questionários aplicados às pessoas; no segundo caso, das bases de dados do projeto de conservação em vigência na ilha de Vamizi e arredores.

Elefantes e Tartarugas Marinhas: os emblemas de uma causa

Os seres humanos têm uma relação bipolar com determinadas espécies. Ou as adoram, ou as detestam. Uma das questões colocadas por quem faz conservação é "até que ponto esta espécie é determinante para alguma função/serviço deste ecossistema?" (Díaz *et al*., 2006). É muito provável que o mundo possa existir sem elefantes (existiram no Alto Egipto antes da sua extinção, apontada por estudos arqueológicos para 3500 A.C., Adams, 1998). Também é provável que um

mundo com menos tartarugas marinhas possa subsistir (sabe-se que o seu número era significativamente maior nas Caraíbas, antes dos Europeus explorarem a América) (Spotila, 2004; Eckert e Abreu Grobois, 2001). Porém, a ausência tanto das tartarugas nos Oceanos/zonas costeiras, como dos elefantes em meios terrestres, tem grande impacto nos ecossistemas.

Tanto os elefantes como as tartarugas marinhas são "long-lived species" (Meffe e Carroll, 1997), sendo símbolos importantes de muitas culturas. Ambos os grupos têm um elevado impacto nos seus ecossistemas, dado que a sua ausência ou presença muda a funcionalidade do ecossistema. São animais corporalmente grandes, migrantes, exploradores de habitats dispersos e dos corredores que os ligam.

Os elefantes são os jardineiros dos ecossistemas terrestres que exploram (savana africana, miombo, floresta, deserto), sendo considerados "modificadores de habitat" (Meffe e Carroll, 1997; van Aarde e Jackson, 2007).

As tartarugas marinhas, especialmente as que comem ervas marinhas como a *Chelonia mydas*, são também "modificadoras de habitat" (Lal *et al*., 2010; Goatley *et al*., 2012); mas as hawksbill são as "arquitetas" dos recifes de coral (Spotila, 2004; Goatley *et al*., 2012), e as loggerhead por serem omnívoras são "keystone species" (Spotila, 2004; Hawkes *et al*., 2009). Uma espécie é considerada como modificadora do habitat se interferir com a dinâmica do ecossistema, o que pode acontecer modificando estruturalmente a comunidade (como os elefantes, e as green turtles), ou alterando as condições edáficas (como acontece com as loggerhead (Spotila, 2004; Lal *et al.*, 2010). Uma modificadora pode ser também uma "keystone species", apesar de estas últimas serem definidas como tendo uma influência dominante na constituição da comunidade de determinado ecossistema (Sadava *et al*., 2011).

Por representarem espécies emblemáticas, a conservação destes dois grupos de seres (elefantes e tartarugas marinhas) pode trazer vantagens ao nível da aceitação dos planos de gestão de grandes áreas ("lanscapes" e "seascapes", *i.e.* paisagens com vários habitats). Porém, a conservação de ambos os grupos, apesar de muito diferentes, acarreta dificuldades que necessitam de uma vigilância multidisciplinar, por vários anos. Os projetos de proteção de tartarugas marinhas têm sido bem sucedidos, principalmente aqueles que integram a proteção de áreas de nidificação (Broderick *et al*., 2006). A conservação de elefantes, marcada por muitos obstáculos, é carreada por organizações como a "Save the Elephants" (http://www.savetheelephants.org/), e a "Elephant Voices" (https://www.elephantvoices.org/), entre outras, geridas pela comunidade dos investigadores mais conhecidos na atualidade que alertam para a eminente extinção destes animais.

Apesar de os elefantes estarem em profunda desvantagem, quando comparados com tartarugas que se movem num meio aquático, a sua inteligência ou instinto, que se revela na sua organização social e espacial (van Aarde *et al*., 2008; Goldenberg *et al*., 2016), tem-lhes permitido permanecer e coexistir, ainda que de forma conflituosa, com os seres humanos ao longo de milénios (Adams, 1998; Lee e Graham, 2006).

O elefante africano, *Loxodonta africana* (Blumenbach, 1797), sendo o maior animal terrestre-continental (Blanc, 2008) é também uma "wide-ranging species" (Blanc *et al*., 2007, Douglas-Hamilton *et al*., 2005), para além de "long-lived species" (Meffe e Carroll, 1997), duas condições que o tornam propenso a sofrer com a fragmentação do seu território. Não obstante, os elefantes adaptam-se relativamente bem a áreas ocupadas pelas pessoas (sobrevivendo da exploração dos seus recursos agrícolas) (Lee e Graham, 2006; Bulte e Rondeau, 2005; Hart e O'Connell report,

s/d). Utilizam e exploram proactivamente uma grande variedade de habitats, muitos deles fragmentados e ocupados, ou modificados, na ordem das centenas de km^2 (>200km^2 até < 800km^2) (Douglas-Hamilton *et al*., 2005). Exercem um impacto ecológico significativo na paisagem, sendo estruturadores da vegetação, pelo que tomam o nome de "landscape gardeners" (Douglas-Hamilton *et al*., 2005). Esse papel estruturante da comunidade vale-lhes o estatuto de "keystone species" (Blanc *et al*., 2007), também. Ao distribuir-se por uma área grande de terreno e ao movimentar-se usando corredores de deslocação/migração entre sectores (preferidos, ou temporários) estabelecem contacto com grupos familiares, podendo dizer-se que uma paisagem alberga num dado momento uma metapopulação (Douglas-Hamilton *et al*., 2005, Pinter-Wollman, 2012), ou seja, uma rede de subpopulações que podem mostrar resiliência aquando fenómenos de eliminação dos indivíduos dominantes/orientadores (Goldenberg *et al*., 2016).

Esta espécie está posicionada na categoria "threatened" de menor gravidade da "Red List Categories and Criteria", *i.e.* o seu *status* é no momento "Vulnerable" critério "A", subcritérios "2a", ou seja "Vulnerable A2a" (Blanc, 2008; ver IUCN, 2012).

A maior ameaça à sua existência é a fragmentação e a conversão de habitats em consequência do crescimento populacional humano (Blanc, 2008), mas também do ressurgimento da caça associada à procura de marfim (Thouless *et al*., 2016). Apesar da fragmentação os elefantes conseguem explorar habitats modificados (para agricultura) e ocupados (por humanos), conseguindo mover-se de "patch" para "patch", mesmo que estes apresentem barreiras físicas, que conseguem derrubar. Mas ficam muito expostos ao ser humano, a sua maior ameaça, pois são grandes, criam estragos avultados, transportam marfim, e representam caça com elevado interesse económico. A fragmentação aliada às movimentações típicas dos grupos e dos animais solitários e à sua capacidade em explorar terrenos de cultivo do Homem, acarreta encontros e conflitos negativos e marcantes para as duas partes, o chamado HEC (Pinter-Wollman, 2012). Porém, a caça ilegal dos animais pelo marfim (traficado para a Ásia) e pela carne são ameaças igualmente preocupantes (Blanc, 2008; Wittemyer *et al.,* 2014).

Estima-se que a resolução do conflito, ou a sua diminuição significativa, possa ser difícil de alcançar devido ao aumento das atividades humanas que continuam a colidir com as necessidades desta espécie (Pinter-Wollman, 2012; Hoare, 2012). A esperança só poderá residir nos seguintes aspetos: alteração da perceção das pessoas em relação à espécie (através da educação) e em relação à forma como o ser humano partilha as áreas com os elefantes, aceitação de medidas que promovam uma coexistência pacífica e protetora dos interesses de ambas as espécies (humanos e elefantes), melhor monitorização dos indivíduos com recursos a tecnologia não invasiva (acelerómetros, por exemplo), principalmente quando atravessam limites de áreas destinadas apenas às pessoas (evitando assim encontros fatais), e a criação de redes de áreas e corredores protegidos.

No caso dos elefantes (africanos de savana e asiáticos) as equipas de conservação têm tido como objetivo a diminuição do HEC (Günther *et al.,* 2004; Wood *et al.*, 2005; O'Connell-Rodwell, 2007; Zeppelzauer *et al.*, 2013; Sugumar e Jayaparvathy, 2014; Rahayani *et al.*, 2014; Prince e Sugumar, 2014; Vanitha e Nithya, 2015; Zeppelzauer e Stoeger, 2015; Stoeger e Baotic, 2016). Uma das estratégias consiste em detetar os movimentos dos elefantes no campo, a ponto de poder emitir alertas às aldeias da sua presença, evitando o confronto. No entanto, é preciso não só sinalizar estes animais, mas permitir-lhes a utilização de áreas onde possam explorar recursos que lhes são fundamentais. Outras equipas debatem-se, com alguma frustração, com o aumento

do abate de elefantes africanos para o comércio ilegal de marfim. Não é possível confinar os elefantes numa área protegida, por muito grande que ela seja, e tal não é desejável. Espera-se que a alteração de comportamento humano, mas também que as novas tecnologias possam auxiliar na mitigação deste problema.

> "When humans came on the scene the oceans were full of sea turtles. More than 600 million green turtles plied the warm shallow seas and 4-5 million hawksbills munched on coral reefs. They shared the ocean with 500 million olive ridleys, 400,000 Kemp's ridleys, and tens of millions of loggerheads. Another 1-5 million leatherbacks swam the oceans devouring jellyfish. The billion or so sea turtles helped make the ocean an aquatic Garden of Eden" (Spotila, 2004).

A conservação das tartarugas marinhas é um desafio que interliga a conservação de áreas terrestres, como as costeiras, e as marinhas de alto mar. Ao longo da sua longa vida, estes répteis marinhos atravessam águas que pertencem a muitas jurisdições diferentes (Obura *et al.,* 2012). Assim, a sua conservação depende da concertação de medidas entre muitos parceiros.

Outro desafio à sua conservação é o seu complexo ciclo de vida: eclodem em praias, nadam para o alto mar e oscilam entre fases pelágica e nerítica, voltando a uma praia de nidificação após atingirem a idade adulta para deixar os ovos na areia (as fêmeas) (Eckert *et al.,* 1999). Este é o esquema geral, mas há variantes.

Outra grande ameaça às populações de tartarugas marinhas são as variações de temperatura, dado que, por exemplo, a determinação do sexo de um embrião depende da temperatura da areia durante a fase de incubação (Davenport, 1997; Hawkes *et al.,* 2009), cuja duração também depende da temperatura do ar/areia (Hawkes *et al.,* 2009). Mas a temperatura é, na verdade, um fator que condiciona estes répteis durante todas as fases da sua vida (Davenport, 1997).

A toxicidade da água (que poderá levar ao desenvolvimento de fibropapilomas) (Perrault *et al.,* 2011; Kunito *et al*., 2008; D'Ilio *et al.,* 2011; García-Besné *et al.,* 2015; Work e Balazs, 2013), a poluição dos oceanos com plásticos (confundidos com alimentos, que obstruem o sistema digestivo) (Nicolau *et al.,* 2016; Work e Balazs, 2013; Nelms *et al.,* 2015), as técnicas de pesca ("shrimp trawling", "gill netting", e "longline fishing") (Spotila, 2004) e a captura intencional (por alguma parte corporal, ovos, carapaça) são ameaças reais à conservação destes animais (Chaverri, 2001). Tal como lembra Spotila (2004), as tartarugas marinhas "probably have been taken in small numbers by local tribes for a long time but they can't feed the world".

As tartarugas têm padrões de comportamento que as tornam vulneráveis, aglomerando-se em zonas de nidificação (praias e zonas costeiras), em zonas de alimentação e nos corredores de migração (Eckert *et al*., 1999). Há também os padrões interanuais que podem resultar em resposta a uma programação interna (neurológica, por exemplo), ou a alterações ambientais (Weishampel *et al*., 2003; Chaloupka, 2001). Claro que os estudos que mostram estes padrões incidem mais nas green (Chaloupka, 2001; Lauret-Stepler *et al*., 2007), e nas loggerhead (Weishampel *et al*., 2003).

A comunidade de investigadores que se dedica às tartarugas marinhas é bem conhecida. Nomes sonantes como o de Colin Limpus, Karen Eckert, Archie Carr, Abreu Grobois entre outros, dedicam-se não só à conservação, mas ao estudo da ecologia destas espécies misteriosas (ver Hamann *et al*., 2010).

O projeto de proteção de tartarugas desenvolvido na ilha de Vamizi em Moçambique, aplicou as técnicas defendidas por Eckert *et al*., (1999). Porém, a análise de dados demonstrou algumas fragilidades do processo de recolha de dados. Como tentativa de melhorar a performance dos trabalhadores de campo e a qualidade dos dados, desenhou-se uma solução tecnológica que pode ser aplicada em qualquer projeto de tartarugas nidificantes, em qualquer parte do globo. Isto porque, tal como o "The State of the World's Sea Turtles", SWOT (2011) preconiza, para avaliar o *status* de uma população, é fundamental colher dados fidedignos. Só assim, é possível a definição mais refinada de RMUs e MUs, tal como Wallace *et al*., (2010, 2011) vêm a defender.

Os artigos das hawksbill surgiram da oportunidade de analisar os dados da biologia reprodutiva evidenciada em Vamizi, e do estudo aprofundado sobre haplótipos.

Áreas Protegidas: estratégia para gerir a natureza e atingir as metas de conservação

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Áreas Protegidas: Definição e evolução

> "By global mandate, in addition to conserving biological diversity, protected areas are to provide economic benefits at multiple scales, alleviate poverty, protect threatened cultures, and promote peace" (Naughton-Treves *et al.*, 2005).

Uma área protegida ("protected area" ou PA) é "um espaço geograficamente bem definido, reconhecido, dedicado e gerido por meios legais ou outros igualmente eficazes, para atingir o objetivo de conservar a longo-prazo a natureza, os ecossistemas e valores culturais a ela associados" (https://www.cbd.int/undb/media/factsheets/undb-factsheet-pa-en.pdf; Juffe-Bignoli *et al.*, 2014).

Uma PA pode apresentar muitas designações, dependendo da terminologia da legislação de cada país. Como tentativa de uniformizar a terminologia a nível global, a IUCN estabeleceu recentemente novas categorias (ver Dudley *et al*., 2008), alegando que o uso das Categorias de Gestão da IUCN para classificar as áreas protegidas aumentará a qualidade das análises no futuro e providenciará um contexto mais claro dos objetivos para a gestão das áreas protegidas (Juffe-Bignoli *et al.*, 2014).

O CBD (IUCN-WCPA, 2010), que considera as PA como pedras basilares da conservação da biodiversidade, informa que muitas já estão compreendidas nas redes nacionais e regionais de áreas protegidas conectadas por corredores. As percentagens demonstram que as áreas protegidas terrestres e marinhas têm aumentado, estando-se, porém, longe de atingir o 11º objetivo de Aichi, uma vez que falta que todas as áreas sejam geridas de forma eficaz e que funcionem como sistemas interligados e integrados na paisagem terrestre e costeira (Juffe-Bignoli *et al.*, 2014). Rands *et al*., (2010) argumentam que as PA funcionam como estratégias eficazes de conservação, mas recomendam que devem ser geridas como pertencentes a uma rede coerente, ao invés de serem geridas como ilhas isoladas.

Através do programa PoWPA "Programme of Work on Protected Areas" (https://www.cbd.int/protected/overview/default.shtml), o CBD e os seus parceiros auxiliam a criação de PA em áreas marinhas e costeiras, sistemas aquáticos intracontinentais, terras secas e sub-húmidas, florestas e montanhas. O PoWPA pretende que os objetivos de Aichi sejam cumpridos até 2020 (de acordo, também, com a década da biodiversidade, estabelecida pelas UN). Estamos, porém, em 2017 e o objetivo do PoWPA de "integrar as áreas protegidas em áreas/setores mais vastos ("land and seascapes") como forma de manter a estrutura e funções ecológicas" contrasta com o objetivo 1.2. de "Em 2015, todas as áreas protegidas e seus sistemas estarão integrados em paisagens mais vastas, ou setores, em resultado da aplicação da abordagem ao ecossistema, e tendo em conta a conectividade ecológica e o conceito, quando apropriado, de rede (network) ecológica" (https://www.cbd.int/protected/pow/learnmore/goal12/).

O CBD (a,b) refere que aproximadamente 13% da superfície terrestre são PA. Juffe-Bignoli *et al.* (2014) refere que são PA 15,4% das áreas intracontinentais, terrestres e aquáticas (ver figura 9). Para os ecossistemas aquáticos, a área sob proteção é dramaticamente menor. O CBD (https://www.cbd.int/undb/media/factsheets/undb-factsheet-pa-en.pdf ;

https://www.cbd.int/protected/overview/default.shtml) refere que 6% da área da superfície do planeta é área marinha protegida (MPA). Segundo Juffe-Bignoli *et al*. (2014) é PA 3,4% da área dos oceanos, 8,4% de todas as áreas marinhas sob jurisdição nacional, e 10,9% de todas as águas costeiras (Juffe-Bignoli *et al.,* 2014).

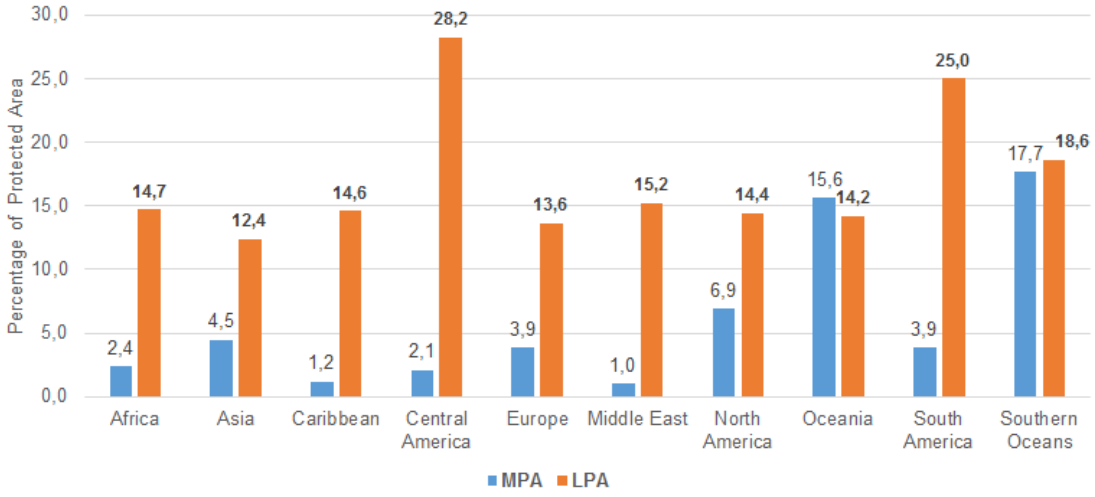

Figura 9. Percentagem (conjunta) de áreas terrestres e áreas aquáticas intracontinentais consideradas áreas protegidas para cada região da CBD (barras cor de laranja), e à percentagem de áreas marinhas dentro de jurisdições nacionais (0-200 milhas náuticas), também consideradas áreas protegidas, por cada região da CBD (Juffe-Bignoli *et al*., (2014) (consultar https://www.cbd.int/protected/implementation/default.shtml do PoWPA para verificação das percentagens mais recentes).

Tal como Naughton-Treves *et al*., (2005) enfatiza, nem todas as PA são geridas tendo em mente a conservação da biodiversidade apenas. Juffe-Bignoli *et al.,* (2014) diz que, cerca de 40% da área das PA é gerida com vista ao uso sustentável dos seus recursos.

As PA são criadas e mantidas para controlar os níveis populacionais das espécies que contêm. Sobre essas populações (que segundo Ceballos *et al*., 2017 são as unidades relevantes motor das funções dos ecossistemas, que fornecem os serviços) ausculta-se: se estarão em níveis viáveis, se vemos nelas padrões normais de perturbação, ou não, se a área permite a migração natural para outras áreas pertencentes aos "home-ranges" de cada espécie, se há ambientes hostis em torno da área protegida, e quais os tipos de pressões que ocorrem fora da área protegida (Naughton-Treves *et al.,* 2005; Meffe, Carroll *et al.,* 1997).

Para atingir o seu propósito e dependendo da sua dinâmica são estabelecidas dentro da PA zonas com diferentes propósitos (*e.g.* zonas de uso-múltiplo, zonas "no-go"; zonas "no-take"), ou alteram-se as suas fronteiras (Naughton-Treves *et al.,* 2005; Crowder e Norse, 2008). As equipas que gerem as PA devem ser multidisciplinares e reunir elementos que permitam uma gestão flexível e fundamentada (Naughton-Treves *et al.,* 2005; Crowder e Norse, 2008; Pollnac *et al*., 2010).

As PA são também estratégias para aliviar a pobreza das pessoas (Naughton-Treves *et al.,* 2005; Tobey e Torell, 2006). Proporcionam numerosos benefícios: para o desenvolvimento de

atividades comerciais e turísticas gerando economia localmente; mitigam a alteração climática e os efeitos de desastres naturais; oferecem água potável, uma vez que as suas linhas de água estão preservadas de construções e poluição; são o armazém de recursos comestíveis, dado que preservam nichos e habitats de muitas populações de espécies diferentes (Naughton-Treves *et al*., 2005). Reduzindo a pobreza, mantendo e melhorando os valores estéticos e crenças e a qualidade do ar que se respira e da água que se bebe, as PA permitem atingir as categorias do "Human Well-Being" (Juffe-Bignoli *et al.*, 2014).

Apesar das vantagens, as PA enfrentam ameaças idênticas às dos ecossistemas não protegidos. Em algumas partes do globo e devido ao crescimento demográfico, a procura de bens alimentares dentro de PAs cria pressões sobre elas, comprometendo os seus objetivos iniciais, inclusive o de aliviar a pobreza (Naughton-Treves *et al.,* 2005). Lausche (2011) enumera as ameaças diretas (que ocorrem dentro) e indiretas (de fora da PA com repercussão para esta) que interferem com as PA. Contam-se como ameaças diretas a "má gestão, exploração ilegal de madeiras, introdução de espécies exóticas, poluição *in situ*, extração de recursos minerais, exploração abusiva de espécies da fauna e da flora, exploração incorreta de visitantes, e catástrofes ambientais *in situ*, como tsunamis, fogos naturais, sismos, vulcanismo, avalanches e derrocadas (Lausche, 2011). As ameaças indiretas relacionam-se com decisões inapropriadas da exploração de terras, expansão urbana, degradação dos ecossistemas circundantes, catástrofes naturais de áreas adjacentes, consequências de pobreza e conflitos civis (Lausche, 2011).

Muitos esforços têm sido feitos para estandardizar a forma como as PA são geridas, apesar de existirem diferentes modelos de gestão (ver secção seguinte). A preocupação com a estandardização pretende aumentar a eficácia da gestão das PA, que tem como ónus gerar recursos e dividendos para a região e para as pessoas. Uma gestão integrada da ecologia, da sociedade e economia e das instituições eleva a gestão das áreas protegidas e dos ecossistemas em geral (Meffe e Carroll*,* 1997).

Os quatro princípios básicos da boa gestão preconizam: manter os processos ecológicos que são críticos e a composição original da biodiversidade local; minimizar as ameaças externas e maximizar os benefícios internos e externos; conservar os processos evolutivos; munir-se de planos e metas adaptativos e minimamente intrusivos (Meffe e Carroll*,* 1997). A gestão pode ser feita em diferentes escalas ecológicas, a saber: escala da "população", escala do "habitat", e a escala da "paisagem" ("land" ou "seascape") (Meffe e Carroll*,* 1997), porém as experiências conduzidas no passado e a dramática perda de biodiversidade (Ceballos *et al.,* 2015, 2017) apela, cada vez mais, à criação e gestão de áreas na escala maior.

Da experiência dos últimos anos, resultam os seguintes conselhos (transcritos na íntegra dada a sua importância):

- "as áreas protegidas marinhas e costeiras deverão ser integradas com os usos terrestres e o planeamento das áreas marinhas, e deve ser dada mais atenção às águas em profundidade dentro da jurisdição nacional;
- novos tipos de governação das áreas marinhas, por exemplo, privadas, indígenas e comunitárias, requerem novas abordagens que necessitam de ser plasmadas pela lei;
- as áreas protegidas transfronteiriças oferecem oportunidades de cooperação entre nações que envolvem leis nacionais e acordos internacionais;

- as alterações climáticas exigem flexibilidade no desenho das áreas a proteger, incluindo no enquadramento jurídico, que permita acomodar cenários de adaptação e mitigação, incluindo a criação de corredores que asseguram a conectividade dentro e entre ecossistemas;
- os sistemas de PA requerem financiamento sustentável, que envolve um conjunto de instrumentos e mecanismos *avant-garde* passíveis de ser implementados por instituições que não são responsáveis pela própria PA" (Lausche, 2011) – um apelo à responsabilidade social de empresas, indústria e ao cidadão comum.

Ciclo da gestão das áreas protegidas

Uma PA necessita de um plano inicial que defenda a sua constituição, que explane o modelo de gestão e qual a equipa para esse trabalho. Mas a boa gestão implicará a alteração do plano. O processo de gestão implica um ciclo de etapas como: planeamento, desenho, implementação, monitorização, avaliação, comunicação e adaptação (Pomeroy *et al.*, 2005) – figura 10.

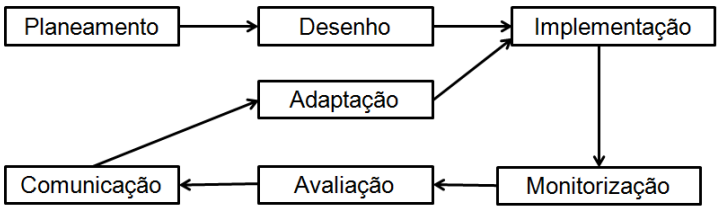

Figura 10. Ciclo de gestão de uma PA segundo Pomeroy *et al.,* (2005).

Basicamente, podem dividir-se as abordagens à gestão de PA em dois grandes tipos: "bottom-up" e o "top-down". Fraser *et al.,* (2006) mostra a importância da abordagem "bottom-up" que se inicia num "well-being assessment" (WBA, ou WA), perspectiva que se procurou no artigo do capítulo II. Este tipo de abordagem fará todo o sentido se a PA for, em si mesma, fundamental para a sobrevivência das pessoas que nela habitam (o que geralmente acontece em zonas muito pobres). As ideologias de gestão "top-down" poderão ser mais técnicas, mais centradas no conhecimento científico, como o modelo "ecosystem approach" (ver de Groot *et al.,* 2010) que será similar ao "ecosystem-based management" (modelo que considera todo o ecossistema em causa, incluindo os seres humanos), que procura também uma abordagem que respeite a conectividade ecológica (Crowder e Norse, 2008; Gaines *et al.,* 2010). Porém, tal não invalida que um modelo de gestão "top-down" não se converta no tempo num "bottom-up" e vice-versa.

Poder-se-á dizer que os projetos do tipo "community-based management" são exemplos de "bottom-up". Nestes modelos, gerir implica envolver as comunidades que se conformam com o estatuto de área protegida e se envolvem no ciclo de gestão. Por sua vez, o grau de conformismo relaciona-se com o grau de investimento feito nas áreas pelos governos e equipas técnicas de gestão, que depende da melhoria das condições de vida das pessoas (Pollnac *et al*., 2010). A "Blue Ventures Organization" aplica com sucesso o "community-based management" nos seus projectos (ver: https://blueventures.org/). Focam-se, sobretudo, nas "Locally Managed Marine Areas" (LMMAs), indo ao encontro da premissa de Tobey e Torell, (2006) « (…) promoting income-

generating businesses as part of community-based coastal management improves community interest and participation, and therefore the likelihood of success».

A abordagem desenvolvida por Fraser *et al*., (2006) implica a tomada de consciência da importância das Ciências Sociais no modelo de gestão de uma área protegida. As Ciências Sociais estão a conquistar o seu lugar ao lado das Ciências Exatas, para a definição de soluções de conflitos socio-ambientais complexos – ver a "complexity theory" ou "interdisciplinary research" (Bradshaw e Bekoff, 2001). Isto reflete-se no modelo "bottom-up", e é por isso que a equipa de gestão se questiona acerca: do grau de pobreza local, *i.e.*, serão as pessoas demasiado pobres para se comprometerem e envolverem num plano a longo prazo?; dos fatores biológicos e físicos, *i.e.*, quais são os problemas ambientais mais presentes na região?; e da estrutura da sociedade, *i.e.*, que grupos (e como) dependem dos recursos naturais locais? (Fraser *et al*., 2006). Assim, o processo de gestão de uma PA compreende, na perspectiva de Fraser *et al*., (2006) o cumprimento dos seguintes pontos:

- Auscultação da visão e ideias da comunidade de "stakeholders" (WBA), *i.e.*, habitantes locais, representantes da indústria, proprietários, líderes rurais e investigadores, a par da investigação na literatura ("ecosystem assessment", EA);
- Implementação do "wellbeing assessment process" sob a responsabilidade das equipas de gestão que deverão ser multidisciplinares;
- Criação de melhores políticas de gestão dos ecossistemas por parte dos legisladores;
- Supervisão da aplicação das leis apropriadas e do plano de gestão por parte dos políticos, com recurso a relatórios.

Pode, então conjugar-se o ciclo de etapas da gestão de Pomeroy *et al.,* (2005) com a visão bottom-up de Fraser *et al.,* (2006), como evidenciado na figura 11.

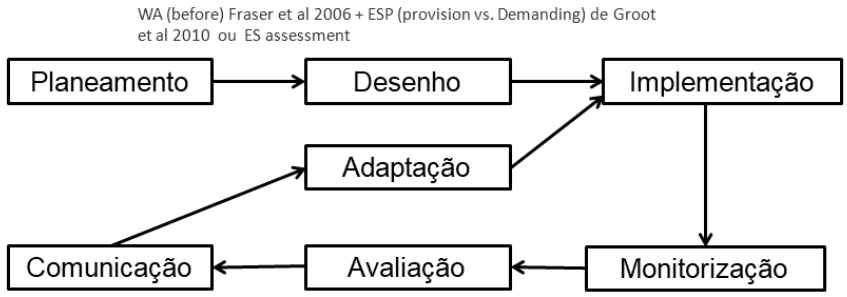

Figura 11. Ciclo de gestão de áreas protegidas com inclusão do well-being assessment (WA ou WBA) e o Ecosystem assessment (EA) para o planeamento do plano de gestão.

O declínio da pobreza e o desenvolvimento sustentável numa área só se conseguem mantendo o plano de gestão cujo grau de eficácia seja então avaliado (Pomeroy *et al.,* 2005; Crowder e Norse, 2008; Mace *et al*., 2013) – o que implica a avaliação da perceção das pessoas – num contexto de combate à corrupção entre autoridades e de redução da competição pelos recursos entre os "stakeholders" (Tobey e Torell, 2006).

"Assessing whether protected areas are being effectively managed is a crucial element of Aichi Biodiversity Target 11, and a vital prerequisite for achieving protected area objectives" (Juffe-Bignoli *et al*., 2014).

Apesar de ser importante uma avaliação permanente do grau de cumprimento dos objetivos (o que é difícil), pois isso garante uma melhor eficácia (Pomeroy *et al*., 2005), não se podem aceitar medidas totalmente inflexíveis na gestão de uma dada área, nem na sua avaliação. Planos que definam poucas metas, mais objetivas, com alguma flexibilidade, que permitam a capacitação das pessoas com vista ao aumento do grau de exigência dos objetivos no futuro, são planos mais propensos ao sucesso (Naughton-Treves *et al*., 2005).

A arte da gestão de uma área protegida é arriscada e incerta, pois requer tempo e depende, quer do grau do envolvimento dos seres humanos que nela vêm interesses (ver MacClanahan *et al.,* 2006), quer da mutabilidade intrínseca aos ecossistemas, que dificultam a ação das equipas de gestão (Meffe e Carroll*,* 1997), quer do financiamento das etapas do ciclo de gestão (figura 12).

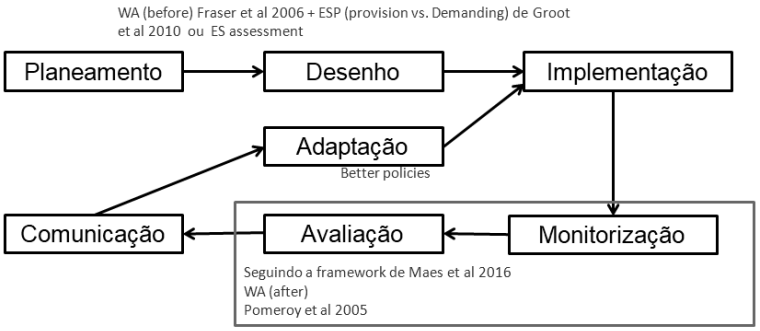

Figura 12. Ciclo de gestão das áreas protegidas com destaque para a monitorização e avaliação que pode seguir a "Framework" de indicadores de Maes *et al.,* (2016), por exemplo, de um WA com auscultação de opinião das pessoas afetadas pelo plano e suas medidas.

Para dar resposta às dificuldades referidas, a CBD, mais precisamente o PoWPA, oferece assistência para o "effectiveness assessment" dos planos de gestão das PA. O "Protected Area Management Effectiveness" (PAME), uma "framework" de avaliação, levanta as seguintes questões: a PA é funcional ao nível dos mecanismos da sua gestão e financiamento?; mantém o seu valor e atinge os seus objetivos, com a produção de mais-valias para: a conservação da biodiversidade (ao nível das populações, percentagem de habitats e qualidade de habitats), os serviços de provisionamento e as vivências humanas? (Juffe-Bignoli *et al*., 2014). Estas questões são bastante objetivas no momento de avaliação de um plano de gestão.

> "A rate of two vertebrate species extinction per year does not generate enough public concern, especially because many of those species were obscure and had limited ranges (…)" (Ceballos *et al.,* 2017).

Tudo possui um valor qualitativo e quantitativo. O valor da biodiversidade é o que guia a "Conservation Biology". Medir o valor da biodiversidade (em dinheiro, por exemplo) não é uma tarefa fácil; mas é uma tarefa necessária, porque o dinheiro é uma medida compreendida numa base global.

> "In order to compare its value with the value of other things, economists have attempted to *monetize* both the instrumental and intrinsic value of biodiversity" (Meffe e Caroll, 1997).

Pode ler-se em Meffe e Carroll (1997) que a biodiversidade tem valor instrumental, dado que representa/proporciona: "bens "goods" (*e.g.* comida, produtos medicinais, fibras, combustível); serviços (*e.g.* polinização, reciclagem de nutrientes, produção de oxigénio); informação (*e.g*. conhecimento cientifico, livraria genética) e satisfação psíquica/espiritual (e.g. beleza natural, admiração religiosa, conhecimento puro)". Mas é mais que isso, pois possui valor intrínseco, ou seja, "tem valor como um fim em si mesma, assim como um meio para atingir o bem-estar humano", pelo que perturbá-la é considerado imoral (Meffe e Carroll, 1997).

À parte da discussão do tipo de valor albergado pela biodiversidade sob a perspetiva humana (se "intrínseco", se "instrumental", se ambos), a verdade é que é consensual que preservar a biodiversidade traz vantagens sobre a sua não preservação ou degradação. Discutir se essa vantagem é elevada ou baixa é quase irrelevante. O que importa é que o ser humano compreenda que sendo ele a comprometer a biodiversidade (mas não o único, dadas as causas naturais), também é ele que a pode conservar. O como fazê-lo é algo que temos vindo a construir.

Quando Constanza *et al.,* (1997) publicaram o artigo "The value of the world's ecosystem services and natural capital" os mercados viviam na lógica do "materialistic consumerism" (Jackson, 2011). Na verdade, é legítimo que todos os indivíduos ambicionem o estilo de vida de um cidadão de um país desenvolvido, pois todas as pessoas têm direito às mesmas oportunidades. Todas as pessoas têm direito a viver com dignidade e isso implica ter bens materiais também. Em contraste, os cidadãos dos países desenvolvidos têm de se habituar a ambicionar um estilo de vida com menos bens materiais, uma "aurea mediocritas" adequada e confortável, um novo modo de vida. Não obstante, como cidadãos (pobres ou ricos) espera-se que mudemos a forma como nos posicionamos em relação aos ecossistemas: de uma atitude de negligência do seu valor ("non-awareness") para uma atitude de valorização dos seus serviços, mesmo que para tal se utilize o valor monetário que eles representam.

> "We must begin to give the natural capital stock that produces these services adequate weight in the decision-making process, otherwise current and continued future human welfare may drastically suffer. (…) the annual value of these services is (…) with an estimated average of US$33 trillion" (Constanza *et al.,* 1997).

Dado que os bens naturais não se encontram distribuídos de forma equitativa no globo, o alívio da pobreza passará pela boa gestão dos recursos locais, e por uma permuta de recursos sustentável entre nações. Assim, Jackson (2011) defende que «the rich world has a responsibility to "make room for growth" where it matters most in terms of improved well-being; that is, in the poorest nations». Mas as projeções não são favoráveis às metas que o Banco Mundial impôs para a erradicação da pobreza. A meta desejável da redução da pobreza extrema à extinção mostra-se ainda distante. As projeções de Bluhm *et al*., (2014) para a extinção da pobreza são dramáticas para a África Subsaariana, especialmente em estados mais fragilizados por conflitos.

Demonstrou-se que a taxa de redução de pobreza pós 2015 terá diminuído (Bluhm *et al*., 2014) e que a taxa de pobreza extrema andará nos 8%, no cenário projetado mais otimista (o que não são boas notícias). À data do estudo de Bluhm *et al*., (2014) existiam 1200 milhões de pessoas nesta "categoria". Significa então que o objetivo do Banco Mundial em reduzir a taxa de pobreza para 3% (pessoas a viver com menos de 1,25 dólares por dia) foi inatingível (Bluhm *et al*., 2014). E diminuir as disparidades torna-se fundamental dado que «novas formas de racismo e de discriminação podem desenvolver-se, apoiadas na ideia da desigualdade das culturas e alimentadas pela mundialização e pelos efeitos da incerteza por ela criada, pelo aumento das desigualdades materiais e a dissociação dos sistemas sociais e educativos» (Sané e Bindé , 2004).

Para escapar a este cenário os países mais vulneráveis terão de resolver os conflitos civis, a instabilidade política e combater a corrupção (Bluhm *et al*., 2014). Têm de adotar uma perspectiva firme de crescimento económico inclusivo e sustentável, o que implica, por exemplo comprometer-se no combate à poluição e às alterações climáticas (Bluhm *et al*., 2014). A economia sustentável e inclusiva será difícil de implementar quando comparada com a economia tradicional, mas transporta a vantagem de respeitar os limites ecológicos do contexto natural (Jackson, 2011). Se mantido o passo de crescimento atual, espera-se para 2100 uma economia 80 vezes maior que a existente em 1950 (Jackson, 2011), altamente disfuncional para os ecossistemas.

O mundo económico tem vindo a despertar para um novo tipo de empresas que oferecem serviços que têm como missão criar uma indústria e agricultura preocupadas com os impactos no ambiente. É necessário que essa preocupação ecológica se estenda a todo o tecido industrial e empresarial e destes para o consumidor; e que o consumidor exija (ver, por exemplo, a iniciativa GRI, em https://www.globalreporting.org/Pages/default.aspx).

Também o "The Economics of Ecosystems and Biodiversity" (TEEB) constitui-se como uma "plataforma para decisores governamentais e do mundo dos negócios que integra o valor económico da biodiversidade e dos serviços dos ecossistemas na sua responsabilidade e sistemas de monitorização" (Sukhdev *et al.,* 2014).

A forma mais poderosa para alterar a cultura económica materialista, assim como os padrões de consumo, é através de uma comunicação eficaz das projecções e dos estudos científico. Tal pode ser feito pelos mass media, mas especialmente nas escolas e nas universidades, tendo impacto na formação dos cidadãos mais qualificados e de todas as áreas. Isto porque é urgente a formação de cidadãos críticos e solidários. O ensino da ciência e de valores altruístas permitirá um maior compromisso para a recuperação dos ecossistemas e, talvez, inverter a sexta extinção em massa, cuja existência deve ser amplamente divulgada (ver Ceballos *et al.,* 2015; 2017) para criar uma força motivadora de resposta.

"The world now needs to adopt solutions that change the entire system of production and consumption in a fundamental manner, that move societies from conditions of energy and materials surplus to scarcity, and that develop the foresight needed to recognize still-hidden threats to sustainability. This goes far beyond the realm of technical adaptations, and instead requires large-scale social, economic, and political engineering—in an effort to create the foundations for a more sustainable human civilization" (SOTW, 2015).

Objetivos e Estrutura da Tese

Dado pretender-se fazer contributos para a conservação da biodiversidade e de recursos naturais em geral e, em particular para a "Messalo Wilderness Area" (MWA) e na ilha de Vamizi, no norte de Moçambique, dividiram-se os contributos numa vertente terrestre e noutra marinha/costeira.

O objetivo central deste trabalho consistiu na investigação do "know-how" para o desenho de projetos de gestão de áreas naturais. No caso do presente trabalho, decidiu-se adotar a metodogia "bottom-up" de acordo com a metodologia de Fraser *et al.,* (2006). Assim, surge o desenho de um questionário digital para fazer o "Human Well-Being Assessment" (HWA). A par do HWA, executou-se um "Ecological assessment" (EA) com base na informação documental existente. Ambos tiveram como cerne propor um plano de gestão dos recursos naturais locais. Esta proposta compõe o capítulo II, que dá continuidade ao trabalho desenvolvido na área pelos "The Cabo Delgado Biodiversity and Tourism Project" (Garnier, 2003) e o "The Maluane Project" (Wacher e Garnier, 2005).

Os resultados do HWA permitiram a identificação de pontos sensíveis na biodiversidade de Quiterajo. Assim, desenharam-se objetivos que permitiriam dar resposta à necessidade de conservação de algumas espécies em risco na região.

Em terra, o conflito homem-elefante (HEC) pede uma solução. Então, um dos objetivos consistiu em conceber uma solução tecnológica acessível, para fazer "virtual fencing" e sinalização de animais em zonas sensíveis de conflito (ver capítulo II, artigo submetido para publicação com o título "Spy out to protect: a new generation of sensing devices for virtual fencing and sensing wildlife activity").

No que concerne à parte costeira/marinha, houve a oportunidade de analisar as bases de dados de oito anos do projeto de conservação de tartarugas marinhas nidificantes da ilha de Vamizi. Assim, um dos objetivos consistiu em analisar a biologia reprodutiva de *Chelonia mydas* (Anastácio *et al.*, 2014b) e de *Eretmochelys imbricata* (Anastácio *et al.*, 2017a), com vista à deteção de prioridades para a sua conservação (capítulo III). Para além da análise dos parâmetros de nidificação (períodos de incubação, tamanho da ninhada, taxas de sucesso de eclosão/emersão do ninho, padrões anuais, entre outros), fez-se a análise da diversidade de haplótipos, com recurso à região de controlo do DNA mitocondrial de amostras de tartarugas nidificantes recolhidas na região (ver Anastácio e Pereira, 2017).

Desenvolveu-se, ainda, uma aplicação para "tablet", de recolha de dados dos parâmetros de nidificação, com vista à melhoria da metodologia de campo. Esta nova metodologia foi testada e publicada (Anastácio *et al.*, 2017b).

Porque a estimativa dos índices de pobreza e de dependência dos recursos naturais para a MWA são elevados, e dado tratar-se de uma zona costeira que vive ou da agricultura de subsistência, ou da pesca de subsistência, fez-se uma minirevisão da informação publicada sobre os efeitos das alterações climáticas na produtividade primária. O objetivo consistiu em apresentar as possíveis consequências da interferência com os ciclos biogeoquímicos e a disponibilidade de nutrientes para o fitoplâncton, quer ao nível dos produtores, quer ao nível dos consumidores finais. Assumiu-se que as alterações do clima irão determinar o desaparecimento de muitas espécies, a redistribuição das resilientes e a alteração da qualidade do contexto ambiental, assim como da

quantidade e qualidade de energia e massa que fluirá nas teias tróficas. Esta revisão é apresentada no capítulo IV, tendo sido publicada por Anastácio *et al.,* (2012).

O último objetivo para este trabalho consistiu em dar um contributo para a área da educação, com o desenho de um currículo de ciência, que permita o desenvolvimento da cultura do "cuidar", ou de "consciência ecológica", tendo em mente os SDG. Este currículo é apresentado no artigo "Global Science Teaching for Human Well-Being", que também faz parte do capítulo IV.

O último capítulo (V) consiste numa discussão geral e conclusão do trabalho desenvolvido.

O trabalho foi desenvolvido em regime de tempo parcial, e decorreu entre setembro de 2010 e outubro de 2017, o que explica o número de artigos que compõem a tese.

Os capítulos II, III, e IV, são compostos por manuscritos publicados ou aceites para publicação, por esse motivo, apresentam-se em língua Inglesa. Muitas figuras do capítulo I também se encontram na língua Inglesa, dado terem sido transformadas de relatórios originais (em Inglês), ou por poderem vir a constituir parte de duas futuras publicações em língua Inglesa, sob os títulos: "From the challenges imposed by climate change to the preservation of ecosystem processes and services"; e "Protected Areas – A challenge for Land and Sea in Quirimbas arquipelago". Este último, tendo como base o enquadramento desta tese e o desenvolvido nos capítulos II e III, poderá ser a base para a definição de um conjunto de áreas marinhas e terrestre protegidas, estabelecidas entre a foz do rio Rovuma e a ilha do IBO no Parque Nacional das Quirimbas, passando pela área do Messalo (Anastácio *et al.,* 2014), à semelhança do que é defendido naquela publicação, e assim enfatizar a área como 'hotspot' de biodiversidade, património da Humanidade, associando-se esta ideia à da criação do parque transfronteiriço Tanzânia-Moçambique defendido por Obura *et al.*, (2012) e pelo The Peace Parks Foundation (http://www.peaceparks.org).

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Capítulo II

Contributions for land resources protection

Anastácio, R.S., Schertenleib, L.N., Ferrão, J., and Pereira, M.J. (2014) Bottom-up approach towards a human wellbeing assessment for the design of a management plan: a study case with contributions to improve sustainable management of resources in a northern area of Mozambique. Open Journal of Ecology, 4(17): 1102-1117. http://dx.doi.org/10.4236/oje.2014.417090

Anastácio, R., Cardoso, S. Pereira, M.J. Spy out to protect: a new generation of sensing devices for virtual fencing and sensing wildlife activity. *Submetido*. **Publicado a 29 de março, 2018 como**: Anastácio, R., Cardoso, S. Pereira, M.J. (2018) Spy out to Protect: Sensing Devices for Wildlife Virtual Fencing. Open Journal of Ecology, 8: 192-208. Doi: 10.4236/oje.2014.417090 http://dx.doi.org/10.4236/oje.2018.83013

Bottom-Up Approach towards a Human Wellbeing Assessment for the Design of a Management Plan: A Study Case with Contributions to Improve Sustainable Management of Resources in a Northern Area of Mozambique

Abstract

The loss of biodiversity and ecosystem services disturbance will result in serious ecological and socioeconomic consequences. How can people be prepared to be more efficient in preserving ecosystems, its services and resources? The Messalo Wilderness Area (MWA) is an area lacking a bottom-up approach for the design of a management plan. This research intended to develop a strategy to gather people's views to begin a human wellbeing assessment for the area, for which a Digital Questionnaire (DQ) was developed and tested. The specific objectives were to 1) verify the dispersion/distribution of people and elephants; 2) study the natural resources used by the inhabitants; 3) locate the areas from where the most important natural resources are extracted and where conflict between humans and animals occur; 4) propose a Management Plan (MP) capable of mitigating the human-animals conflict, promoting the conservation of elephants and, consequently, of other types of biodiversity, thus working towards a better socio-economical development of the area. The elements gathered in the consulted references were used to design several maps and cartographic figures shown in this article, using the Map Window software. These maps describe: fresh water distribution, habitat distribution, population dispersal and main road connections, crop fields distribution and main exploitation spots of the different resources, orography and topography. The results from the DQ analysis helped to gather indicators to the human wellbeing assessment. The information gathered in the literature and by inquiry was effective in confirming the high dependency of local people on land and sea resources, as well as the conflicts between people and wild animals, such as elephants and African wild dogs, and the reasons for those conflicts. The DQ is effective in gathering people's opinions and it constitutes an important tool in a bottom-up approach to the design of a management plan as to the design of the MP for the MWA.

Keywords

North of Mozambique, Ecosystem Services, Ecosystem Based-Management

Introduction

In the Millennium Ecosystem Assessment (MEA 2005) it can be read that "economists typically seek to identify the various reasons why biodiversity and ecosystems are valuable to people", but facts show that most supporting, cultural and regulating services of nature are not valued because people are not aware that if services are not preserved they must be paid for (MEA 2005). These services are not directly observed or measured. Being aware of their importance and existence is not yet valued. Either directly or indirectly, ecosystems support one's own consumption, as well as the consumption of other species. Biodiversity is important for human wellbeing because it provides security, basic materials, health, good social relationships and most important of all, freedom of choice and action (Díaz *et al.*, 2006). This is done directly because biodiversity is the core and

basis of ecosystem services—Figure 1 (MEA 2005; Díaz *et al.*, 2006; Palmer, 2010). Ecosystem goods (such as food) and services (such as waste assimilation) represent the benefits human populations derive from ecosystem functions. Ecosystem functions "refer variously to the habitat, biological or system properties or processes of ecosystems" (Constanza *et al.*, 1997). This article, following Costanza *et al.*, (1997), chose also to refer to ecosystem goods and services as Ecosystem Services (ES). The study they presented estimated the economic value of several ecosystem services. The calculus is important because it helps to be aware of ES value and the implications of certain governmental choices which interfere with nature services. People have to understand and believe that all actions will improve their quality of life (Rands *et al.*, 2010). Individuals "who rely most directly on ecosystem services, such as subsistence farmers, the rural poor and traditional societies, face the most serious and immediate risks from biodiversity loss" (Díaz *et al.*, 2006).

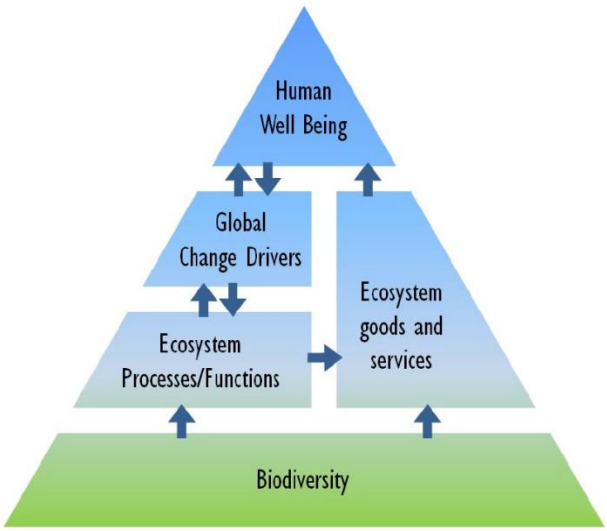


Figure 1. Interconnections among human wellbeing, global change drivers biodiversity, ecosystem processes, ecosystem services and biodiversity (MEA 2005; Díaz *et al.*, 2006).

What would happen if people had to pay for most of the supporting, cultural and regulating services of nature? The value would be considerably high. The awareness of its value is still to come by means of education (MEA 2005). It's because these services are not directly observed, perceived nor measured that people still use them without knowing they have such value. The lack of awareness constitutes a problem for investigations that intend to enforce strategies to reduce pressure on ecosystems goods and services, with long-term results. Without the support of the ecosystems and their biodiversity, the consumption of basic natural materials is not possible, and the absence of those materials doesn't allow the accomplishment of the "human wellbeing" status, shown in the Figure 1 (MEA 2005; Díaz *et al.*, 2006; Palmer, 2010).

Planning and managing natural goods and services are recognized as being achievable and also a great challenge, because they involve investigators, stakeholders and communities in a long-term experience in which the consequences are unpredictable (Fraser *et al.*, 2006). And because there are so many actors to listen, it is becoming increasingly important to develop strategies to gather their knowledge and views when it comes to making a wellbeing assessment.

Mozambique is a rich country in terms of natural resources. The Cabo Delgado Province is not different (Garnier *et al.*, 1999). This paper focuses on the Messalo Wilderness Area (MWA), an area with 32.931 ha (Garnier, 2003), on the evaluation of its natural resources and the means through which they are being explored by the inhabitants. Like other adjacent areas, MWA is being

depleted of its natural capacity, due to overcrowding. The pressure on the land and seashore is observed in soil erosion, in wildlife habitat fragmentation, in the low productivity of the fields that are abandoned. The growing establishing of people in the MWA has been enabling several conflicts with wildlife. This scenario led to the need to understand what the local perceptions of the inhabitants towards wildlife (especially towards elephants) and ecosystem goods and services were. This perception is important for the design of a sustainable management plan of the natural resources. It's a bottom-up kind of approach, pursuing recommendations of Fraser *et al.*, (2006), since it intended to use the community knowledge of different villages to design the first step for a "wellbeing assessment".

This paper derives from a team work that was built to answer to a mission: contributing to the rural organization and management abilities of the natural resources of MWA. It also aims to contribute to the understanding of people's choices and needs, predicting and proposing changes which can improve sustainability locally, followed by an attempt to understand and evaluate local perceptions towards wild life and resources. This stage was centered in the Human-Wildlife Conflicts (HWC). It was intended to understand the position of people about a species of elephants: *Loxodonta africana*. Another wild animal was chosen, the carnivorous African Wild Dog (AWD), *Lycaon pictus*. Both species have the statutes "vulnerable" and "endangered", respectively, in the IUCN Red List of Threatened Animals (http://www.iucnredlist.org/apps/redlist/search). The study also aims to produce a base plan with the contributions of the population, stakeholders and the available investigators, which can be refined by their continuous involvement in the creation and implementation of management committees. The organic structure of these committees is also proposed in this paper. The community and its stakeholders were engaged in the process by participating on the survey.

Material and Methods

Having this in mind, the first challenge was to collect information on people's livelihoods and their use of the available resources, as well as their perceptions towards wildlife in the MWA. The analysis of this information was critical to make decisions about strategies that would be suitable and/or accepted by inhabitants. This represents a small scale study, but it was organized in the following steps, based on Fraser *et al*., (2006): 1) organize and assess the people's knowledge; 2) choose some indicators from the people's knowledge; 3) collect the available indicators about the context; 4) combine and map indicators and indices; 5) propose a management plan.

For the first step the investigation team developed a Digital Questionnaire (DQ). Several investigators like Bradshaw and Bekoff (2001) emphasize the importance of hearing and consider people's opinions to engage them with conservation measures. This is shared by a crescent opinion which defends that understanding and integrating social sciences with ecology is important to achieve success (Paterson *et al.*, 2010; Pollnac *et al.*, 2010). The indicators we were trying to fulfil, in steps 2), 3), 4) were to: 1) verify dispersion/distribution of people and elephants; 2) make a recognition of the natural resources used by the inhabitants; 3) locate the areas from where the most important natural resources are being extracted and 4) where conflict between human-animal occurs.

This information led us to be able to combine and map the knowledge gathered for this area. It culminated with the proposition of a management plan to mitigate the Human-Elephant Conflict

(HEC), and to promote the conservation of elephants, and, consequently, of other types of biodiversity that may sustain the human wellbeing in the MWA. It also led us to try to answer to the following questions exposed by Fraser *et al.*, (2006) in their paper: “Are people from MWA too poor to engage in a long-term management plan?”; “What are the major environmental issues in the MWA?”; “Do some groups depend on the environment for different resources?”
This plan was not yet been put into practice. But we believe this “bottom-up” and “close” approach can provide general awareness of how individual actions will result, in the future, in improvements in everyone’s quality of life (Rands *et al.*, 2010).

The Area

This study was carried out in the North of Mozambique in an area known as Messalo Wilderness Area (MWA) (Figure 2, Table 1), situated above the buffer zone of the QNP. It was initiated in April of 2009 and had the duration of two years, with field work done during 2010.

Field Work Methodology

Maps and Cartographic Figures

The cartographic figures shown in this and subsequent sections were generated in Map Window GIS 4.8.1. version, from the documental analysis of the existent charts, and from information collected through inquiry and observation during field work. Field-work information corresponds to coordinates measurement with a GPS device (Garmin model, Colorado 300), to the marking of the different habitats, to the signalizing of animal tracks, signs and remains on field charts (sightings, kill sites, pellet/droppings), and to photographic and video records in several parts of the area.

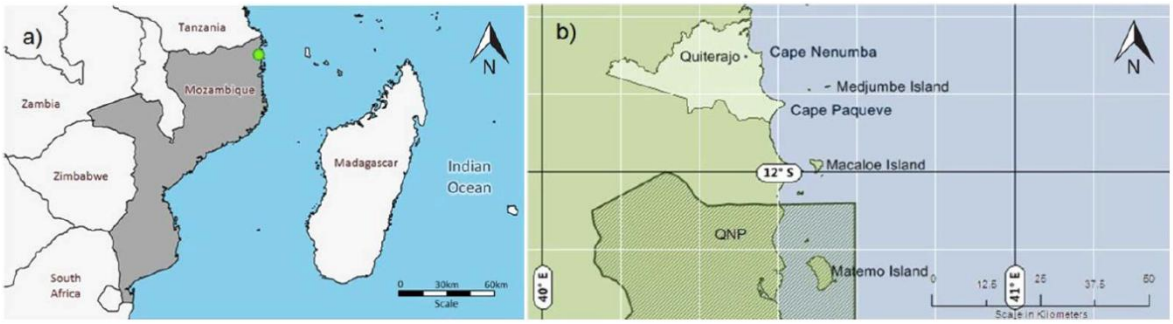


Figure 2. (a) The study area location (dot in Figure 2(a)) in Mozambique; (b) and the same area enhanced. Quirimbas National Parque (QNP), acording with: Decreto n˚ 14/2002 de 6 de Junho (RM, 2002).

Table 1. Limits of the area.

Area Limits	East limit	Indian Ocean
	North limit	Messalo river estuary Lat 11˚40'17.83"S; Long 40˚26'16.02"E
	Norwest and West limits	Mainstream of Messalo river
	South limit	Paqueve cape Lat 11˚53'5.94"S; Long 40˚27'59.86"E
	South-West limit	Part coincident with the Diquide river and part coincident with the north line of the QNP buffer zone Lat 11˚52'23.53"S; Long 40˚18'46.18"E - Lat 11˚47'22.84"S; Long 40˚8'10.26"E

Analysis of satellite images (from Google Earth) and of written documents from previous investigations in the area (see reports in reference section) were carried out.
The coordinates of the places, paths, villages and spots of interest were registered.

Data Collection: Digital Questionnaires and Statistical Analysis and Definition

To inquire the habitants using a computer, it was developed a digital questionnaire (DQ), as shown in Figure 3. This tool allowed for collecting and collate data according to human wellbeing categories (health and population, wealth, knowledge and culture, community, equity) and ecosystem wellbeing categories (land, water, air, species and genes, resources use) (Fraser *et al.*, 2006).

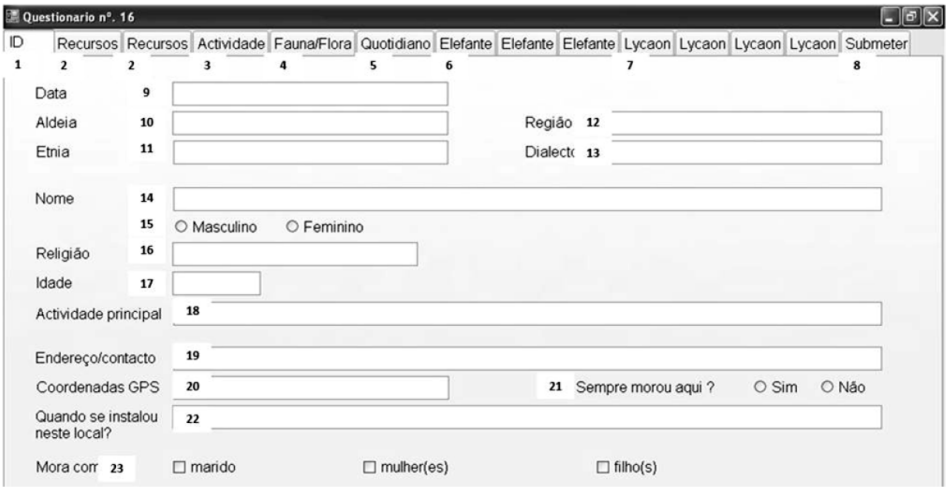


Figure 3. First window of the questionnaire. Numbers show the English translation of the section's titles: 1. Identification of the subject; 2. Resources he/she uses/explores; 3. Daily activities; 4. Wild fauna/flora explored/ observed; 5. Relationships and community methods; 6. Opinion about elephant and human-animal type of conflict; 7. Opinion about African wild dog and human-animal type of conflict.

In detail, the DQ allowed for analysing the resources used, pressure on land and marine resources, positive and negative impacts of daily activities (e.g. forestry, agriculture, fishery, hunting, among others), the causes for human-animal conflicts (using the examples of African elephants and African wild dogs) and perceptions towards conservation actions. Missions, prior and during data collection, involved camping in Quiterajo and daily expeditions to the field and villages in the

studied area. This provided an opportunity to inquire the population and stakeholders from different villages. During this stage, one community leader provided leadership, security and interpretation of the local dialects. Local guides and people also gave support and helped in the preparation of field logistics.

The sampling method was a mix of convenience sampling and purposive sampling (in the subtype's heterogeneity and snowball sampling) (Moreira, 1994; Pinto, 2009). Because the context is so particular (people are not used to being inquired and filling questionnaires), a type of convenience sampling was used and only volunteers were inquired.

The DQ was made in the Visual Basic Express Edition Software 2008. The collected data was stored in the Microsoft Access Database.

A pre-questionnaire was applied in January 2009 and the data was analyzed as a preview-test to identify bias in the procedure/questions. Then it was rectified and applied in the field again. The questions were asked face-to-face and the answers were typed in the DQ box by the interviewer. This way it was easier to make sure that every question was being answered. The process became very practical, fast, efficient and ecological.

Part of the collected data from the DQ was analyzed by a qualitative content methodology. Data was clustered in created categories, following Moreira's (1994) and Bardin's (2004) recommendations in the literature.

The sample was performed by 189 volunteers (2.3% of the resident population) of which 6.5% were major stakeholders. Then data was analyzed using the following programmes: Microsoft Office Access 2007, Microsoft Office Excel 2007, PASW Statistics Data Editor 18, where variables were analyzed and categorized (Pinto, 2009; Pereira, 2006).

The last two were used to perform descriptive statistical analysis and tests (nonparametric tests of Chisquare, Kruskal-Wallis H; and parametric tests of Oneway ANOVA and T-test).

The design of committees to develop and apply the plan mentioned in Section 4 was made from the field studies, from the results of the questionnaires and also from the analysis of other proposals.

Results

Indicators Chosen from Literature

Coastal Aspects

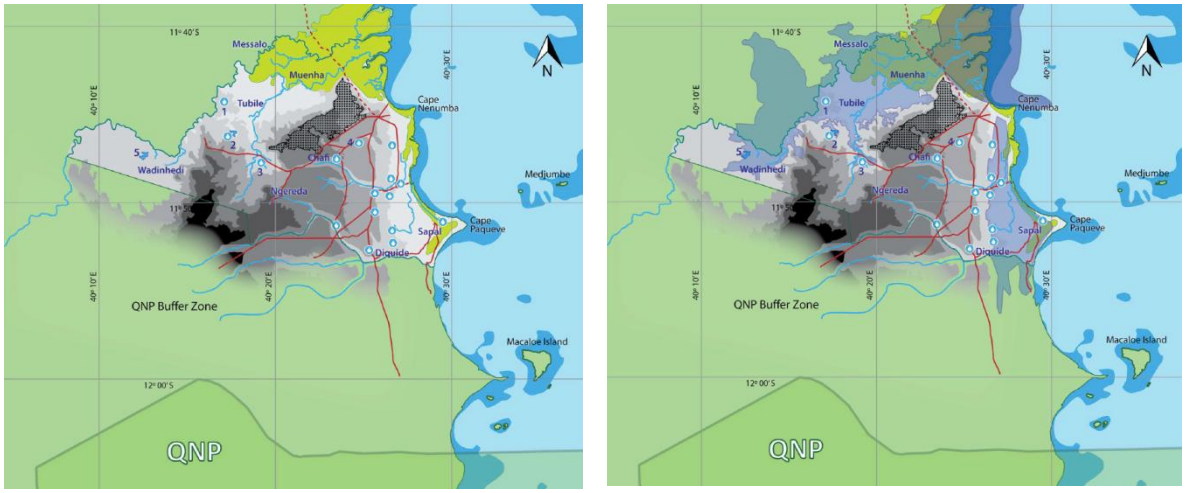
The MWA has approximately 32.931 ha (Garnier *et al.*, 1999), and it is located on the East coast of Africa in the North of Mozambique, Macomia district in Cabo Delgado Province (Figure 2, Table 1). Quiterajo is the village where the headquarters of the administration of the area is located (sede de posto administrativo). The area possesses several villages, each headed by one or two chiefs. Each village is also under the jurisdiction of the office of Quiterajo and is headed by its chief, who reports to the district administrator.

The coastal line has several coralliferous formations, sandy beaches and mangrove areas of which the most important one is the mangrove of Messalo river estuary. The inland shows several marine sedimentary rock formations (DSA 1960). It also shows variable elevations (under 135 m) and presents an orography conditioned by various aquatic formations such as lakes (Kinhanquindu, Macungue), streamlets (Tubile, Chafi), rivers (Messalo, Muenha, Wadinhedi, Ngereda, Diquide)

and also alluvion zones of the Messalo river, located in Buani and near the coast, between Paqueve (South) and Milamba (Centre) (Figure 4(a), Figure 4(b)).

Besides being influenced by the south equatorial current, the littoral (with thin continental platforms) is conditioned by the existence of three submarine canyons of East-West orientation (Kero Niuni in the North; Medjumbe in the Centre; Macaloé in the South) and also by barriers which constitute the islands and reefs of the Quirimbas Archipelago.

The littoral's turbidity, salinity and nutrient concentrations are influenced by Messalo, Muenha and Diquide rivers' discharges and by sediments brought by sliding waters resultant of intense rain. The Messalo river influence favors the existence of a large estuary and vigorous mangrove.



(a) **(b)**

Figure 4. Main rivers (Messalo, Muenha, Tubile, Ngereda, Wadinhedi, Diquidi) in the dry season (a) and in the rainy season (b) showing the floodable areas. The numbered dots correspond to lagoons (1. Likuedo lagoon; 2. Macungue lagoon; 3. Buani lagoon; 4. Kinhanquindu lagoon). Figure prepared with information from: (IH 1965); Google Earth, assessed in January 2010 and information obtained in the field by the authors.

Climate

The area is influenced by the southern and northern monsoons, which create two seasons (winter/dry, summer/rainy). The first monsoon affects the dry season and the second the rainy season. The climate is rainy and hot from October/January to April/May, summer period, and dry from June to September during the winter period. The summer monsoon influences the region with North-Northeast-East winds, which blow less than 5 m/s in average, from September or November to February or March. The winter winds (9 m/s in average) blow from south and southeast from March or May to September or October (Richmond, 2002).

Earth and sea winds, connected to tide movements, influence the coast. The Mozambique current, which presents a flow of up to 4 knots and a tidal range of, in average, 0.7 - 4.6 m during spring tides and 2.1 - 3.0 m for neap tides (IH 1965), also influences this region. Sea water temperature varies between 20/25˚C to 29/30˚C (Richmond, 2002), and usually presents higher values on the surface in low-tide periods. Sea surface temperatures can be inferior to 20˚C (17 - 18˚C). The air temperature average is about 18 to 32˚C (DSA 1960). The annual precipitation is about 900 to 1000 mm (not much different from 1960), with values going from 800 to 1000 mm per year (DSA 1960; Sousa 1966); and the relative humidity varies between 65% and 82% (Azevedo, 1955). The

index of aridity (De Martonne, 1925) goes from 20 to 30 (DSA 1960), which indicates a climate type predominantly moderately arid.

Ecosystems Diversity

The area is located in the Eastern Miombo Woodland ecoregion (White, 1983), being occupied by the characteristic open forest of Brachystegia-Isoberlinia-Julbernardia (*Brachystegia allenii*, *B. boehmii*, *B. spiciformis*, *Isoberlinia orientalis*, *Julbernardia globiflora*) (Wild and Grandvaux 1967; Timberlake, 2009; Timberlake *et al.*, 2011). Alluvium areas can be found in Miombo, where some lagoons appear temporary (or relatively permanent), with the predominant herbaceous plants constituting pasture to herbivorous animals. These areas are extremely important, particularly in the dry season when herbaceous Miombo stratum dries. Between Miombo and the maritime border, a tropical grassland and a savanna develop, presenting small bushes and thick deciduous. Here, important biodiversity is also present such as *Guibourtia schliebenii*, climbing shrub or large liana (*Strychnos spp.—S. spinosa*, *S. madagascariensis*) and spine climbing shrubs like *Guilandina bonduc*.

Other habitats like floodplains, grasslands, lowland forests and a mountain forest plateau (the Quiujulo location) can be found and represent a refuge for several animals (Figure 5) (Wacher and Garnier, 2005).

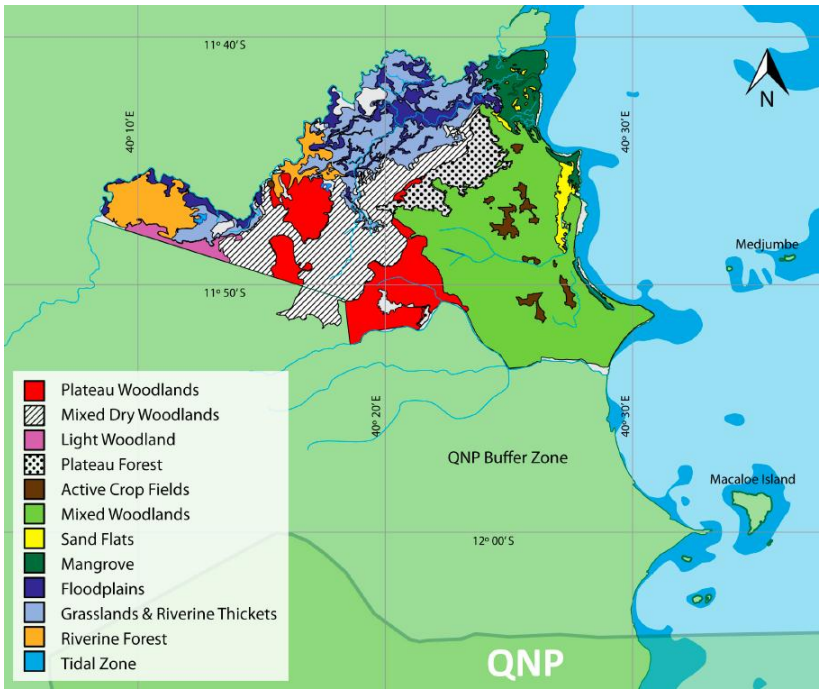


Figure 5. Distribution of habitats in the region (adapted from (Wacher and Garnier, 2005) and field observations by the authors).

They show several valuable plant species (Bandeira and Nacamo, 2007). Mammals that have already been identified include elephants, buffaloes, various antelopes (waterbuck, eland, greater kudu, sable, suni, oribi, duiker), pigs and primates, elephant shrews and several large predators (spotted hyena, leopard, African wild dog and lion) (Wacher and Garnier, 2005; Wacher and Garnier, 2003). The terrestrial vertebrates, particularly mammals, have been included in a census to analyze their distribution and abundance. Monkeys (*Papio cynocephalus*, *Cercopithecus pygerythrus*), elephants (*Loxodonta africana*), suni (*Neotragus moschatus*) and waterbuck (*Kobus ellipsiprymnus*) and several species of reptiles and birds were identified by direct observation.

Population Distribution and Numbers in the Literature

This region has approximately 8164 inhabitants. Table 2 shows the distribution of individuals in the villages where the study was conducted. The data was first gathered in the Garnier report (2006) and then updated using the information collected on the field. Unidade is a new village, and it was established as such in 2004. A negative variation means population loss by migration to other areas or surrounding villages. By analyzing the values of variation from 2004 to 2010 it is possible to conclude that some villages have suffered a decrease in their population: Natugo I, Milamba, Namaneco and Gaza. On the other hand others have been increasing its population: Unidade, Mwera.

Table 2. Population, distribution per village and tendency: 2004/2006/2010.

Village	Population			Variation		
	2004[a]	2006[b]	2010	2004-2006 %	2006-2010 %	2004-2010 %
Mitacata	1391	1442	1472	**3.7**	**2.1**	**5.8**
Natugo I	163	213	158	**30.7**	**−25.8**	**−3.1**
Natugo II	474	576	*576	**21.5**	-	-
Paz	113	130	*130	**15.0**	**0.0**	**15.0**
Unidade	0	310	500	**100.0**	**61.3**	**100.0**
Malada	252	257	*257	**2.0**	-	-
Milamba	1796	1827	459	**1.7**	**−74.9**	**−74.4**
Namaneco	597	697	250	**16.8**	**−64.1**	**−58.1**
Ilala	1166	1366	1360	**17.2**	**−0.4**	**16.6**
Mwera			320	-	-	-
Paqueve	1117	1426	2175	**27.7**	**52.5**	**94.7**
Likuedo		60	*60	-	-	-
Gaza	352	0	125	**−100.0**	**100.0**	**−64.5**
Ibo		114	*114	-	-	-
2000		208	*208	-	-	-
Total	7421	8626	8164	**16.0**	**-5.3**	**10.0**

*Values of 2006; NA: note available; [a, b]Data from Garnier, 2006 [30].

The area has an approximate density population of 24.8 individuals per Km2. The majority of the population (93.8%) lives along a corridor defined by the main road Mitacata-Ilala (no 247), and the coastal line Mitacata-Paqueve (15.766 ha). This corridor area has a population density of not less than 48.6 habitants per Km2 (Figure 6). As shown in Table 2, population is distributed over 15 villages. Ntumi *et al.* (2009) refer to Cabo Delgado as a “less densely” populated province in which “elephants and other wildlife persist widely, especially close to protected areas such as the Niassa National Reserve, the Quirimbas National Park and the Zumbo region”.

Immigration has become another important aspect, which interferes in the economy of the region and increases the exploitation of natural resources.

The official language is Portuguese. In the Quiterajo district only 13.5% of the population in 1997 could speak Portuguese (MAE 2005). DSA (1960) shows Mwani (spoken by the ethnic group Muani), Swahili (spoken by the ethnic group Suhaili), Makonde (spoken by the ethnic group Maconde), Makua-Medo and Makua-Makuana (both spoken by the Macuas) as language groups for this area.

Indicators Shown by Inquired Perceptions (DQ Analysis)

Socioeconomic Indicators

The interviewed (N = 189) are distributed by 13 of the 15 villages in the area according to the percentages: Gaza (1.1%), Ilala (14.3%), Malada (0.5%), Milamba (13.2%), Mitacata (23.8%), Mwera (0.5%), Namaneco (4.8%), Natugo I (6.3%), Natugo II (9.0%), Paz (3.7%), Paqueve (12.1%), Quiterajo (4.2%), Unidade (6.3%). The average age is 46.74 ± 15.63 years (N = 186). Figure 7(a) shows a gender box plot of the inquired. Their ages range from 20 to 84 years old in both genders. Figure 7(b) shows a diagram of the education levels of the inquired individuals.

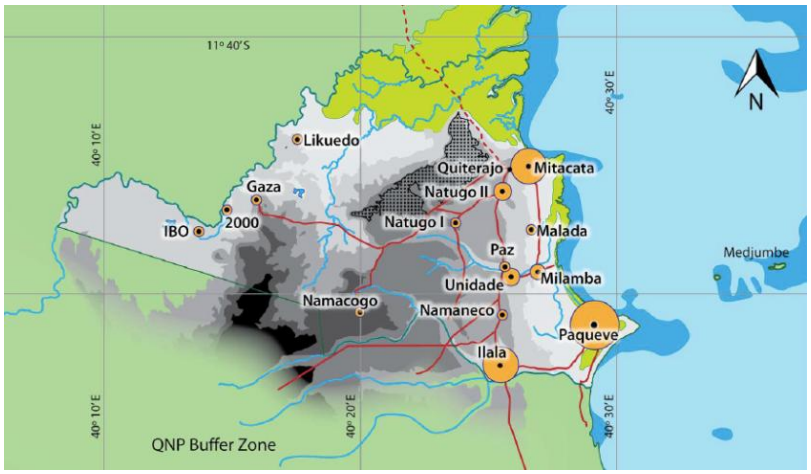


Figure 6. Main villages and main roads/pathways distribution through the area and population density/distribution (circles are proportional to density of population). Namacogo is an abandoned village.

Values and Beliefs

The main religion is Muslim (94.7%). A considerable percentage of the interviewed (46.6%) have always lived in the area. From the total sample, 55.0% live with a spouse, and 50.8% live with their children. The average of sons per household goes from 1 - 4 (depends on the village). The average of daughters per household ranges from 2 - 4. There are families with more than 10 children at their care.

The qualitative analysis of some answers to the open questions “who do you respect the most”, “who has knowledge”, “who takes important decisions”, “who commands the reunions of the village council” revealed cultural aspects. These questions intended to define the stakeholders in whom people have confidence. Answers show that the traditional and political village leaders, the religious leaders and the elderly are recognized as the most respected people. They are also the knowledge keepers of the region culture and people. The interviewees mentioned the justice actors (such as judges) and traditional healers (“curandeiros”) as being also important. Main decisions are taken in meetings with village leaders and councilors. These reunions take place in a central spot of the village (as a community house, or plaza), or in the political/traditional leader’s house, or even in the moss. In these meetings stakeholders plan land distribution amongst other important decisions for the community.

Economic Activities

The majority of the interviewees practice traditional agriculture (62.4%), without profit (39.2%), meaning no income generation for the family (see Figure 8). The main economic activities of the region are linked to agriculture. There is no use of machines in farming. This shows a precarious agrarian system.

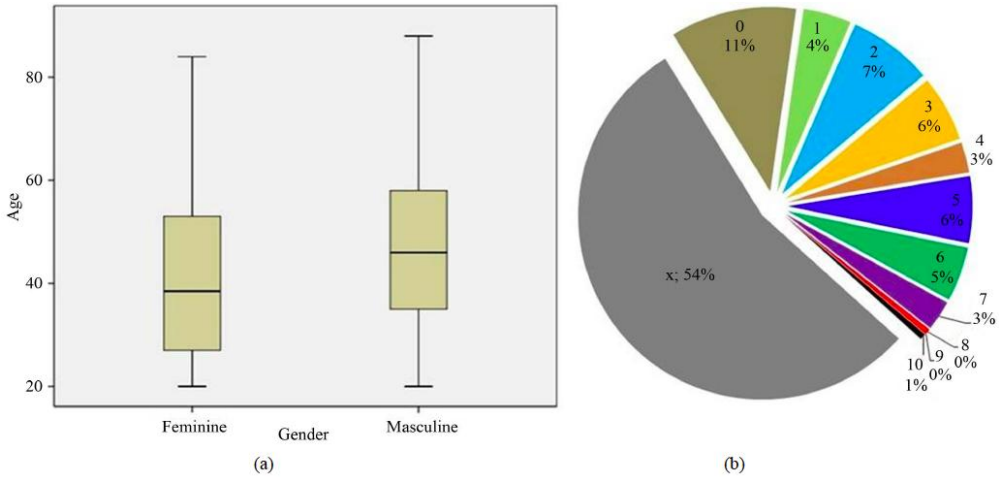


Figure 7. (a) Gender box plot from questionnaires results; (b) Pie Chart with percentages of the education levels from the inquired individuals; x—don't say his/her education level; 0—no education; 1—first class; 2—second class and so on.

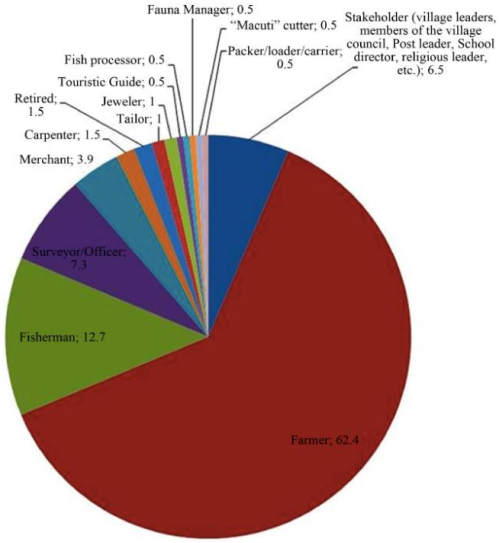


Figure 8. Professions/activities of the interviewees and the correspondent percentages.

Another traditional practice is fishery (34.9%). For 12.7% of the interviewees it is the main profession. Only 18.5% of the individuals collect some profit of fishery. 10.6% use small boats, but there is no fishing fleet in the area or considerable port.

Hunting is also an occupation. Only 2.1% admit to hunt wild animals and 94.0% of the interviewees admit to eating wild animals.

Use of Natural Resources

In Figure 9 it is possible to locate the spots from where the main resources are extracted.

Mitacata, Paqueve and Ilala are the villages with the biggest populations. This justifies the search and strong exploitation of resources in the periphery of these villages. Other villages are concentrated in the north-south axis near the coast. It is evident that the concentration of crop fields and resources spots in the surroundings of the same axis. Tables 3-5 gather the number of answers collected by inquiry, and respective percentages per village. These answers concern to resources exploitation. The goal was to make a list of the main natural resources explored in the area.

Hydrologic Resources

Fresh water is a very important resource (93% of answers). Most of the interviewees (50.3%) extract water from traditional wells with or without manual pumps (Figure 4(a), Figure 4(b)). Not only do people use water from these wells, but animals also drink from them. This similar need provides encounters. Water spots and paths are scarce and shared by animals and people. In the dry season some wells dry out. The drought obligates animals and people to search more frequently the same water spots. These shared places by the community and by wild animals can get very crowded. Most of the interviewees (>90%) said to have other options not very far (less than 500 m from home). The water is used mostly to drink, cook, wash and bathe. Often, water from wells is of bad quality, frequently salinized and polluted.

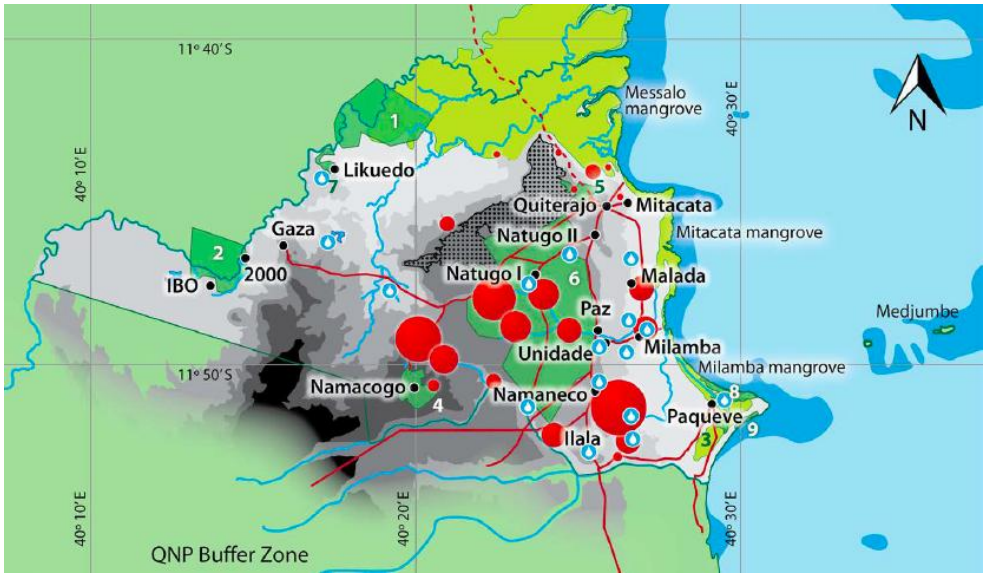


Figure 9. Areas of extraction of resources (numbers 1, 3, 7 are signalizing rice fields; 2, 4, 5, 6 are signalizing diverse crop fields (maize, cassava, sorghum, others); number 8 is signalizing the North Paqueve palm tree grove; number 9 is signalizing the South Paqueve palm tree grove). Circles (adapted from Wacher and Garnier (2003)) are proportional to the rate of extraction of the resources from the correspondent area. Dots (with rain drops) correspond to fresh water sources (traditional wells, lagoons).

Table 3. Distribution of the energy/construction explored resources named in the sample; with number of cases and percentages per village and in total.

	Anguane & Paqueve		Gaza		Ilala		Malada		Milamba		Mitacata		Muera		Namaneco		Natugo I		Natugo II		Paz		Quiterajo		Unidade		Total	
Sample Size	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
	23	12.2	2	1.1	27	14.3	1	0.5	25	13.2	45	23.8	1	0.5	9	4.8	12	6.3	17	9.0	7	3.7	8	4.2	12	6.3	189	100
Petroleum	20	10.6	0	0	24	12.7	1	0.5	20	10.6	39	20.6	1	0.5	6	3.2	9	4.8	8	4.2	7	3.7	6	3.2	9	4.8	150	79.4
Coal	4	2.1	0	0	8	4.2	1	0.5	1	0.5	20	10.6	0	0	1	0.5	2	1.1	0	0	2	1.1	4	2.1	0	0	43	22.8
Rocks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Natural Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.5	0	0	1	0.5
Minerals	0	0	0	0	1	0.5	0	0	0	0	1	0.5	0	0	1	0.5	0	0	0	0	0	0	0	0	0	0	3	1.6
Sand	23	12.2	2	1.1	25	13.2	1	0.5	25	13.2	45	23.8	1	0.5	9	4.8	12	6.3	16	8.5	7	3.7	6	3.2	12	6.3	184	97.4

Table 4. Distribution of the green resources (forest resources, crop resources, etc.) named in the sample, with number of cases and percentages per village and in total.

	Anguane & Paqueve		Gaza		Ilala		Malada		Milamba		Mitacata		Muera		Namaneco		Natugo I		Natugo II		Paz		Quiterajo		Unidade		Total	
Sample Size	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
	23	12.2	2	1.1	27	14.3	1	0.5	25	13.2	45	23.8	1	0.5	9	4.8	12	6.3	17	9.0	7	3.7	8	4.2	12	6.3	189	100
Wood Lenha	23	12.2	2	1.1	26	13.8	1	0.5	25	13.2	43	22.8	1	0.5	8	4.2	12	6.3	17	9.0	7	3.7	7	3.7	12	6.3	184	97.4
Wood Estacas	23	12.2	2	1.1	26	13.8	1	0.5	25	13.2	43	22.8	1	0.5	8	4.2	12	6.3	17	9.0	7	3.7	6	3.2	12	6.3	183	96.8
Wood Tocos	23	12.2	2	1.1	24	12.7	1	0.5	25	13.2	38	20.1	1	0.5	8	4.2	12	6.3	10	5.3	7	3.7	5	2.6	12	6.3	168	88.9
Forest Fruits	23	12.2	2	1.1	26	13.8	1	0.5	25	13.2	43	22.8	1	0.5	8	4.2	12	6.3	17	9.0	7	3.7	6	3.2	12	6.3	183	96.8
Roots	23	12.2	2	1.1	26	13.8	1	0.5	25	13.2	42	22.2	1	0.5	8	4.2	12	6.3	17	9.0	7	3.7	4	2.1	12	6.3	180	95.2
Leaves	23	12.2	2	1.1	25	13.2	1	0.5	25	13.2	42	22.2	1	0.5	8	4.2	12	6.3	17	9.0	7	3.7	5	2.6	12	6.3	180	95.2
Bark	11	5.8	2	1.1	21	11.1	1	0.5	14	7.4	18	9.5	1	0.5	6	3.2	8	4.2	12	6.3	6	3.2	1	0.5	8	4.2	109	57.7
Drink (Sura)	2	1.1	0	0	7	3.7	0	0	3	1.6	2	1.1	1	0.5	1	0.5	3	1.6	2	1.1	0	0	2	1.1	4	2.1	27	14.3
Honey	23	12.2	2	1.1	25	13.2	1	0.5	25	13.2	42	22.2	1	0.5	8	4.2	12	6.3	17	9.0	7	3.7	7	3.7	11	5.8	181	95.8
Cashew	23	12.2	1	0.5	26	13.8	1	0.5	25	13.2	42	22.2	1	0.5	8	4.2	12	6.3	14	7.4	7	3.7	7	3.7	10	5.3	177	93.7
Copra	23	12.2	0	0	25	13.2	1	0.5	23	12.2	38	20.1	1	0.5	8	4.2	12	6.3	8	4.2	7	3.7	7	3.7	10	5.3	163	86.2
Sugarcane	23	12.2	0	0	24	12.7	1	0.5	23	12.2	42	22.2	1	0.5	8	4.2	12	6.3	17	9.0	7	3.7	7	3.7	10	5.3	175	92.6
Citrus	23	12.2	2	1.1	26	13.8	1	0.5	24	12.7	42	22.2	1	0.5	8	4.2	12	6.3	17	9.0	7	3.7	7	3.7	10	5.3	180	95.2
Cotton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Medical Plants	23	12.2	2	1.1	25	13.2	1	0.5	25	13.2	40	21.2	1	0.5	8	4.2	12	6.3	15	7.9	7	3.7	7	3.7	12	6.3	178	94.2
Wild Pastures	0	0	0	0	1	0.5	0	0	1	0.5	1	0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	1.6

Table 5. Distribution of the livestock and wild animals explored named in the sample; with number of cases and percentages per village and in total.

	Anguane & Paqueve		Gaza		Ilala		Malada		Milamba		Mitacata		Muera		Namaneco		Natugo I		Natugo II		Paz		Quiterajo		Unidade		Total	
Sample Size	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
	23	12.2	2	1.1	27	14.3	1	0.5	25	13.2	45	23.8	1	0.5	9	4.8	12	6.3	17	9.0	7	3.7	8	4.2	12	6.3	189	100
Goats	23	12.2	0	0	25	13.2	1	0.5	25	13.2	43	22.8	1	0.5	8	4.2	12	6.3	13	6.9	7	3.7	7	3.7	10	5.3	175	92.6
Sheep	23	12.2	0	0	25	13.2	1	0.5	23	12.2	39	30.6	1	0.5	8	4.2	12	6.3	13	6.9	7	3.7	6	3.2	10	5.3	168	88.9
Pigs	0	0	0	0	0	0	0	0	1	0.5	0	0	0	0	0	0	4	2.1	0	0	0	0	4	2.1	0	0	9	4.8
Birds	22	11.6	2	1.1	26	13.8	1	0.5	24	12.7	43	22.8	1	0.5	8	4.2	12	6.3	16	8.5	7	3.7	7	3.7	12	6.3	181	95.8
Savage/ Wild Animals	23	12.2	1	0.5	25	13.2	1	0.5	25	13.2	42	22.2	1	0.5	8	4.2	12	6.3	16	8.5	7	3.7	6	3.2	11	5.8	178	94.2
Fish	23	12.2	2	1.1	26	13.8	1	0.5	25	13.2	43	22.8	1	0.5	8	4.2	12	6.3	17	9.0	7	3.7	7	3.7	12	6.3	184	97.4
Crustaceous	23	12.2	1	0.5	25	13.2	1	0.5	25	13.2	43	22.8	1	0.5	8	4.2	12	6.3	17	9.0	7	3.7	7	3.7	11	5.8	181	95.8
Molusks	23	12.2	0	0	26	13.8	1	0.5	24	12.7	43	22.8	1	0.5	8	4.2	12	6.3	17	9.0	7	3.7	7	3.7	11	5.8	180	95.2

Mineral and Energy Resources

The use of clay (89%) and sand is very relevant (Table 3). It will be important to understand from where it is extracted. Petroleum and coal are expensive sources of energy to cook, for example. Not all individuals have access to these resources.

Forestry

The most important resources are wood, roots, leaves, wood bark, honey, cashew, copra, sugarcane and various herbaceous medicinal plants (Table 4). All types of wood are always named and in all villages. The majority seeks this resource in forests. The main purpose is to use them as an energy source. They also use them for construction of infrastructures (houses, for example). The interviewees also referred to macuti leaves (palm tree leaves of *Hyphaene coriacea*) (82%) and bamboo (19%) as materials used in construction.

Other results came from the qualitative analyses of the questions “What do you eat?”, “What do you cultivate?”, “What products can’t you find in your village?”, “Do you trade your products?”, because some products are not named in the resources section, but then appear in the nutrition plan of the villagers. The main crops are beans, cassava (*Manihot esculenta*), maize, pumpkin, rice, watermelon. Less cultivated crops are sweet potato and cucumber. This type of vegetables integrates their meals. Other vegetables were referred; 10% refer having to search for products in other villages or locations. Copra and cashew cropping and wood exploitation in forestry are still observed nowadays.

Livestock and Wild Animals

Goats, sheep and birds (chickens) are the most used livestock (Table 5). Pigs are not important nor raised, because most of the individuals are Muslims. The number of people who refer to wild animals as a source of nutrition is high (94.0%), but people don’t mention where they get the meat.

Wild animals are seen very often. Turtles, snakes (“mamba” with 14.8% answers), and crocodiles (63.5%) are the most seen reptiles. The most important seen birds are bush chickens (“Nambiri”, “Ololo”, “Anga” are common names for bush chickens). The Figures 10(a)-(c) show graphs and correspondent list (see Table 6) of mammals seen in the area. Several antelopes (grouped and identified by the letter (A), monkeys and baboons (B), elephants (C), bush pigs (D), leopards (E), lions (F) and buffalos (G)) are the most seen and reported mammals. Several can be seen in the Quiujulo location, which is situated in the Muenha river basin. This area is very particular as it is almost untouched by human actions (see Figure 5, the Plateau Forest location).

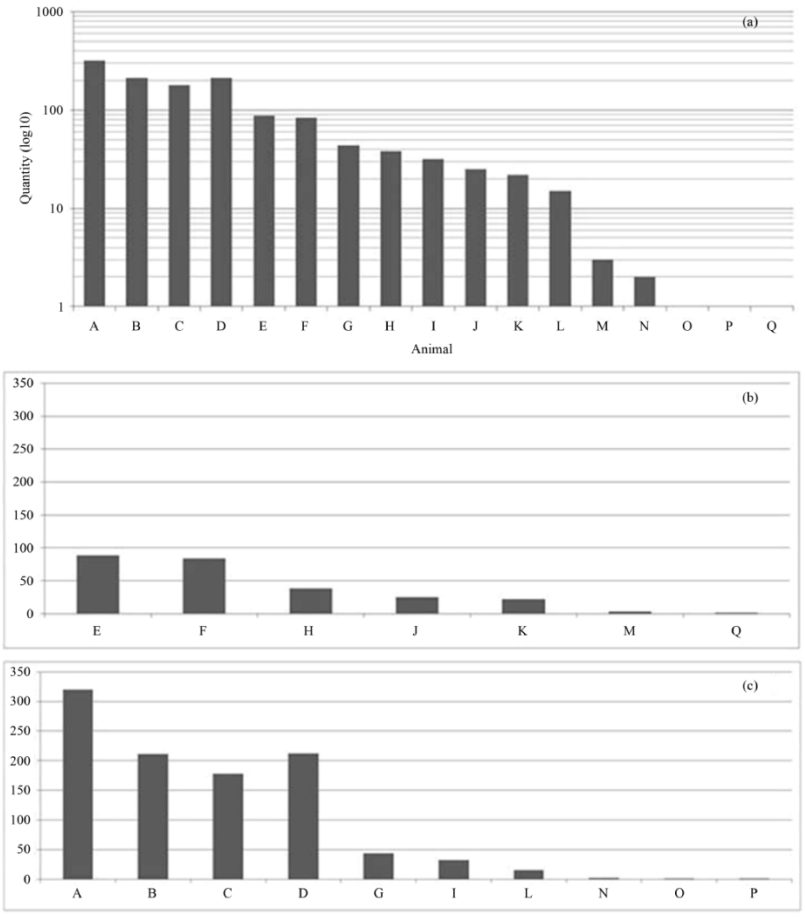


Figure 10. (a) Graph showing the main mammals seen by the interviewees in the region. For knowing the meaning of the letters see Table 5; (b) Graph showing carnivorous seen in the region; (c) Graph showing herbivorous and other mammals seen in the region. Letters’ meanings are the same shown in (a). Y-axis shows the number of answers for each animal.

Marine Resources

Fish, crustaceous and marine mollusks are part of the diet. Coral reefs have been suffering destructive actions due to activities and arts related to fish and mollusks catch. The population also transforms corals into lime, using this product in construction. Trophic chains linked to coral environments are diverse. However, human practices have been compromising intermediate levels in this trophic connectivity. The catch of fish larvae, juveniles of several species and of adult specimens for human consumption and commercialization is a practice in the MWA. The intensive capture of crustaceans like crabs, lobsters, prawns and shrimps has been frequent as well.

Table 6. Table with the identification of the animals seen by the villagers.

Animal	Comon name (English)	Comon name in Mwani	Species
A	**Great Kudu**	Nandolo	*Tragelaphus strepsiceros*
A	**Impala**	?	*Aepyceros melampus*
A	**Nyala**	Inhala	*Tragelaphus angasii*
A	**Waterbuck**	Nandoro (Kimwani) = Nandolo (Makonde language) = Inhacoso = Piva	*Kobus ellipsiprymnus*
A	**Suni**	Nazolo	*Neotragus moschatus*
A	**Sable**	Palavi (Makua language)	*Hippotragus niger*
A	**BushBuck**	Mbawalla = imbabala	*Tragelaphus scriptus*
B	**Baboon**	Nyani	*Papio cynocephalus*
B	**Samango**	Ima	*Cercopithecus albogularis*
B	**Vervet**	Nhumbire	*Cercopithecus pygerythrus*
C	**Elephant**	Nembo	*Loxodonta africana*
D	**Warthog**	Mango	*Phacochoerus africanus*
E	**Leopard**	(Suhui) Suwi	*Panthera pardus*
F	**Lion**	Simba	*Panthera leo*
G	**Buffalo**	(Inhati) Nyati	*Syncerus caffer*
H	**Spotted Hyaena**	Fisi	*Crocuta crocuta*
	Bush Duiker	Nanjanga	*Sylvicapra grimmia*
I	**Red Duiker**	Kutuku (Makua language)	*Cephalophus natalensis*
	Oribi	?	*Ourebia ourebi*
J	**?**	Raposa (?)	?
K	**African Wild Dog**	Mwizi	*Lycaon pictus*
L	**Hippo**	Chiboko (Maconde language), Namonto	*Hippopotamus amphibius*
M	**Side-striped Jackal**	Nancheto	*Canis adustus*
N	**Porcupine**	Nachinugo	*Hystrix africaeaustralis*
O	**Aard-vark**	Nanyoma	*Orycteropus afer*
P	**Wildebeest**	?	*Connochaetes taurinus*
Q	**Wild cat**	Maka nundu	*Felis lybica*

Cartilaginous and bony fishes from the families Dasyatidae, Carangidae, Hemiramphidae, Lutjanidae, Scaridae and, with less frequency, Serranidae have been also intensively captured. Turtles such as “Assa” (Green, *Chelonia mydas*), “Nhamba” (Hawksbill, *Eretmochelys imbricata*) and “Liluvi” (Loggerhead, *Caretta caretta*)—names in Kimwani dialect—are also present (69.3%).

Local Perception of the Importance of Biodiversity

Human Wildlife Conflict with African Wild Dog

One problem concerning the African wild dog has been pointed out. Their occasional attacks on livestock preoccupy the population. However, the African wild dog shares this guilt with other carnivorous (lions, leopards) and are less feared. Monkeys are also pointed out as animals that attack people and resources. In contrast, *Lycaon pictus* are not as hated as elephants, because they also present some advantages to the interviewees. People referred that when African wild dogs are present other dangerous carnivorous are kept away. African wild dogs eat some

resources (livestock) but don't destroy crop areas like elephants do when they invade crop fields. So African wild dogs are seen as useful and other predators and elephants are not. This doesn't mean people accept their near presence. People would prefer all type of wild animals to be in a different area, specially because they don't like to share natural resources, as they admitted. So the major solution advanced by the inquired was physical separation between African wild dogs and people.

Human Elephant Conflict (HEC)

Conflicts in the Quiterajo-Ilala area occur, mostly, between January and June. Garnier (2006) refers, for the period between 2003 and 2006 that 94% of elephant crop raiding occurred during the first semester.

When it was asked "what do you think of the presence of elephants", 33.3% of the interviewed weren't favourable about their presence (only one favourable answer). These animals are considered a problem and are non-desirable. It was understood why the interviewed have this perception: 51.9% of them said they had problems caused by elephants. Mostly related with consumption of water and crop products (22.2%), followed by the invasion and destruction of crops and goods (14.8%). Also attacks to people are mentioned (3.7%). However, when it was asked what they thought of total disappearance of elephants from the area, though 37% give any answer, 33.3% said it would be bad, against 29.6% saying it would be good. Their reasons are stated in Table 7.

Table 7. Positive and negative views/ideas stated in questionnaires by the interviewed about the presence of elephants in the area (qualitative analysis of the answers).

Positive factors/ideas	Negative factors/ideas
27.45%—elephants are benefic resources to the community; 12.25%—elephants are living creatures; they belong to nature; 6.86%—elephants are creatures of God; must be preserved; 5.39%—elephants cannot disappear, because future generations have to see them.	34.31%—elephants must disappear because they cause problems; 5.88%—elephants must be shot, killed, sent away, because they cause problems; 3.92%—elephants must disappear because they kill people and cause worry/panic.

The interviewed are receptive to support measures to diminish the conflict with the elephants (59.3% in favour vs. 40.7% missing). The presence of elephants creates insecurity among residents of MWA. However, the answers clarify that communities don't want to share space or resources with these animals: 18.5% saying there is "no possible solution of sharing space", 66.7% saying animals should be in a fenced area, apart from the people, 7.4% saying culling would be the solution, and 3.7% saying they don't have ideas for solutions (and 3.7% missing answers). This shows that 92.6% of the inquired think that the solution of the conflict is non-coexistence. People want physical separation from wild animals. There is only one opinion/suggestion of co-existence and space sharing, which implies the construction of community crop fields with surveillance.

Another relevant aspect is that the need for resources overcomes the fear of wild animals. This is the reason why populations occupy some of the passages previously used by elephants (Figure 11).

In this scenario, perceptions towards wild animals are shared between the ones that were victims and the ones that weren't victims. This was concluded after the application of a Pearson Chi-square test to a subsample, derived from the division of our sample in three: sample "corridor

villages" (most affected by elephant attacks); sample "coast villages"; and sample "interior villages" (less attacked). The results showed to be not statistically significant, in what concerns to the opinion of these three groups (the Pearson Chi-square = 3.160; P = 0.206; N = 137) for the question "Do you think it would be good if elephants disappeared?".

Discussion

Human Well Being Issues in the Area

The analysis of the results showed that the major environmental issues resident communities face are: conflicts with wild animals, mainly elephants, low productivity of crops and fisheries and deficient water supply, low income, insufficient access to energy sources and low education levels. Problems also emphasized by Ntumi *et al.*, (2009) in their work on Mozambique. Because of these indicators, the human well-being is not easily achievable, given that people are poor and vulnerable. Also, exploring natural resources is a problem, as maintaining these resources are increasingly challenging and difficult. The same problems are highlighted by Mabunda (2005), Rosendo *et al.*, (2011) for adjacent regions.

One reason why local communities and corresponding crops are vulnerable to wild animals, such as elephants, is highlighted by the topographic analysis of the region revealed by Figure 11. In certain areas a natural passageway (a corridor) gives direct access to the coast where food and water can be found in the dry and rainy seasons. The area covered by elephants is larger than what is visible in Figure 11. The corridor passes in the middle of the largest crop area that belongs to Paz, Unidade, Milamba, Namaneco and Ilala villages and overlaps, to a large extent, the area where Garnier (2006) reported crop damage (54%) and other incidents (76%) (Garnier, 2006). Some of the villages were created near this corridor or moved closer to it. The Unidade population, for example, was set after 2004 by the former inhabitants of Namacogo, and has been showing a considerable population growth since then.

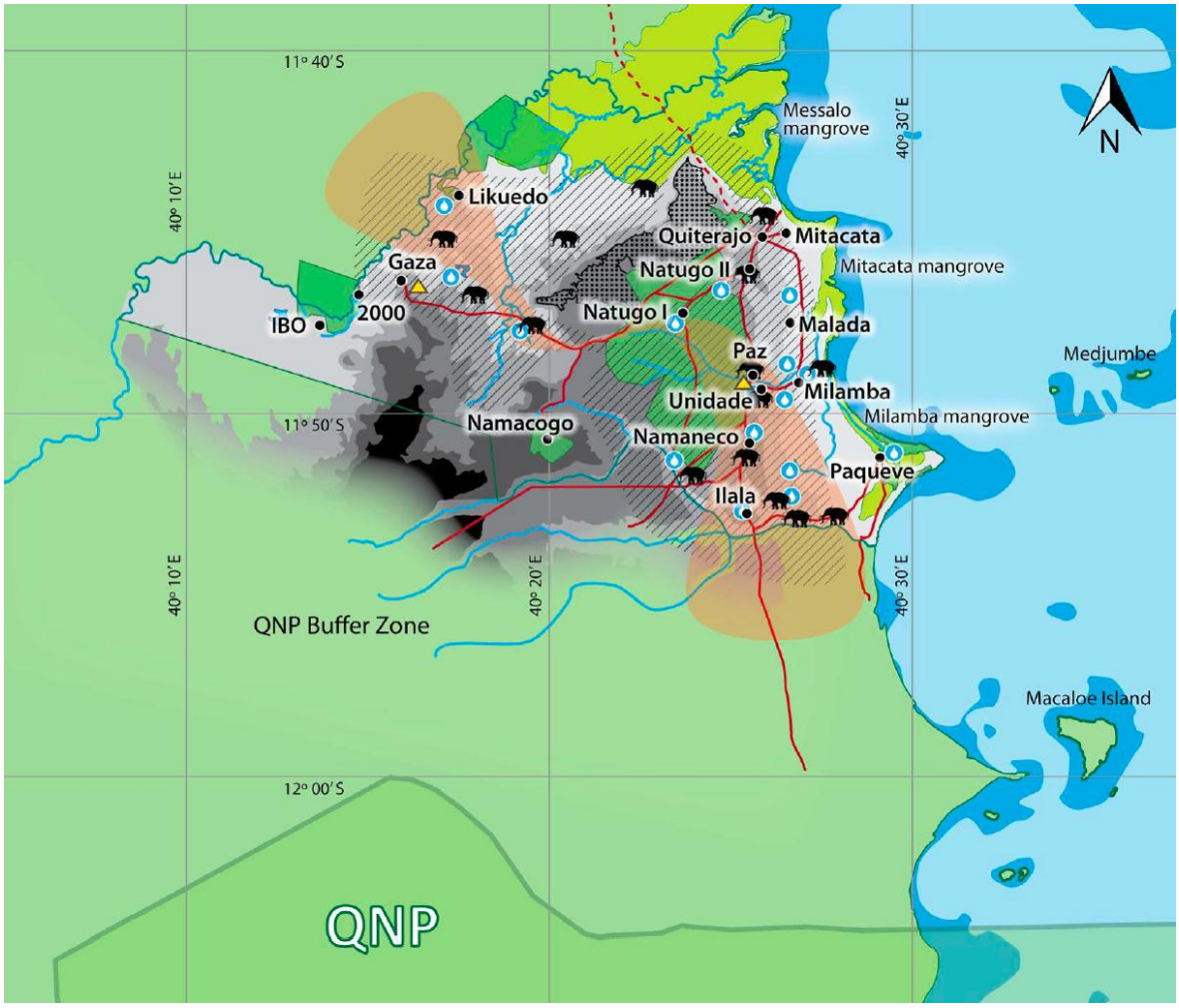


Figure 11. Area of distribution and occurrence of elephants (dashed area). Triangles indicate African wild dogs occurrences. The delimited area at the center of the Figure 11 indicates the possible corridor used by animals to Quirimbas National Park (QNP). In grey are altimetry levels (0 (white)-20-60-100-140-180-200 (black) meters). Polygonal areas are crop fields of the villages.

Freshwater spots and paths are shared by animals and people, specially in the dry season. The drought obligates animals and people to search more frequently the same water spots. This is one of the reasons why respondents argue for physical separation between them and wild animals. The great pressure is mainly in the coastal area, concerning the villages of Natugo I, Paz, Unidade, Namaneco and Ilala. The freshwater points are also concentrated near these villages.

In the MWA, like in other locations of MZ and Africa, the problem with wildlife is related with land use. This is the grand reason for the existence of human-elephant conflicts as emphasized by Hoare (2012), who defends that “in any country the solution must involve people at many different administrative levels”. This is possible in MZ with a Vertical Integration Model (VIM), since the African Elephant Specialist Group (AfESG) evaluation of the application of a VIM in Mozambique and Tanzania was favourable (Hoare, 2012) due to other actions on the field.

The Management Plan

There was a major concern to design a plan capable of minimizing the HEC pointed out by the interviewed, and of protecting wild life forms. The MWA was visualized and subdivided in: protected areas, corridor and conditioned-use areas. Figure 12 shows the distribution of villages, existent crop fields to maintain, crop fields to propose (areas A, B, C and D), main rivers, mangroves, resource exploitation sites (dots), and non-use areas. The non-use areas are coloured for the land (Land Protected Areas, LPA) and for the sea (Marine Protected Area, MPA). The MPA is proposed for the Paqueve Cape area and the Messalo estuary and it contains different ecosystems, like mangroves at the north, and important geological features (see Figure 5). The objective of this MPA is to protect the mangroves of Mitacata, Malada and Milamba.

The corridor is marked in grey color in Figure 12. It is essential to allow passage for elephants and other wild animals to areas with fresh water and food near the shore. To minimize the HEC a fence-strategy is proposed (dashed lines, Figure 12) to protect some villages (Unidade, Paz, Milamba, Ilala) and crop fields (D section, specially).

Douglas-Hamilton *et al.*, (2005) emphasize that elephants have home sectors linked by travel corridors. In their study they say that “the areas required by elephants are so large” that it would be inconsistent to confine them solely to protected areas. They seem to have the need for moving from one area to another. That is why Douglas-Hamilton *et al.*, (2005) propose an investment in keeping open crucial corridors. The MWA seems to have an important corridor used by elephants, which is possibly used for a long time. Information gathered inclines us to suppose that this corridor gives access to the coast, and also provides food and water in the dry season. This wildlife natural corridor also allows passage between terrain elevations (like the Quiujulo formation). Wall *et al.*, (2006), suggest that “even minor hills are considerable energy barriers for heavy animals” like elephants, which they studied. Mountaineering seems to imply for these animals overheating, risk of injury, lack of water or unsuitability of forage. Crossing and comparing Figure 11 with Figure 12 makes it evident that the protection of this corridor is crucial, because it represents a passage through long elevations. Artificial barriers (fences) can be conjugated with natural barriers to protect people and crops. Systems of detection and vigilance can be implemented and can serve as an attempted alert. Low-tech (low-cost) solutions can also be implemented particularly in remote areas such as in the rice fields of Messalo. Low-tech (also low-cost) measures like chilli pepper were used with some success (range between 37 and approximately 100% of efficiency) in the MWA (Garnier, 2006).

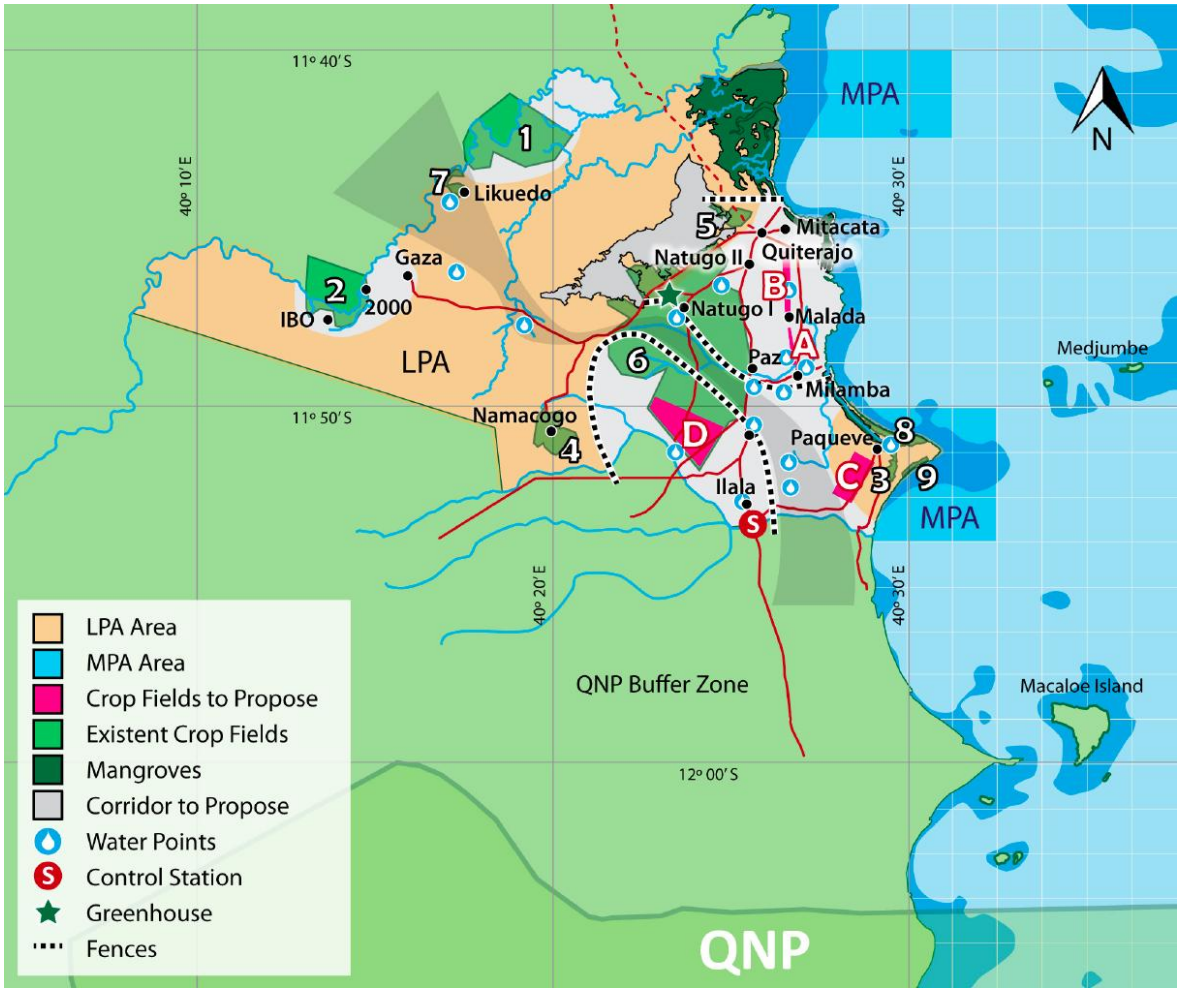


Figure 12. Case study area with identification of proposed protected areas (orange and dark blue areas). Grey-blue color is the proposed corridor at the center of the area, enclosed by fences (dashed lines). The "S" red point identifies the proposed location of the control station. Numbers correspond to green areas (farmed crop fields). Pink areas are proposed field. QNP is the "Quirimbas National Park".

Certain areas (conditioned-use areas) can be determined as "interdict" for certain periods of time. Committees can set exceptions on a seasonal basis for resource exploitation. These areas include Mitacata, Malada and Milamba mangroves and all the beaches. The supervision of these areas could be made by "fiscais" from nearby villages.

It is important to keep specific areas (specific use areas) for free exploitation of resources. They encompass crop areas occupied by main villages like Mitacata, Natugo II, Malada, Milamba, Namaneco, Paqueve and Ilala. Rice fields in Likuedo, 2000 and Ibo should continue to be explored. Areas from nº1 to 9 are crop fields which must continue to exist, with exception of area nº4. Proposed crop fields are the ones signalized with the letters A, B (palm groves), C (rice fields), and D (diverse vegetables). Area nº6 requires rehabilitation for future sustainable usage (see Section 4.2.1.1). The coastal and marine area and respective resources, situated between Messalo estuary and Paqueve-cape, could be divided subareas and consequently explored with careful supervision (see Section 4.2.1.3).

The creation of a control station is proposed near area limits, at south ("S" dot signalized near Ilala in Figure 12). This control post is intended for the recording of trade patterns and "migrations" of wild animals like elephants from the buffer zone of the QNP to the MWA. This action would allow: 1) the quantification of resources being taken from (and to) the area, and enable the identification of resource origin and destiny; 2) a complement to an accurate evaluation of the area's wealth; 3) understanding of the rate of depletion of area's natural capacity; 4) the design of a strategy to stop abuse and bad exploitation practices. A tax could be applied on goods, such as meat, noble wood, and marine resources destined to consumption outside the MWA, and on tourism activities. This is already contemplated in Mozambican law. Profit derived from this taxation method could be used to improve infrastructures such as roads and community facilities and the population's quality of life (Dec.-Lei no 10/99, 7 July, 35 article and 38 article) (RM, 1999).

Specific Aspects of the MP

1) Forest and Crop Management

Results showed a high dependency on wood materials that are used for fuel and construction. Therefore a strict plan is important regarding this matter. These "pristine areas" are already inside the proposed LPA in Figure 12. Also, there is a delimitation of areas only for agriculture practices (areas n˚ 1 to n˚ 9). An additional concern was the definition of arborous species for plantation, to renew forest cover inside the MWA. What is intended is the rehabilitation of palm tree groves (section A and B), *Afzelia quanzensis*, *Millettia stuhlmannii*, *Pterocarpus angolensis*, *Dalbergia melanoxylon*, *Euclea natalensis* (Mulala), *Olax dissitiflora* (Mussiro), *Strycnos spinosa* (Massala), *Hyphaene coriacea* (Macuti-Palm tree leaves), *Cocos sp*. (Palm trees), cashew nut trees, *Mangifera indica* (Mango trees), *Sclerocarya birrea subsp. caffra* (Marula, Ocanho), *Citrus sinensis* (Orange trees), *Agave sisalana* (Sisal plant) dispersed in areas like D, and nº1 to nº9. The improvement of forest cover would have the effect of creating new occupations, and the wood waste could be used as firelighters for cooking (thus alleviating the energy problem). Also, many of these species are used by locals on their daily tasks.

The construction of community crop fields (the machambas) away from pathways of elephants and near water supplies that are not shared with wild animals is also important to avoid and diminish HWC (see Forest and Wild Life Law (RM, 1999); Forest and Wild Life Regulation (RM, 2002), Land Law (RM, 1997, 1998) and Land Regulation (RM, 1999); Law of the Environment (RM, 1997)).

Implementation of apiculture is also advised to create new jobs (supervision and care of beehives), to increase resources (directly by collecting honey and wax, and indirectly by protecting crop fields from wild animals), and to improve bee pollenisation (an important ES).

2) Fauna Management

Elephants are not the only wild life responsible to create problems, as the answers revealed. Baboons are frequent and cause destruction of crops, albeit being more tolerated than elephants. The creation of zones only for wild life is a demanded strategy by the interviewed. However, the habitats for wild life have already been fragmented inside the MWA. Jackson *et al.* (2008), for example, say that "land-use and zonation must be carefully planned to ensure that future patterns of human settlement avoid areas that are well used by elephants". Results show that ungulates are frequent, but are also the target of hunting. This is an indicator that the MWA provides ground for high levels of uncontrolled hunting practices, which put at risk in the short run, the existent

biodiversity. An astute management of wild populations in the MWA is needed and actions against illegal hunting need to be taken. This can be supervised by the committees following taxation posted by the government to ensure animal populations' regeneration. It would also ensure that the annual hunting of animals would be done on special request to the government, providing an element of careful consideration for sustainability and a scientific based decision (RM, 1999, 2002). There is, however, a need for further surveys and multispecies monitoring programs so as to be able to identify the diversity, abundances, occurrences, seasonal distribution patterns and ecological requirements. This information would be instrumental for policy makers and law enforcement bodies.

3) Fishery and Mangrove Management

Wells *et al.*, (2007) say that the need for further MPAs is undeniably urgent, especially in Eastern Africa. Mozambique was in 2006 the country furthest away of achieving the Convention on Biodiversity MPA area target. But Mozambique and its government seems to have recognized "the economic benefits to be gained from well managed marine resources, particularly in terms of coastal livelihoods and the revenue generated from tourism" (Wells *et al.*, 2007).

Estuaries and associated mangroves are ecologically vital because they provide habitat and breeding grounds for numerous fish and crustaceous species. They also filter and retain silt brought by rivers (which could be deadly to coastal coral reefs).

Mangrove harvesting is an important source of construction materials. In a study carried in the mangroves of river Limón, older mangrove harvesters reported a decrease in local availability of the favored size of mangroves for harvesting. These observations were supported by the scientific data about the effect of harvesting.

This consistency between local and scientific knowledge, suggested that harvesters have conscience of the impact of their practices in exploited mangroves (López-Hoffman *et al.*, 2006). Ferreira *et al.*, (2009) reported from 1995 until 2005 an increase in mangrove area, including around the Messalo estuary. These were practically undisturbed (Wacher and Garnier, 2005). However, direct observations in 2009 and 2010 in the southern area stated that part of the mangroves was being damaged by anthropogenic action. There are still well preserved areas within the Messalo and Muenha mangroves in the North, and between Micataca and Paqueve beaches. These need to be preserved through legal enforcement and education of youngsters. Also, the creation of two small-scale marine protected areas is proposed, as seen in Figure 12: Messalo estuary-MPA and Paqueve cape-MPA. Before prohibiting fisheries in these areas there is a need to understand the opportunity costs by using a choice model, as suggested by Smith et al. (Smith *et al.*, 2010). The opportunities are the ones concerning "opportunities that arise in space (*e.g.*, reserves eliminate some possible fishing grounds), in the biological domain (*e.g.*, reserves affect the abundance of target species), and in the financial realm (*e.g.*, reserves may alter the costs of fishing)" (Smith *et al.*, 2010).

We focused on the preservation of the unique biodiversity of the selected areas and the preservation of the mangroves and leave the type of management decisions to the committees. Perhaps the design of a marine reserve network could be thought for the future of the region. It would be important since the area is already considered a natural reserve, it is nearby the QNP (Quirimbas National Park), whose marine area covers a coastline of 100 Km encompassing 11 islands, and it is nearby an area which was selected as a potential transfrontier MPA. Networks of

marine reserves bring benefits, not only because they are designed to meet fisheries goals focus on yield and profitability, but also because they enable "estimating ecosystem-wide effects of fishing to inform ecosystem-based fisheries management, spatially explicit stock assessments, and disentangling effects of fishing from climate change and other impacts" (Gaines *et al.*, 2010). These networks are, probably, more effective in preserving natural and cultural heritage, and since it has a chance of increase compliance of fishermen, will yield an education of the population and younger. However, the creation of networks is a new approach, implemented only recently (Gaines *et al.*, 2010), which needs scientific supervision.

A marine turtle conservation project can be implemented. Identification and protection of nesting sites is extremely important (see Law of the Environment (RM, 1997); Water Law (RM, 1991) and Law of the Sea (RM, 1996) for environmental protection and land use). The nearby Vamizi Island has a program for conservation of marine turtles and expertise acquired by the Maluane Project that works in Vamizi (Anastácio *et al.*, 2014) can be precious.

To achieve the proposed goal, Rosendo *et al.*, (2011) advise stakeholders' participation in the MPAs planning and implementation. This would help to develop a sense of ownership, to improve compliance with conservation measures (Rosendo *et al.*, 2011; McClanahan *et al.*, 2006) and to address potential conflicts between users (Rosendo *et al.*, 2011). These investigations also emphasize the need for creating local-level "community fisheries councils", and recommend that marine conservation tools should be made in conjunction with resource workers (Rosendo *et al.*, 2011). It must not be forgotten that poverty is a limiting factor to conservation efforts (Tobey and Torell, 2006).

Proposal for Creation of Committees for Wellbeing Assessment and Management

Management plans have been applied all over the world, with the configuration of local committees, with stakeholders and advisors, but also with local people. The involvement of the local inhabitants in a multidisciplinary approach for designing a management strategy is advised by specialists like Paterson (2010), Pollnac *et al.*, (2010) and Pomeroy *et al.*, (2005). Following these specialists' recommendations a committee was configured to manage the MWA, shown in Figure 13. It is proposed that local decision groups (committees) lead the wellbeing assessment, having this study as basis.

It is recognized, however, that the implementation of successful management plans is extremely difficult (MEA, 2005; Oldekop *et al.*, 2010; Dahlberg and Burlando, 2009). Several studies reinforce that management plans are more successful when they simultaneously create incentives for local communities (Dahlberg and Burlando, 2009), or when they involve the population during plan preparation (Rosendo *et al.*, 2011). Fraser *et al.*, (2006) emphasize the need for integration of local knowledge, scientific research and policy support, in a bottom-up perspective, in the preparation of a list of indicators to project a MP. The idea of the creation of management committees is also supported by Mozambican Law (RM, 1999). Hence, following these perspectives we suggest the creation of one Central Committee (CC) with multidimensional knowledge (Laumonier *et al.*, 2008), and four Partial Committees (PC) for the area (Figure 13).

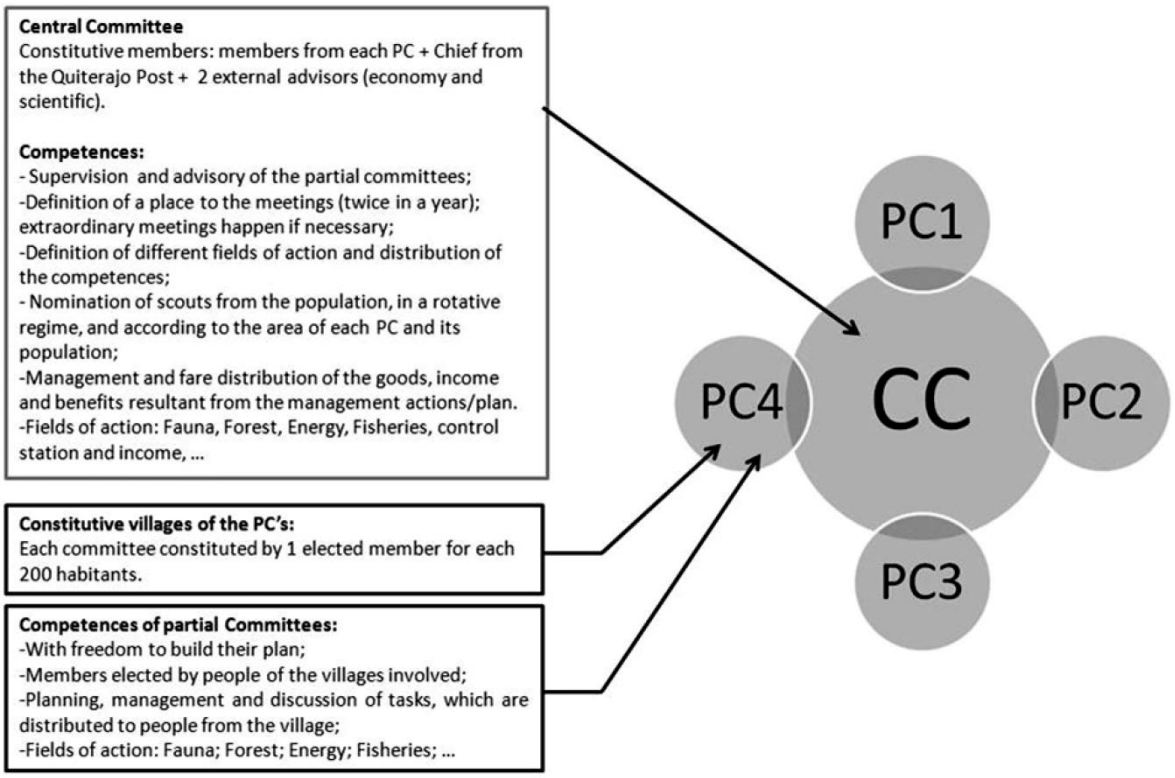


Figure 13. Structure for the committees. The central committee (CC) may be composed by 7/8 members: 4 members (or more) from partial committees (PC) and 2/3 more invited members (scientific supervisor, member of one NGO operating in the area, etc.). Each PC may be composed by one village chief (political, traditional; both if they exist), a teacher, one traditional healer, the religious leader and one citizen member elected for each 200 inhabitants. The proposal of distribution of villages by committees is the following: PC Quiterajo-Mitacata (reunites villages of Quiterajo, Mitacata, Natugo I, Natugo II, Likuedo, Gaza, Ibo and village "2000"); PC Ilala-Namaneco (reunites villages of Ilala and Namaneco); PC Milamba (reunites villages of Milamba, Paz, Unidade and Malada); PC Paqueve (reunites villages of Paqueve and Mwera).

The roles of the CC can include, among others, ensuring the participation of local communities, articulating government strategies in sustainable exploitation of natural resources, supervising PC administration, administrating generated income, managing revenue application into community facilities, searching for relevant external assistance and funding to establish and maintain the management regime, spreading awareness on and applying education programs and, finally, creating community support programs. PCs may decide on field practices, and therefore an argument can be made on giving them the control to adapt CC measures. They may organize food provision, reinforcement of intercommunity relations, and conflict mitigation (among resource users, among animals and humans).

Conclusions

There is a considerable amount of methods and recommendations that need to be taken in consideration before designing an ES management plan. Each case is different as regards the community, their culture, aspirations and expectations, their views and commitment levels towards wildlife and natural resources. The MWA management plan and the creation of committees represent a strategy. The DQ is a tool which can easily be applied by these committees to complete the human wellbeing assessment, and it can be applied for the same purposes in other

areas of MZ or eastern Africa, and similar coastal areas of the world. There are, however, problems to debate and deal with. The attraction of further numbers of people to the MWA can increase pressure on natural resources.

Overall, following the work presented in this study, we hope to achieve the emergence of ecological awareness and change of values that promote biodiversity, as a first step towards a sustainable economy for the MWA, and for other areas of Eastern/Central Africa.

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Spy out to protect: a new generation of sensing devices for virtual fencing and sensing wildlife activity

Abstract

To avoid wildlife-human conflict several solutions are used, like electrical fences, the most expensive solution. Nowadays, technology enables alternative and cheaper approaches for conservation projects. A technological device was developed to detect elephants, moving on their habitat, and predict and react by avoiding confrontation with man. The devices were tested in field experiments, and proved to be efficient in capturing floor vibration, and air-sound signals. Collected data also enabled the estimation of the vibration-source by calculus (using triangulation), revealing the importance of the methodology for real-time location and tracking of high mass animals (e.g. elephants). Building up a mesh of devices, separated 25 m from each other, is estimated as possible to monitor and identify different animals (by discriminating patterns) in an area, like a virtual fencing system. Though the devices may be effective for animal behaviour research, or even animal communication analysis, or other Biology field, other applications outside Biology are possible for them, like monitoring of: rock-falling, micro seismic railway, infrastructures, and people movements.

Keywords

Micro-Electro-Mechanical Systems (MEMS), Microseismic Detection, Virtual Fencing, Free-Ranging Wildlife

Introduction

The purpose for using a vibration sensor is related with its specifications and application. There are several types of vibration sensors, and they all have different performances. Geophones, for example, are generally used as ground sensors in seismic studies (Arosio *et al.*, 2009; Collins *et al.*, 2014; Senfaute *et al.*, 2009; Zimmer and Sitar, 2015), and can be used to detect elephant walking vibrations (Günther *et al.*, 2004; O'Connell-Rodwell, 2007; Prince and Sugumar, 2014; Zeppelzauer and Stoeger, 2015). Liang and Lin (2013) in their paper about ground vibrations generated by the impact of rocks upon the ground, refer that microphones, seismometers, geophones, accelerometers, hydrophones and fiber-optic sensors are viable technologies to detect ground-vibrations. Ground vibrations are, in fact, mechanical waves, which are defined as a periodic disturbances travelling through a medium (Jewett and Serway, 2007).

Ground-vibrations can be produced by a walking being, or by an earthquake, or by rocks free falling from a cliff. However, an earthquake releases much more energy than anthropogenic activities on the surface. Seismologists classify seismic events by its magnitude (Kearey *et al.*, 2002) and energy signals from a typical seismic event can be captured by classical geophones, but microseismic events ($M < 0 - 2$), which result from weak natural tectonic motions or are induced by man-made changes on the surface of the earth (Kamei *et al.*, 2015), can be captured by other type of technologies, not so expensive.

According with a frequency scale, sound waves are categorized into: infrasonic waves (below 20 Hz), audible waves (20 Hz - 20000 Hz; lie within the range of sensitivity of the human ear), and ultrasonic waves (have frequencies above the audible range) (Jewett and Serway, 2007). Also, the properties of a non-vacuum medium (gas, liquid or solid), conditions waves speed, and attenuates waves propagation in different ways (Kearey *et al.*, 2002).

Sound waves, for example, "travel through room-temperature air with a speed of about 343 m/s, travelling with higher speeds through most solids" (Jewett and Serway, 2007). Seismic waves speed depends also on the medium through which they travel, especially its matrix and its porosity. Soil is generally a heterogeneous medium, composed by different layers, with different compositions. Also, the amount of sources that produce microseismic and sound vibrations on the soil surface interferes with ground-wave caption by technological devices (Kearey *et al.*, 2002).

Accelerometers are used as microseismic sensors (Zimmer and Sitar, 2015), with potential to capture low-frequency ground signals. Lainé and Mougenot (2014) used micro-electro-mechanical systems (MEMS)-based digital sensors and compared them to traditional coiled geophones, founding advantages and disadvantages in these two technologies. Using its advantages when compared to traditional geophones, and concerned in reducing the logistic complexity and expenditure of the technology to capture low-frequency vibrations produced on the soil surface, this work developed triaxial MEMS accelerometers to detect and capture ground vibrations, especially low-frequency vibrations. It was aimed at testing the feasibility and limitations of this seismic/acoustic monitoring device/system that was named "loxophone".

The new device aims at overcoming issues found in other attempts to do geofencing based on vibration sensing.

Material and Methods

Model for source location

To estimate the location of a source-vibration using stationary stations, we can use techniques based on elapsed time or vibration intensity. For example, in the seismic monitor solutions, an elapsed time technique is used to estimate the epicentre of an earthquake. In our case, due to the short distances between the sensors, a vibration intensity solution is a more efficient approach. Advances in electronic sensors, namely, triaxial MEMS accelerometers, gave a significant contribution to implement these solutions at an affordable cost. These modern sensors enable us to sense very small vibrations, with high axial accuracy.

To estimate the location of a vibration source using the intensity received by stationary vibration sensors, we use the mathematical model described below.

Vibration intensity (I_n) at a certain distance (r) is given by the following equation, where I_{source} is the intensity of the source of the vibration.

$$I_n = \frac{I_{source}}{\pi r^2} \quad (1)$$

Ground waves propagate in very different ways (P-waves, S-waves, Rayleigh waves, etc.), so I_n is given by the vector sum of the intensity sensed on each axis (x, y, z):

$$I_n = \sqrt{(I_{x\_axis})^2 + (I_{y\_axis})^2 + (I_{z\_axis})^2} \quad (2)$$

Considering that the Intensity of the vibration source (I_{source}) is the same for all 4 sensors, then:

$$I_1 r_1 = I_2 r_2 = I_3 r_3 = I_4 r_4 \quad (3)$$

The distance between the vibration source and the sensor (r_n) can be expressed using the coordinates of the location of the source (x_{source}, y_{source}) and the sensor (x_n, y_n), as follow:

$$r_n = \sqrt{(x_{source} - x_n)^2 + (y_{source} - y_n)^2} \quad (4)$$

The intensity of the vibration source (I_{souce}) is unknown, so we need to estimate the location using the ratio of the intensity received by a pair of sensors (Figure 1):

$$I_1 r_1 = I_2 r_2 \quad (5)$$

Drilling down the Equation (5) using the x, y version of the r_n, we obtain the Equation (6), where x_1, y_1, I_1, are known values from sensor 1, x_2, y_2, I_2 are known values from sensor 2.

$$x_{source} = \frac{2x_1 I_1{}^2 - 2x_2 I_2{}^2 \pm \sqrt{\left(2x_2 I_2{}^2 - 2x_1 I_1{}^2\right)^2 - 4\left(I_1{}^2 - I_2{}^2\right)\left[\left(I_1{}^2 - I_2{}^2\right) y_{source}{}^2 + \left(2y_2 I_2{}^2 - 2y_1 I_1{}^2\right) y_{source} + I_1{}^2 (x_1{}^2 + y_1{}^2) - I_2{}^2 (x_2{}^2 + y_2{}^2)\right]}}{2\left(I_1{}^2 - I_2{}^2\right)} \quad (6)$$

The Equation (6) represents the relation between x_{source} and y_{source} variables. This relation can be geometrically represented by a line of all possible points for the location of the source of the vibration. The diagram below (Figure 1) shows this line for a set of I_1/I_2 examples (I_1/I_2 = 4.00; I_1/I_2 = 2.00; I_1/I_2 = 1.33; I_1/I_2 = 1.00; I_1/I_2 = 0.75; I_1/I_2 = 0.50; I_1/I_2 = 0.25), considering the location of $sensor_1$ = (−100.0) and the location of $sensor_2$ = (100.0).

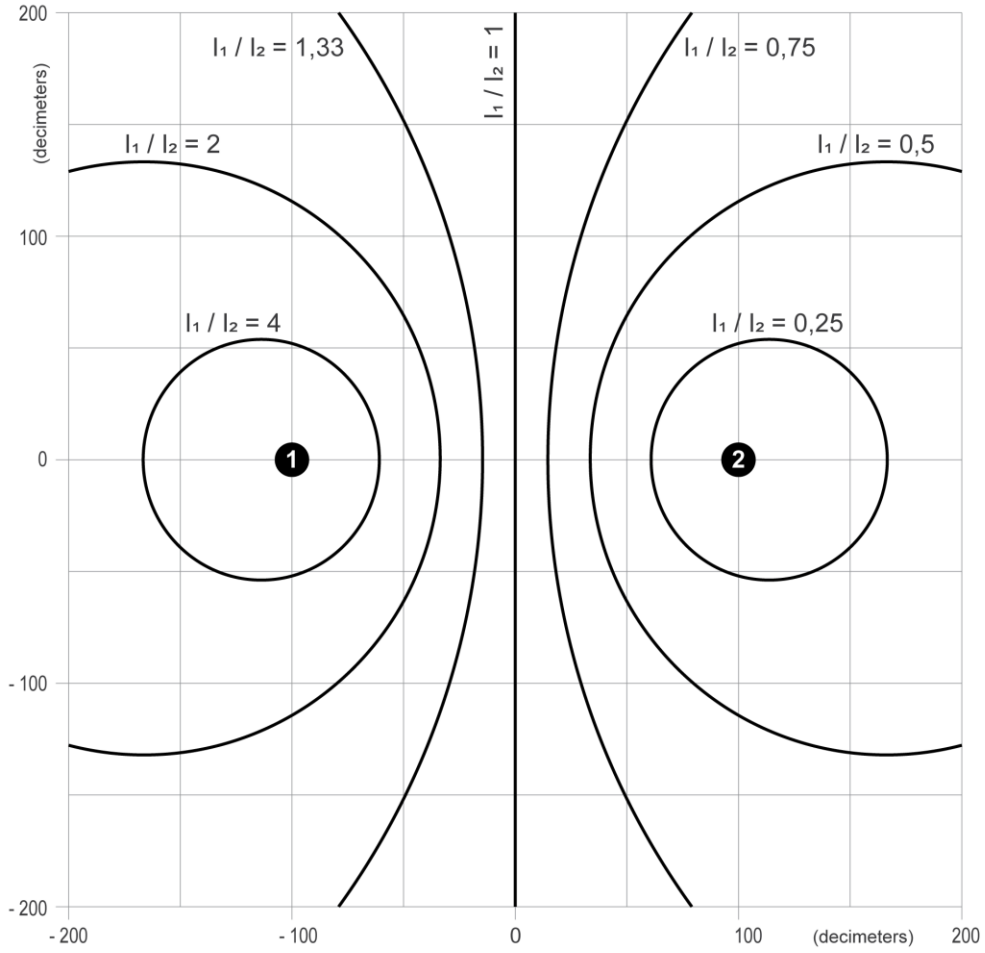


Figure 1. Set of examples for I_1/I_2 ratios. Number 1 and 2 in the figure mean the location of sensors number one and two

As shown above, whenever the ratio between the intensities measured is not 1, the line is represented by an elliptic curve. Excluding some particular cases, the interception of two elliptic curves will be two points. So, a third independent curve is required to obtain one single interception point that represents the location of the source of the vibration:

$$\begin{aligned} I_1\, r_1 &= I_2\, r_2 \\ I_1\, r_1 &= I_3\, r_3 \\ I_1\, r_1 &= I_4\, r_4 \end{aligned} \tag{7}$$

A representation of the scenario described above is given by Figure 2. The interception point of three lines represents the location of the vibration source (Figure 2).

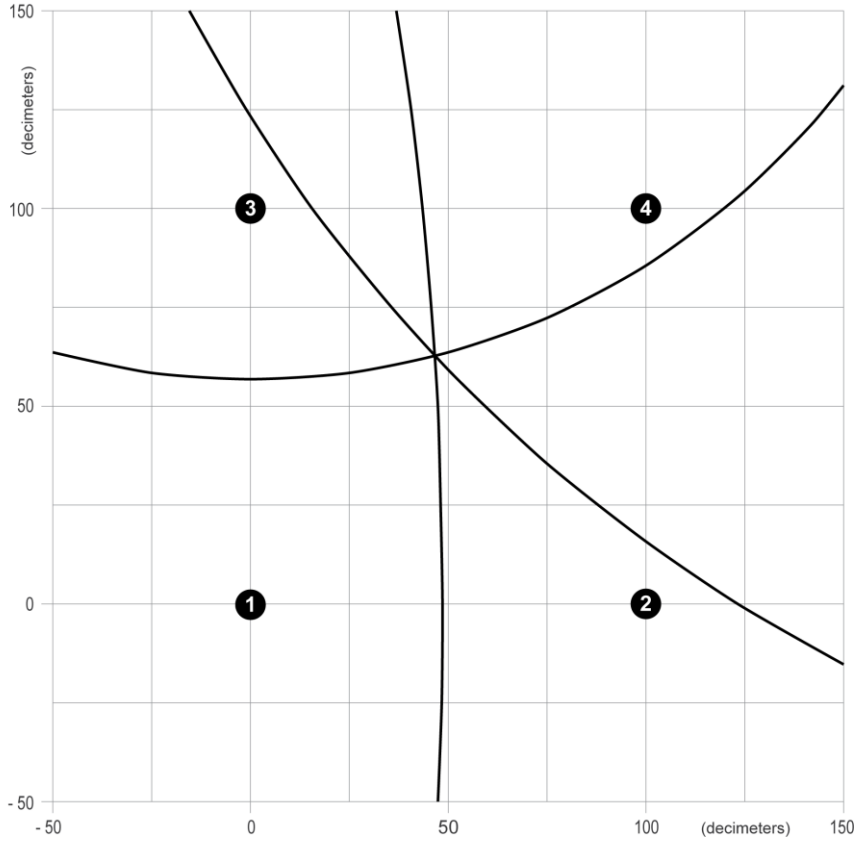


Figure 2. Example of an estimation of the vibration source location. Numbers 1, 2, 3, and 4 represents each sensor.

As shown above, a minimum of four sensor are needed to estimate the location of the vibration source, and the vibration must be sensed in all of them. Whenever the lines interception does not represent an exact match (i.e. a single point), we will get a cloud of nearby points, obtained from the interception of each pair of lines. In this case, the average point represents the estimated location of the vibration source, and the distance to the furthest point will be the estimation error.

Field Setup and Experimental trials

To test the new method proposed above, field trials were made which used four prototype vibration sensing units, developed specifically for this project. The diagram of each unit is shown in Figure 3, and specifications of the units are listed in Table 1.

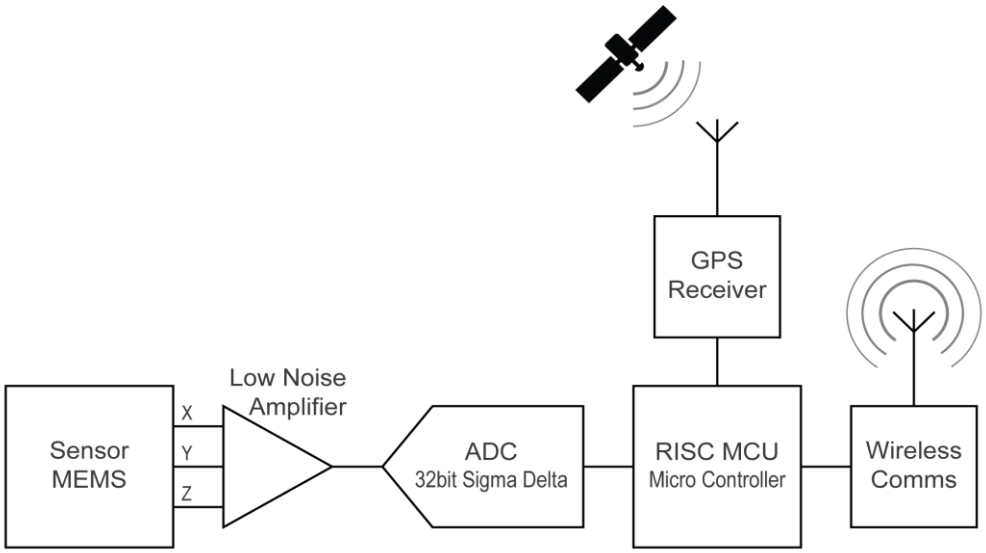


Figure 3. Sensor units' diagram: of the structure of the sensor, and of the detection system in each prototype

Table 1. Technical specifications of prototype vibration sensing units.

Issue	**Specifications**
Power	5VDC, 70mA
Dimensions	90 x 50 x 17 mm
Weight	60 grams
Vibration sensing	High-performance and low noise tri-axial MEMS accelerometer
Maximum acceleration sensing range	±2g
Lowest frequency sensitivity	0.001 Hz
Signal non-linearity	below 0.1%
Signal noise density	45 µg/$\sqrt{Hz}$
Signal conversion	32 bits precision (1 bit represents 0.19 µg) with >20 noise free bits at 1000sps
Sampling rate	Programmable, 1000sps as default
Signal conversion integral nonlinearity (INL)	±2.5 ppm of full scale range (FSR)
Low drift internal signal reference	2ppm/ºC
Inter-axis interference (crosstalk)	-120dB at 1kHz
Ultra-low signal distortion	0.000022%
Micro Controller Unit (MCU)	Embedded; for local data processing
Wireless data communication	Wi-Fi 802.11b/g/n with maximum transmission power of +18dBm
Antenas	Embedded ; 2.4GHz
GPS receiver	Embedded; 48 channels, signal sensivity of -163dBm, Accuracy lower than 2 meters for best scenario and time sync with an accuracy of 33ns (good conditions)
IP Communications	With a data stream rate of 256ksps for 1000sps signal sampling rate

The field setup consisted in turning on units 1, 2, 3 and 4, and placing them on the ground. Devices were connected to a portable PC, a Microsoft Surface Pro 3, connected to a Wireless LAN network named “iSense”, and a SciLab version 5.5.2. was run (the custom application) do receive and show the signals from the units.

Field Trials

We performed field trials to collect data that allowed us to analyse the following parameters: 1) Maximum sensing distance determination of the prototypes; 2) Location source vibration (math calculation); and 3) Identification of distinct signal patterns of ground vibrations. The trials were conducted in the winter season (air temperature ranged from 9˚C - 12˚C, and soil humidity was approximately 90%) in 2016 in a pine forest with stabilised sand soil from dunes (modern sedimentary deposits) at the following coordinates 40˚34'41.6"N 8˚43'54.2"W (place 1), and in 2017, at the following coordinates 40˚33'55.73"N; 8˚29'42.86"W (place 2), Aveiro, Portugal. This second location corresponds to a soccer game field with a homogeneous floor of pliocene-pleistocene sands and the Triassic Eirol sandstone (Teixeira and Zbyszewski, 1976) as base rock of this field. To ensure the accurate relative locations for all sensors and simulated source-vibration, we used a measure tape (with 20 meters as maximum length). In each field trial, and with the propose to create a standard ground vibration signal, we repeated the dropping of the 8 kg mass, from a height of about 1 meter from the soil, to simulate a vibration source. For each spot marked to drop of the mass, we repeated three times the procedure. This was done in experiments with the four prototypes in line, or in a square distribution setup on the floor. Also, the ground-signals generated by an 80 kg running man were collected by the prototypes. A third kind of signals were generated by the reproduction of audio record (Stoeger and Manger, 2014) by a FIIO device, X1 model coupled to a Subwofer Logitec Z-4i 2.1 speaker attached to the ground, to simulate an elephant sound propagation over the ground.

Maximum sensing distance

To test the maximum sensing distance, we placed one sensor on the floor and simulated a sequence of vibrations at a known distance from the sensor (Figure 4) and, at each point three impacts were repeated.

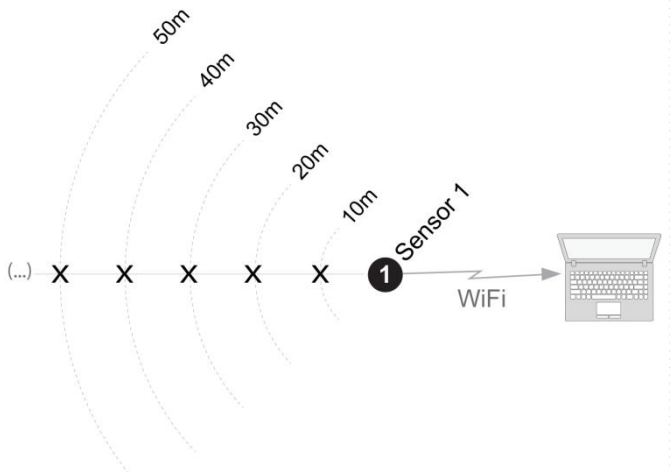


Figure 4. Diagram showing the field tests setup.

Location of the source-vibration

To estimate the location of the signal source we need to know the relative distances between the units and to receive clear signal in the four units. The field trial described in Figure 5 was repeated in three sequences. We applied the model described to estimate the location of the vibration source, as well as the maximum error for that estimation. For the location of the vibration source trial, the four sensors were placed as shown in the diagram of Figure 5.

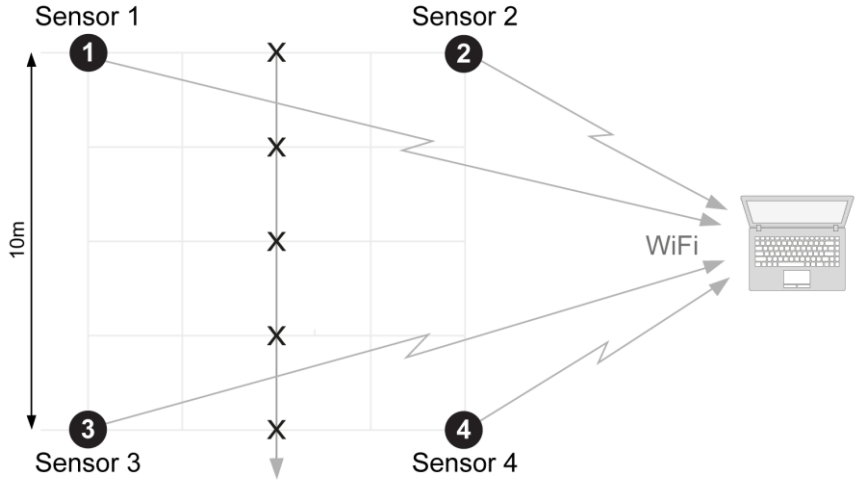


Figura 5. Field tests setup for the location of the vibration source. The X in the figure, represents the spots (points) where the signal was generated (place 2).

Identification of distinct signal patterns of ground vibrations: Spectral Signature

To assess the spectral diversity of the signals according with the type of the signal source, we used the same field, and simulated a vibration episode using different sources, such us, the drop of an 8 kilogram weight, a man running, and the reproduction of African savannah elephants recorded sound (Stoeger and Manger, 2014) using a vibration speaker attached to the ground. The spectral signatures data provides, helps in assessing the potential for movement detection and identification of a source (animal, human, or other).

Results

Maximum sensing distance

The distance sensing performance of the units for several different signal sources, and the unit setup is shown in Figure 6. For the 8 kg mass drop scenario, the maximum sensing distance can go from 25 to approximately 52 meters (Figure 6).

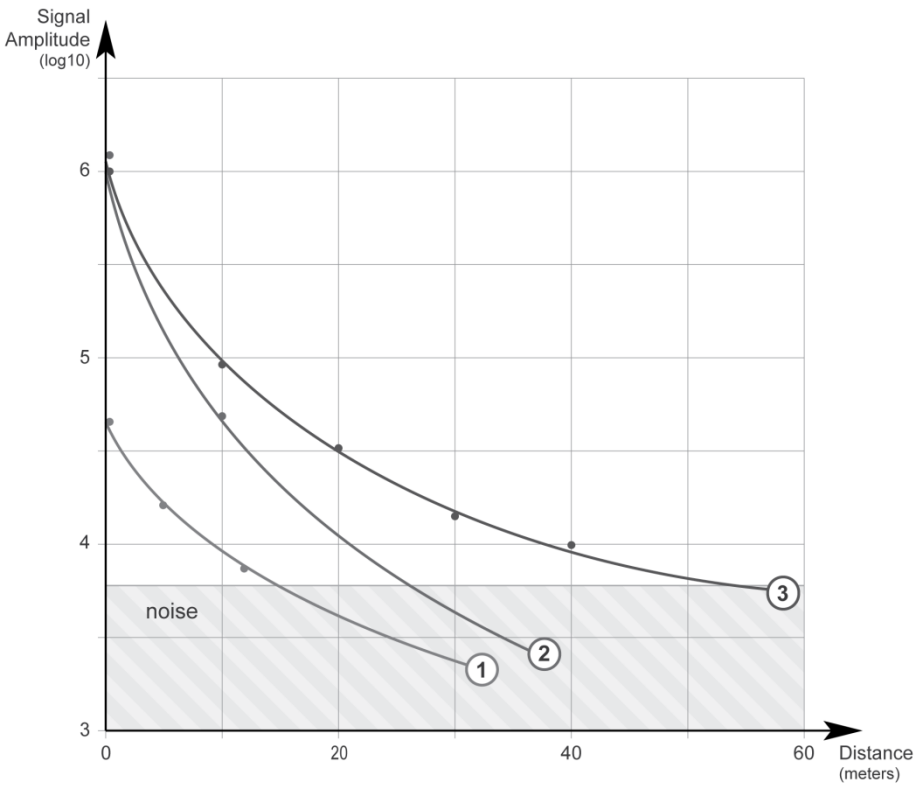


Figure 6. Signal amplitude variation with distance to the vibration source: runner (curve 1, place 1), 8 kg mass drop (curve 2, place 2; curve 3, place 1). The gray area in the figure represents the background noise signal.

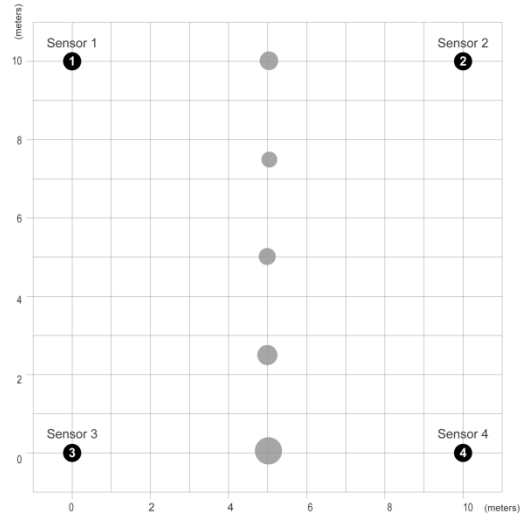
The graph shows that a man running causes lower soil vibrations, when compared with the 8 kg mass weight. The maximum sensing distance is approximately 15 meters for this setup.
The experimental data is consistent with the theoretical model of the mechanical wave's intensity (the equation number 1).

$$I_n = \frac{I_{source}}{\pi r^2}$$

Location of the source-vibration

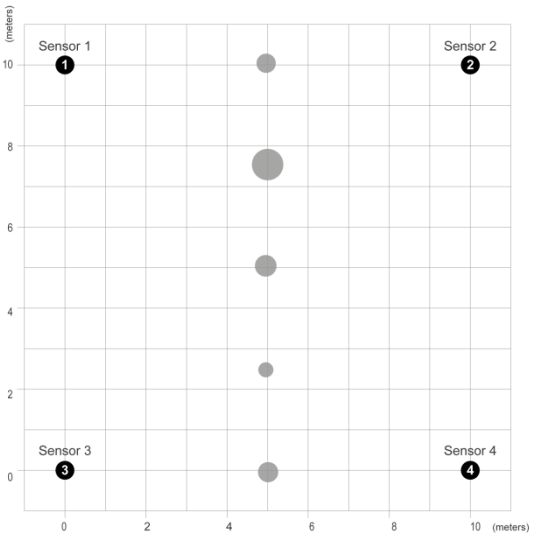
The following diagrams of the Figure 7 show the accuracy between the location of the impact point of the vibration source and the obtained by the sensors.

(a)



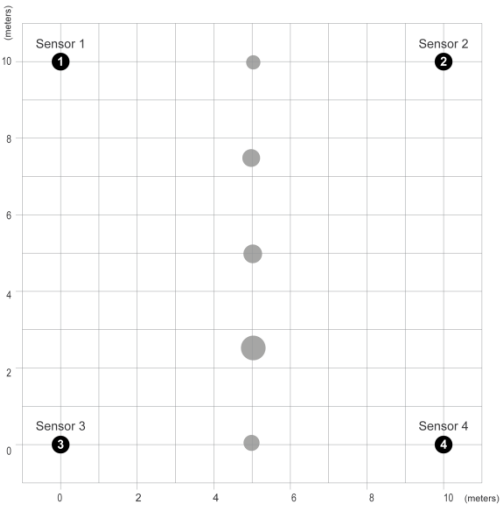
Average point X (m)	Average point Y (m)	Maximum error (m)
5.028	10.021	±0.215
5.031	7.491	±0.189
4.979	5.016	±0.203
4.986	2.483	±0.238
5.018	0.026	±0.321

(b)



Average point X (m)	Average point Y (m)	Maximum error (m)
4.991	10.038	±0.215
5.027	7.542	±0.358
4.973	5.038	±0.241
4.968	2.476	±0.175
5.032	-0.037	±0.228

(c)



Average point X (m)	Average point Y (m)	Maximum error (m)
5.032	9.981	±0.168
4.983	7.487	±0.213
5.019	4.992	±0.223
5.022	2.523	±0.293
4.979	0.057	±0.198

Figure 7. (a) Results obtained from the first sequence of the field trial; (b) Results obtained from the second sequence of the field trial; (c) Results obtained from the third sequence of the field trial (place 2).

Considering the estimated errors obtained above for each point, the global average error is ±0.232 meters. Having in consideration the dimension of this array of sensors, with an interval of 10 meters between sensors, the average error is 4.64% of the size of the sensors array.

Identifying distinct signal patterns

Using the signals collected from the field trial, we obtained the spectrograms shown in Figures 8-10.

As shown in the spectrograms (Figures 8-10), distinctive and unique patterns are gotten for the different events. The data obtained from the field trials also showed the repeatability of this pattern so we can establish a relation between the pattern and the event. For the purpose of this solution, a library of signatures will be required to allow the system to recognize events along the virtual fence. This library can be developed using a machine learning approach, that is, continuous expansion of the library by cross-checking unknown events.

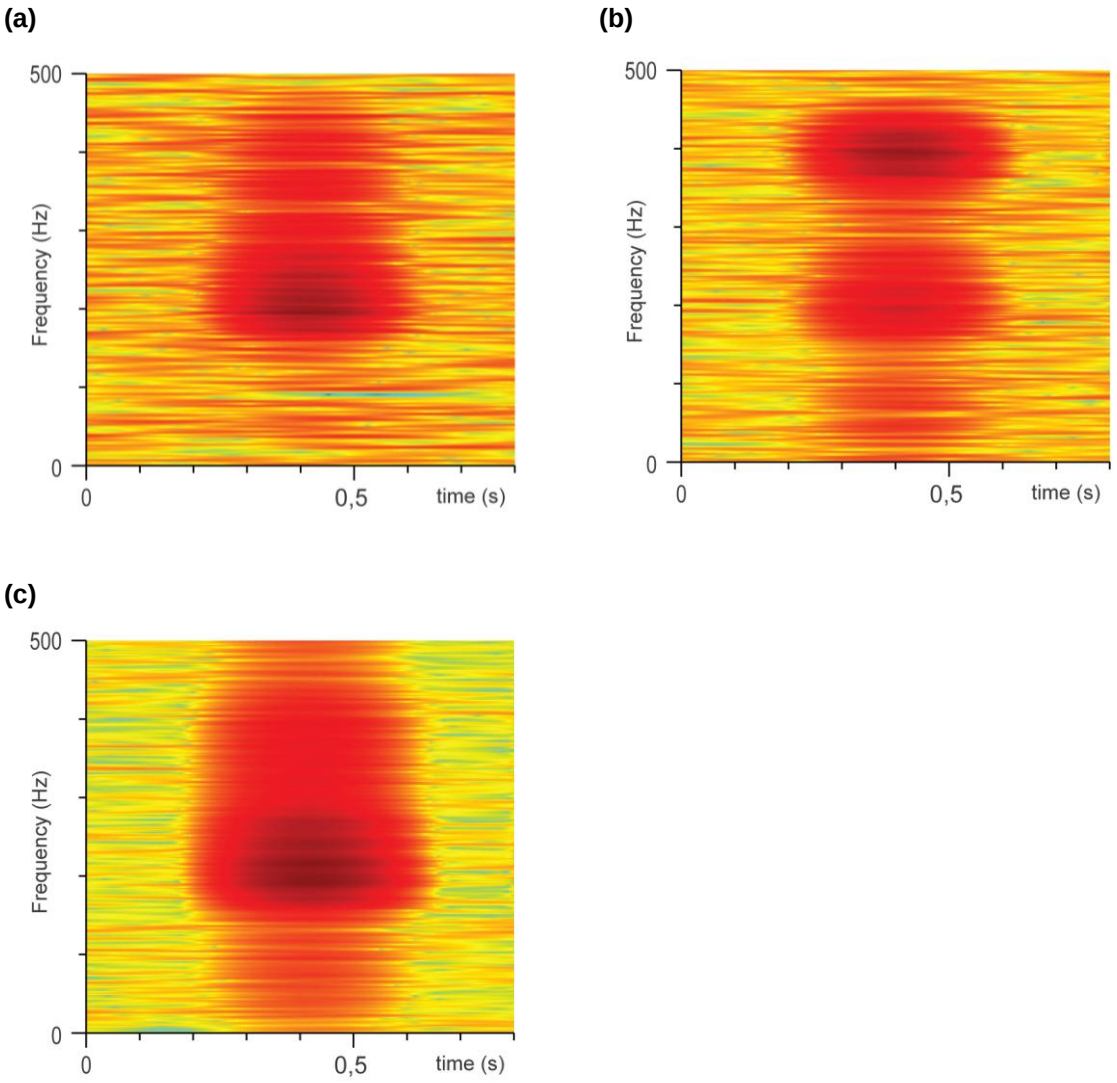


Figure 8. Spectrograms of an 8 kg weight drop off (in free fall). (a) X axis; (b) Y axis; (c) Z axis (place 1).

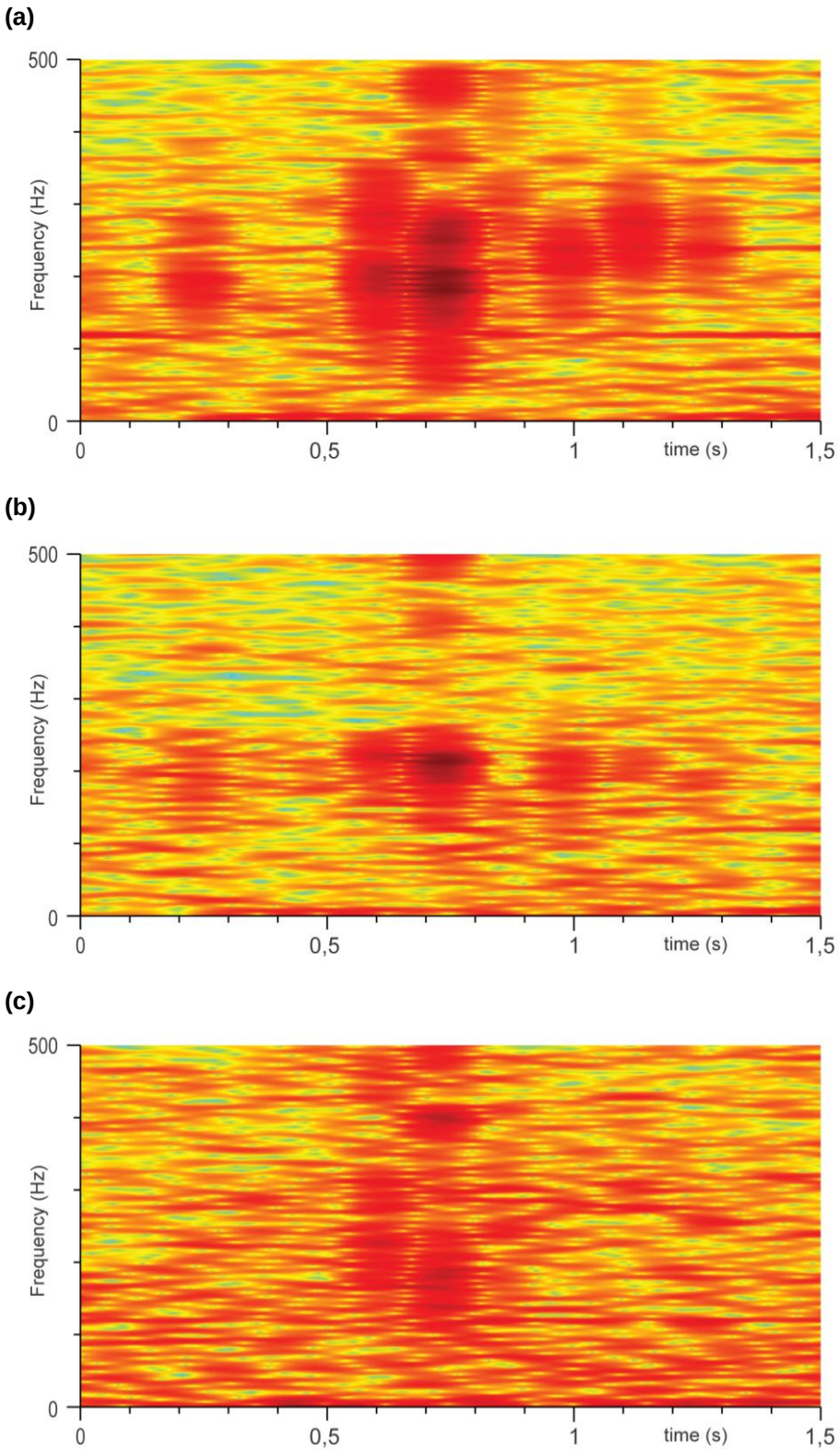


Figure 9. Spectrograms of a man running. (a) X axis; (b) Y axis; (c) Z axis (place 1).

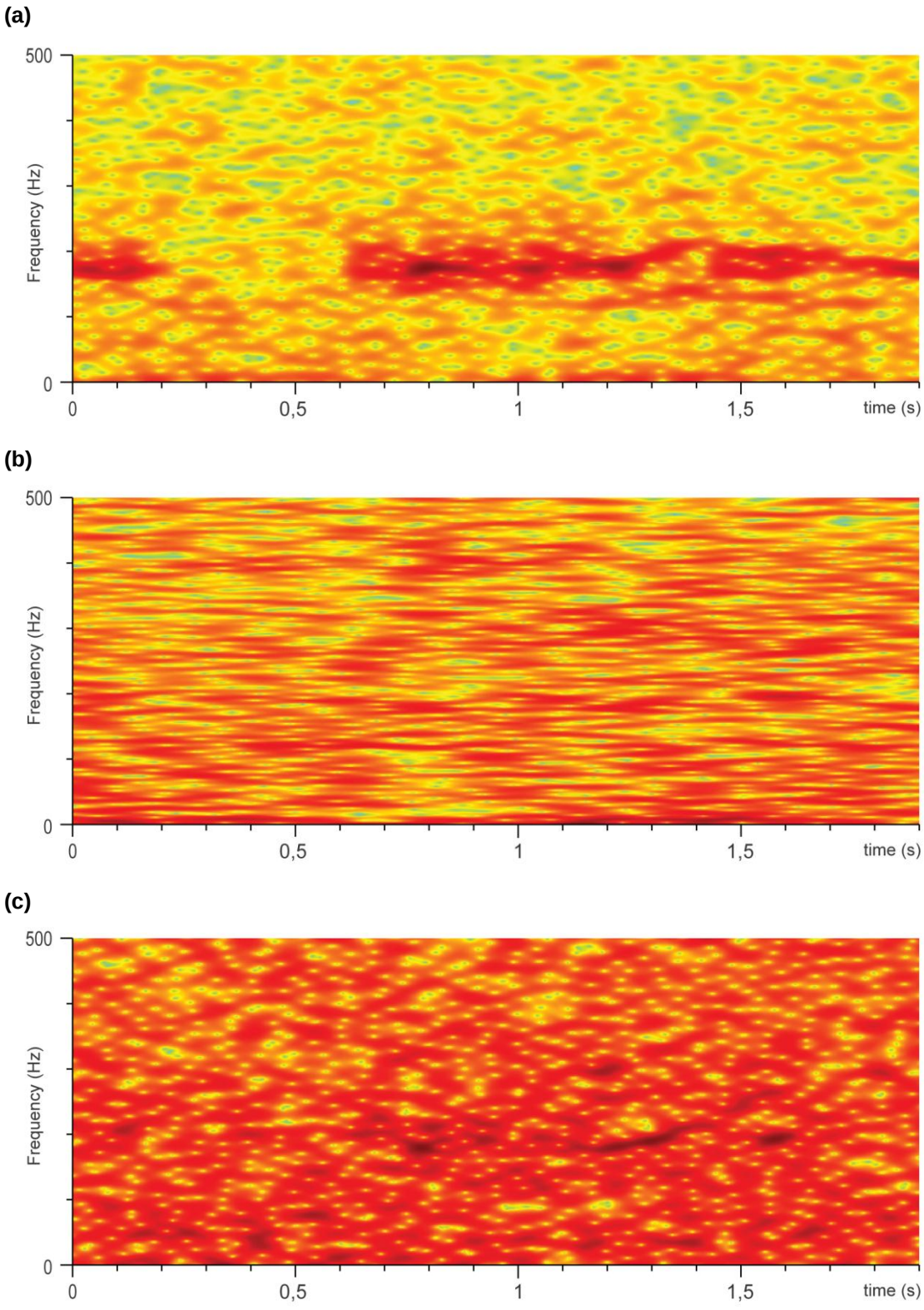


Figure 10. Spectrograms of elephant's record sounds to trigger a vibration source. (a) X axis; (b) Y axis; (c) Z axis (place 1).

MEMS-based digital sensors have their advantages, since these sensors offer new capabilities compared with conventional arrays of geophones, because they "provide better vector fidelity thanks to its accurate calibration (amplitude and orthogonality), broadband linear response (from DC to 800 Hz) and low distortion (< −90 dB)"; also integration of the sensor with the station electronics allows size/weight reduction provide complete digital transmission, from the sensor to the central unit, which is less sensitive to electromagnetic pick-up, cross-talk, and leakage offers the potential to reduce costs while improving data quality (Lainé and Mougenot, 2014). Having in mind the need to address human-wildlife conflict (HWC), and to overcome the limitations and issues of the traditional solutions, this work focused on developing the "loxophone" device.

HWC is a critical aspect of any wildlife conservation initiative. From the human perspective and as referred in Woodroffe *et al*. (2014), this conflict often involves the damage of goods (valuable livestock, crops, or infrastructure), carry of diseases and risk for human lives. In other hand, human pressure over wildlife causes degradation of wildlife habitat with significant risk for reduction or local extinction of their wildlife species.

Pitman *et al*. (2017) shows that the mitigation mechanism to prevent HWC, not only promotes (and is highly effective in) the protection of wildlife species, but can ramp-up local economies with great benefits for local populations.

To mitigate this conflict, fencing has been a widely used approach to define the borders of protected areas. The physical solid barrier created by the fences, has proven to be an effective way to enforce the separation between humans and wildlife. However, and as discussed by Woodroffe *et al*. (2014), fencing comes with some drawbacks, namely, habitat fragmentation with direct impact on the local ecosystem balance. Also fencing costs are high (Evans and Adams, 2016; Huijser *et al.*, 2009), limiting the feasibility of fencing of large or very large protection areas.

The "loxophone" solution provides: an affordable cost, since it uses nowadays technology, and avoids expensive geophone sensors; wireless mesh network, avoiding the need of long cables and time consuming installations; high sensitivity, since the MEMS sensor is a high resolution Analog to Digital Converter to capture very low vibrations; 3 axis analysis to improve sensing capability for all waves independently of the polarity of the wave when crossing the sensor, contrasting with mono axial sensors; GPS data to identify the location of the sensor and provide time synchronization, and to support triangulation calculus to determine location of the source-vibration; a viable solution to implement medium to large size geofences, since traditional solution are expensive and complex for such scale. As potentialities for this technology the research team became aware that vibration sources produce spectral signatures that enable the identification of the vibration cause; e.g. if an animal produces a specific signature, it is possible not only to know "where" it is, but also "what" is crossing the virtual fence. As shown on results, we can obtain distinctive spectral signatures that can be related with different events and vibration sources. Günther *et al*. (2004) and Mehmood *et al*. (2012) show this same conclusion about unique spectral signature using traditional single-axis geophone sensors. This approach enables the free-ranging of wildlife and humans because this virtual fence is not intrusive by default. This means that it is required an action mechanism associated to react to the real-time alerts triggered by this solution. As example of action mechanisms, we can have field teams, local visual and/or sound alert signals or unmanned aerial

vehicle, like autonomous quadcopters, to take-off and fly to the incident location and take some action.
With this solution, the location and identification not only of the large size wildlife, but of pouching activities is possible.

Conclusions

The field trials conducted with these prototype sensors shown that we can locate the vibration source with an error below 5%. Considering the objective of this solution, we believe that this provides a good level of accuracy to track events along the virtual fence.
We found from the results above that the location accuracy and system sensitivity is dependent on the distance between sensors. So, the shorter is the distance between sensors, higher will be the level of sensitivity and accuracy of the virtual fence, but more sensors per kilometre will be required.
Considering the sensing distance obtained from the trials, we believe that an interval between sensors of about 25 meters will provide enough sensitivity and accuracy to detect and track large size wild animals, such us elephants. For this solution scenario, we forecast that the sensors network mesh would cost less than 25% of the traditional fencing costs per kilometre. This forecast, based on components and industrial process costs simulation, allows us to offer an effective virtual fence at a cost that would enable medium to large fencing.

Author Contributions Statement

R.A., S.C. and M.J.P. collaborated from the first stage of the investigation, making contributions to test the equipment, data acquisition, data analysis, and writing the manuscript. S.C. developed the hardware device, the SciLab instructions set and the mathematical model.

Statement

This project was supported by the authors which disclaim any conflict of interests.

Competing financial interests

The intellectual property of the prototypes belongs to S.C. and he owns the rights to use this solution in commercial applications.

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Capítulo III

Contributions for marine resources protection

Anastácio, R., Santos, C., Lopes, C., Moreira, H., Souto, L., Ferrão, J., Garnier, J., Pereira, M.J.. (2014) Reproductive biology and genetic diversity of the green turtles (*Chelonia mydas*) in Vamizi Island, Mozambique. SpringerPLus.2014, **3**:540 http://dx.doi.org/10.1186/2193-1801-3-540

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Reproductive biology and genetic diversity of the green turtle (*Chelonia mydas*) in Vamizi island, Mozambique

Abstract

Vamizi, an Island located in the Western Indian Ocean, is visited by a small and not fully characterized green turtle (*Chelonia mydas* (L.)) population. This population is threatened by natural hazards and several human activities, which are used to identify conservation priorities for marine turtles. It was our aim to contribute to the knowledge of marine turtles that nest in Vamizi, with respect to its regional management, and to an area that may possibly be included on the UNESCO World Heritage List due to its potential Outstanding Universal Value. Here, we evaluate the nesting parameters (incubation period, clutch size, hatching and emergence successes rates) and patterns over an 8-year (2003 – 2010) conservation program. We also present the results of genetic diversity based on the analysis of approximately an 850 pb fragment of the mitochondrial DNA control region. We found that Vamizi beaches host a small number of nesting females, approximately 52 per year, but these have shown a reduction in their length. High hatching success (88.5 ± SD 17.2%, N = 649), emergence success rates (84.5 ± SD 20.4%, N = 649) were observed, and genetic diversity (N = 135), with 11 haplotypes found (7 new). It was also observed, in the later years of this study, a reduction in the incubation period, a dislocation of the nesting peak activity and an increase in the number of flooded nests and an increase of the number of nests in areas with lower human activity. Some resilience and behavioral plasticity seems to occur regarding human territory occupancy and climate changes. However, regardless of the results, aspects like what seems to be the reduction of some cohorts, the number of flooded nests and the diminishing of the incubation period (East and South facing beaches), show that conservation efforts have to be improved.

Keywords

*Chelonia mydas, r*eproductive behaviour, mtDNA diversity, Climate changes, Mozambique Channel (MZC)

Introduction

Mozambique (MZ) possesses a vast coastline and several islands that are used as nesting sites for a number of species of turtles. Five marine turtles species are known to nest along the coast of MZ, green (*Chelonia mydas* (L.)), hawksbill (*Eretmochelys imbricata* (L.)), loggerhead (*Caretta caretta* (L.)), olive ridley (*Lepidochelys olivacea* (Eschscholtz)) and leatherback (*Dermochelys coriacea* (L.)) (Hughes 1971; Costa *et al*. 2007; Videira *et al*. 2008).

The green turtle is widespread (Hughes 1971; Videira *et al*. 2008) and occupies several marine habitats dispersed over extensive areas (Tröeng *et al*. 2005; Piniak and Eckert 2011; Blanco *et al*. 2012). In MZ the species nests in cape São Sebastião (Narane 2008a), Bazaruto Archipelago (Narane 2008b) (22°10'S) and at the north region (Hughes 1971; Costa *et al*. 2007), with the majority found in the Quirimbas Archipelago (Videira *et al*. 2008). Vamizi is one of the largest islands of the MZ Quirimbas Archipelago and it has been an observed rookery for green and hawksbill turtles (see Garnier *et al*. 2012).

Though reproductive females migrate hundreds to thousands of kilometers between rookeries and feeding grounds (Limpus 2008; Godley *et al*. 2010; Tröeng *et al*. 2005), they are known to show some fidelity to their nesting grounds (Meylan *et al*. 1990; Lee *et al*. 2007; Limpus 2008). Some of the most important green turtle rookeries in the Western Indian Ocean (WIO) have been previously described. At the Eparses Islands of Europa, Tromelin and Grande Glorieuses, green turtle populations have been monitored since the 1980's (Lauret-Stepler *et al*. 2007). Other studies include those at Juan de Nova (Lauret-Stepler *et al*. 2010) and Mayotte Island (Comoros Arquipelago) (Bourjea *et al*. 2007a). However, information on nesting turtles is either sparse or lacking in other adjacent countries (Mortimer 2002), especially in Mozambique, Madagascar and Somalia, where this species is vulnerable to human activity (Shanker 2004; Mortimer 2002; Bourjea *et al*. 2008). Studies of tracked nesting green turtle females have revealed the migratory pathways of these females in the WIO, showing that they use the Madagascar coast as foraging ground, as well as Mozambique, Kenya, Tanzania and Somalia coasts (Bourjea *et al*. 2013). The study identifies two oceanic corridors (one in the north of the Mozambique Channel (11°S - 14°S) and the other at the south of the Mozambique Chanel (17°S - 23°S) from the north of Europa to the north of MZ (38°E - 41°E)) as well as two coastal corridors (one at the east African coast, between Mozambique and Tanzania (16°S - 7°S), and the other across the west coast of Madagascar), which emphasizes that the extreme north of Madagascar is an important coastal migratory corridor (Bourjea *et al*. 2013). Using satellite transmitters, Garnier *et al*. (2012) showed the migration routes of four green turtle females tagged in Vamizi travelling to foraging grounds in Tanzania, Kenya and northwest Madagascar (Nosy Makamby).

To further our knowledge on the movement of turtles, investigators have been using tracking approaches but also molecular analysis (Lee 2008). Molecular methods have been used with the aim to better understand the life cycle of green turtles. With the use of molecular markers, such as mitochondrial DNA (mtDNA), it has been possible to understand aspects of their biology such as: natal origins and connection to foraging grounds (Meylan *et al*. 1990; Lahanas *et al*. 1998; Dutton *et al*. 2008), population structure (Encalada *et al*. 1996; Bjorndal *et al*. 2005; Formia *et al*. 2006, 2007), and phylogeography (Avise *et al*. 1992; Encalada *et al*. 1996; Formia *et al*. 2006; Bourjea *et al*. 2007b). Comprehension of the genetic diversity and structure of each population is important, especially for biodiversity managers who use that information to define conservation units to protect (Bagda *et al*. 2012). For the WIO, the latest published data about mtDNA haplotypes are from Formia *et al*. (2006) and Bourjea *et al*. (2007b). For the Vamizi rookery, however, there is currently no molecular information published in the literature. We suggest that owing to its context, molecular data from the Vamizi rookery may contribute important insights for green turtle conservation and management.

The aim of this study was to provide information on green turtle nesting activity and seasonality at the Vamizi rookery. We also analysed mtDNA control region sequences of *C. mydas* to provide information on its genetic diversity. An additional aim was to explore possible changes in nesting due to climate and anthropogenic pressures.

Methods

Study area

The study area was Vamizi Island (Figure 1), a 12 km long, 0.5–2.0 km wide land mass situated at the north of the Quirimbas Archipelago (a chain of 32 islands) at the northwest edge of the Mozambique Channel (MZC). It belongs to the WIO Ecoregion 95 designated as the "East Africa Coral Coast" by the Marine Ecoregions of the World (MEOW) classification scheme (Obura *et al*. 2012). The island belongs to the specific location named "Northern Mozambique to southern Tanzania – Nacala – Quirimbas – Mtwara" (Obura *et al*. 2012) with potential Outstanding Universal Value (OUV) to be considered as a World Heritage site.

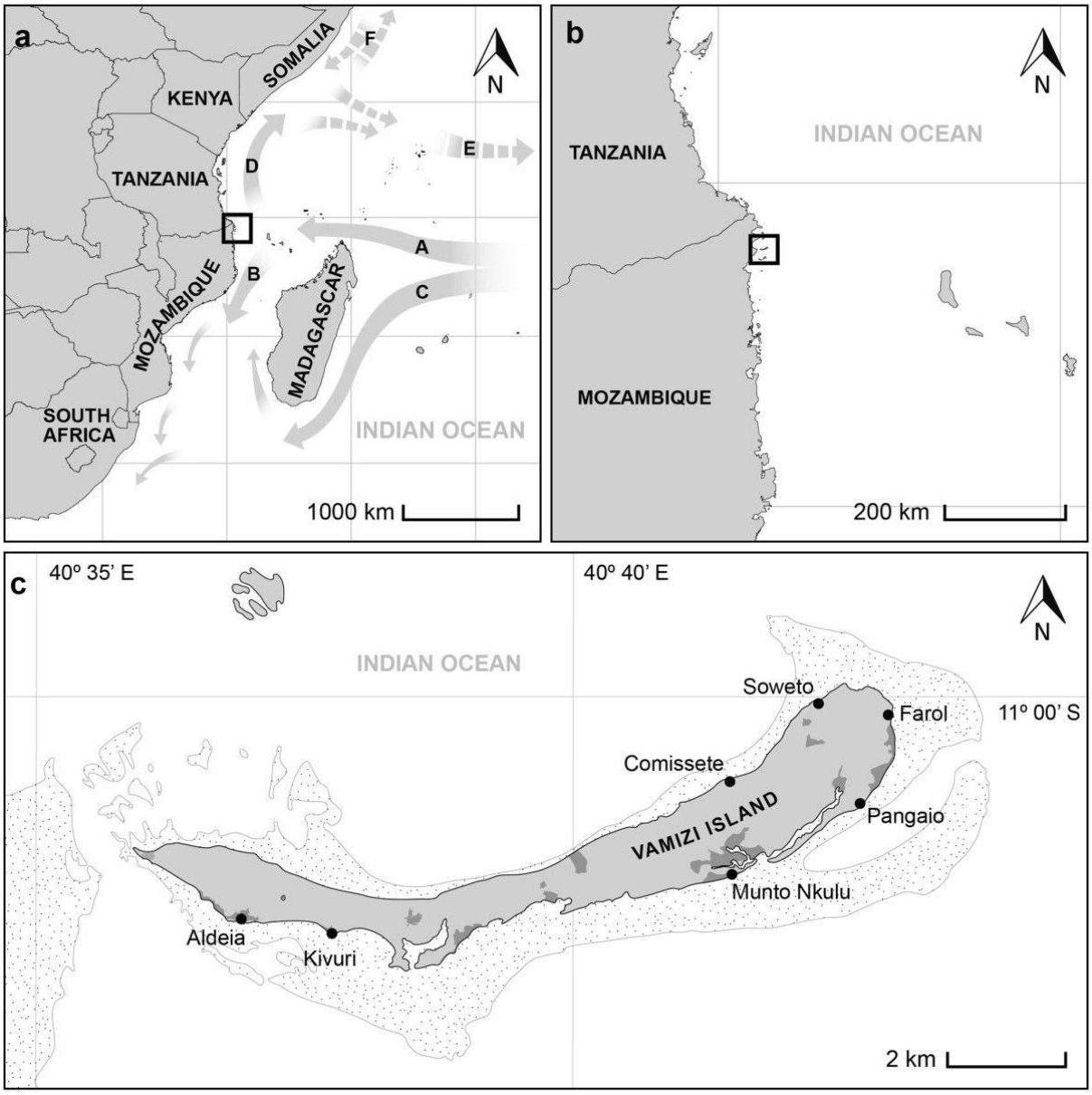

Figure 1. Vamizi Island, its beaches, and its location in the Quirimbas Archipelago, Cabo Delgado Province on the northern Mozambique coast. a Currents: A – South Equatorial Current (SEC); B – Mozambique Current; C – Madagascar Current; D – East African Coastal Current; E – Equatorial Counter Current (Nov–April); F – Somalia Currents. b Vamizi location in the MZ Channel. c Vamizi island with main beaches (a adapted from Richmond 2002). b, c adapted from Missão Hidrográfica

de Moçambique MHM Missão Hidrográfica de Moçambique MHM 1974). Redrawn with Adobe Illustrator C.S.5.5 program. North facing beaches: Comissete (11° 00′ 54″ S, 40° 41′ 23″ E), Soweto (11° 00′ 08″ S, 40° 42′ 17″ E); East-South facing beach: Farol (11° 00′ 17″ S, 40° 42′ 55″ E); South facing beaches; Pangaio (11° 01′ 07″ S, 40° 42′ 39″ E); Munto Nkulu (11° 01′ 44″ S, 40° 41′ 33″ E); Kivuri (11° 02′ 18″ S, 40° 37′ 44″ E); Aldeia (11° 02′ 11″ S, 40° 36′ 57″ E).

Vamizi has monsoon seasonality with variation of temperature and rainfall, which is likely enhanced by mesoscale dynamic eddies. McClanahan's (1988) review of seasonality patterns in east Africa's coastal waters, focusing on the area 10° north and south of the equator, stated that the division between northeast (NE) (October/November to March) and southeast (SE) monsoons (March to October) are indicative of two coastal seasons, which affect oceanographic processes (physical, chemical, biological). The SE monsoon has lower air temperatures which lower surface seawater temperatures. Also, wind run and speed are greater during SE monsoons and, as a consequence, current speed and water column mixing are higher (McClanahan 1988). The monsoon seasonality of the Indian Ocean, considered as a strong ocean-climate interaction, does strongly modulate current speed and variability of the south MZC (Obura *et al*. 2012). Yet, at the north of the Channel, the influence of the monsoon northeast winds dominates along the northern coast of Mozambique (e.g. Pemba, 13°S) in the austral summer (NE monsoon), affecting Vamizi, and southwest winds dominate during the austral winter (SE monsoon) (Ternon *et al*. 2014; see Climatogram of Pemba for the period 2004 – 2010 at Figure 2).

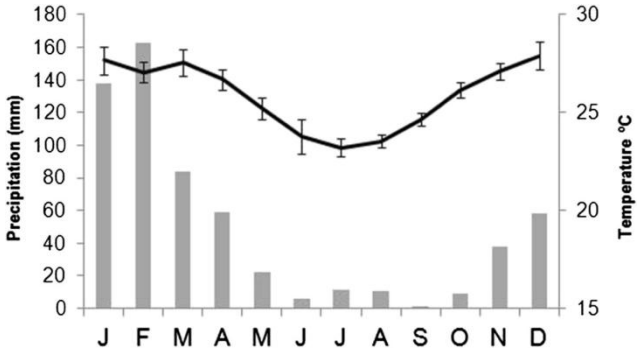

Figure 2. Climatogram of Pemba with averages between 2004 and 2010, obtained from National Oceanic and Atmospheric Administration (NOAA, http://www.noaa.gov/index.html).

Vamizi has small air temperature amplitudes and considerable variation in precipitation values. The period 2004 – 2010 had lower rainfall averages of below 50 mm, with 2005 being particularly dry with an average rainfall of 22.6 mm, and 2006, 2008 and 2010 having higher average precipitation of 85.4, 68.4 and 73.7 mm, respectively.

These waters receive the South Equatorial Current (SEC). After reaching the African coast, the NMC splits into the East African Coastal Current (EACC) and a southerly branch (Mozambique Current) that flows into the northern MZC (Figure 1) (for details, see Ternon *et al*. 2014). The water circulation in the MZC is highly variable and eddy driven. These eddies have a strong impact on food webs, especially affecting top-level consumers such as turtles, seabirds and marine mammals (Obura *et al*. 2012).

Monitoring program and data collection

Field effort

The monitoring program in Vamizi Island started in September 2002 with daily foot patrols conducted by monitors. Each team comprised at least, three trained scouts and the information was gathered daily following the standard protocols (Eckert *et al*. 1999).

Comissette and Farol beaches have been monitored in day patrols since October 2003 and night patrols since January 2004, every hour for at least 3 months (Table 1) during the peak of the nesting activity. This night monitoring was conducted by teams of 3–4 members that were responsible for tagging and for gathering information on emergences, nest attempts, species identification and specimen size.

Table 1. Field effort, months with night-time patrols

2004	2005	2006	2007	2008	2009	2010
March – July	March – July	February – July	January – December	January – August	February – September	February – July

Every morning at the day patrols, activity was checked above the high tide line. The team recorded tracks, species identification (based on tracks type) and nesting activity (differentiating between nesting and non-nesting emergences). For any new nests, monitors recorded their GPS coordinates and then marked them with bamboo poles behind the nest. In addition to recording nesting date, monitors gathered associated information of hatching activity, such as hatching date, excavation date, and other nesting parameters (hatched at the nest and/or undeveloped (not before 90 days after eggs laid)) to evaluate hatching success.

Following Schroeder and Murphy (1999) a “crawl” was interpreted as “tracks and other sign left on a beach by a sea turtle”; a “false crawl” was interpreted as “a crawl resulting from an abandoned nesting attempt (a non-nesting emergence)”.

Biometric information

Identification (Pritchard and Mortimer 1999) and the biometric information, made in triplicate after egg deposition, is represented by CCL (minimum curved carapace length) and CCW (curved carapace width) lengths from the observed turtles (following Bolten (1999) methodology) and by size and shape of the tracks (Pritchard and Mortimer 1999; Schroeder and Murphy 1999).

Tagging

Turtles were tagged, according to the methodology described by Balazs (1999). The examination for tags occurred during night patrols. Titanium tags (http://www.stockbrands.com.au/titanium.html) (Stockbrands Pty Ltd., Perth, Australia, http://www.stockbrands.com.au) were applied at proximal end of both front flippers. The presence of tags (tag series MZC 0000 – MZC 0999) was recorded. Missing tags were replaced or applied if not previously tagged. The first external tags were applied on 18th March 2004 (MZC 0004/MZC 0005; turtle ID VZ001). For all turtles captured, date, site, tag number and activity were recorded. The individuals’ location (latitude and longitude) was recorded with a GPS (Magellan NAV5000D, used in 2D non-differential mode).

Tissue collection

Samples were taken following recommendations of Dutton (1996) between 2008 and 2010 by biopsy punch (approximately 5 mm3) from the extremity of back flippers from adult females (N = 63) or dead hatchlings. All samples were registered with date of collection, tag number and beach ID. Samples (N = 135) were from six nesting beaches and were stored in ethanol 70%, and frozen in 1.5 mL eppendorf tubes.

Mitochondrial DNA control region extraction, amplification and sequencing

Samples were obtained to determine the genetic diversity of the green turtles that use Vamizi Island as a rookery, and to compare this with other populations/subpopulations. DNA extraction was performed following the standard phenol/chloroform procedure (Sambrook *et al*. 1989) with some modifications and Chelex procedure (Walsh *et al*. 1991). A 1000 bp-fragment of the mitochondrial DNA control region was amplified via PCR in a Bio-Rad iCycler Thermal Cycler (Hercules, CA, USA), using LCM15382 (5′-GCT TAA CCC TAA AGC ATT GG-3′) and H950g (5′-GTC TCG GAT TTA GGG GTT TG-3′) (Lara-Ruiz *et al*. 2006, Abreu-Grobois, F.A. pers. comm., abreu@ola.icmyl.unam.mx) primers. PCR conditions (for 25 µL: 2.5 µL buffer containing 1.5 mM of MgCl2, 0.5 µL dNTP (200 µM), 1 µL (0.4 µM) each primer, 0.5 µL (2.5 U) Taq DNA Polymerase, 1 µL (2 ng) DNA and 18.5 µL H2O) for these primers were as follows: initial denaturation of 5 min at 94°C, followed by 36 cycles of 30 s at 94°C, 30 s at 50°C and 1 min at 72°C, and a final extension step of 10 min at 72°C. Amplification was verified by electrophoresis of 6 µL of each reaction product in 2% agarose gel and a Transiluminator UVP Bio Doc-It™ System. Amplicons were sequenced in a company: PCR product was sequenced using the BigDye® Terminator v3.1, Cycle Sequencing Kit (Applied Biosystems; Princeton, USA). Purification was done through gel filtration, using Centri-Sep™ 96-Well Plates (Applied Biosystems; Princeton, USA). Sequence detection was done on an automatic sequencer ABI PRISMR 3730XL Genetic Analyser (Applied Biosystems; Princeton, USA).

Data analysis

For determining of nesting parameters we used samples from Comissete, Farol, Pangaio, Munto Nkulu and Soweto beaches (Figure 1). For genetic diversity analysis we used samples of tissue from Comissete, Farol, Pangaio, Kivuri, Aldeia and Munto Nkulu beaches.

Reproductive biology – nesting parameters

Nesting parameter averages were obtained using records of all beaches combined and per beach. The parameters of Farol and Comissete were given emphasis because these beaches represent 54.7 and 28.8%, respectively, of the total records of our sample.

Using the entire database (N = 1303), we counted the amount of records per year in percentages for the two main beaches, to obtain polynomial tendency lines.

Nesting success: The nesting success was defined as “the proportion of nesting activities that resulted in a nest” (Godley *et al*. 2001).

Inter-nesting period and remigration interval: The inter-nesting period and remigration interval were obtained using the records of tagged females that visited Vamizi in the sampled beaches between November 2004 and October 2010. Following Bourjea *et al*. (2007a) the mean inter-

nesting interval was calculated as the mean of all observed inter-nesting intervals from the records of tagged turtles, after excluding intervals <7 days. These were considered to be unsuccessful nesting events. The remigration interval was obtained from records of tagged females that visited Vamizi in different nesting seasons and years and was defined as “the period, in years, between nesting seasons for an individual female.” (Alvarado and Murphy 1999).

Nesting females and clutch frequency: We estimated the number of nesting females per year based on the number of tagged turtles and on the observed clutch frequency (obtained as the average number of nests laid per tagged female per year) and on the total number of nests laid per year (Alvarado and Murphy 1999).

Clutch size, hatching and emergence successes: Clutch size, hatching and emergence successes were determined following the methodology described by Miller (1999) using records from all beaches. We calculated the number of eggs laid per year, average of nests/year and average of nests/month. Hatching success was defined as “the proportion of hatchlings that hatched out of their shells respectively” (Miller 1999). Emergence success was defined as “the proportion of hatchlings that reached the beach surface” (Miller 1999). The formulas used to calculate the clutch size, hatching and emergence successes were described by Miller (1999).

Incubation period: The incubation period was obtained using all records from all the sampled beaches and according to the date when the nest was laid.

Flooded nests: The percentage of flooded nests per year was generated from the records considering that a nest was considered to be flooded when it had been completely over washed.

Statistical analysis

Our initial sample included 1303 records, registered between 2002 and 2010, corresponding to observations in situ of adult green turtles (nesting and doing other activities) in all beaches combined. Data from 2002 were scarce, corresponding to a different field effort from the 2003 – 2010 period.

All statistical analyses were performed on PASW Statistics 18 and the Microsoft Office Excel 2007 Programs. Significance was estimated at the 95% confidence level. Variables like incubation period, clutch size, hatching and emergence successes were compared between years (data between January and July) using One-Way ANOVA and the post-hoc tests of Games Howell, Tukey or Scheffe, when statistically significant differences were detected ($p < 0.05$).

Genetics diversity and phylogenetic analysis

Sequence alignments were performed with the software CLUSTAL W software version 1.3.1.1 (Thompson *et al*. 1994) and nucleotide analysis with BioEdit Alignment Editor v.7.0.9 (http://www.mbio.ncsu.edu/BioEdit/bioedit.html). Basic Local Alignment Search Tool (BLAST) search was used to verify existing similarities with deposited sequences in the GenBank database (http://blast.ncbi.nlm.nih.gov/Blast.cgi). New sequences were deposited (3, 9.05.2011) in the GenBank database under the accession number JF926556, JF926557, JF926558, JF926559, JF926560, JF926561, JF926562.

The network tree of the haplotypes was built by the median-joining (MJ) method (Hamabata *et al*. 2009) using Phylogenetic Network Constructions version 4.6.0.0 (http://www.fluxus-engineering.com).

Haplotype (h) diversity was obtained using DnaSP v. 5 (Monzón-Argüello *et al*. 2010).

Turtle biometry

The CCL average of the turtles measured on night patrols (2004 – 2010) was 106 ± 5 cm (N = 401) ranging from 85 to 125 cm (Figure 3), and the CCW average was 99 ± SD 6 cm (N = 398) ranging from 76 to 120 cm.

This distribution (Figure 3) shows the occurrence of specimens of several sizes/ages but also indicates that several cohorts where removed with particular incidence in thus below 110 cm. The CCL shows, in yearly average, a reduction from 108 ± 5 cm (N = 38) in 2004, to 105 ± 4 cm (N = 49) in 2010.

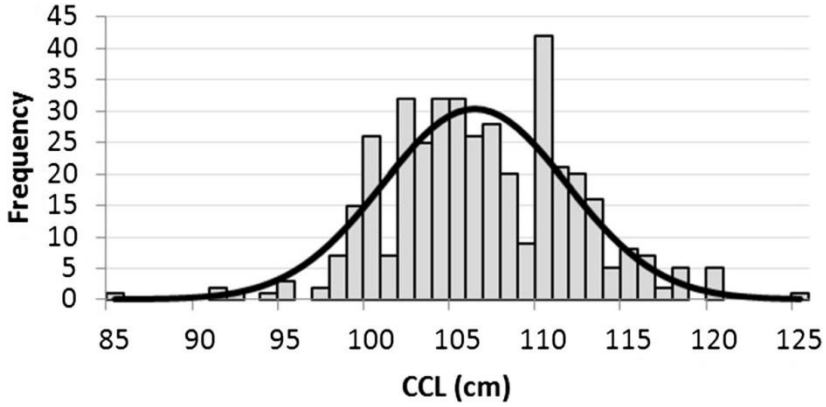

Figure 3. Distribution of average minimum curved length, CCL (N =401).

Reproductive biology – nesting parameters

The average number of green turtles that visited Vamizi was 162.9 ± 44.9 individuals.year^{-1} (N = 1303). The average annual number of nests was 130.00 ± 32.7 (N = 1040) ranging from 79 nests (2004) to 173 (2008).

Nesting success: The nesting success was above 73% for all years. The highest average of nests.month^{-1} (all sampled beaches combined) peaked in May with 17.6 ± SD 9.9 nests (N = 141) in 2003 – 2010. The first semester shows the highest nesting activity (Figure 4).

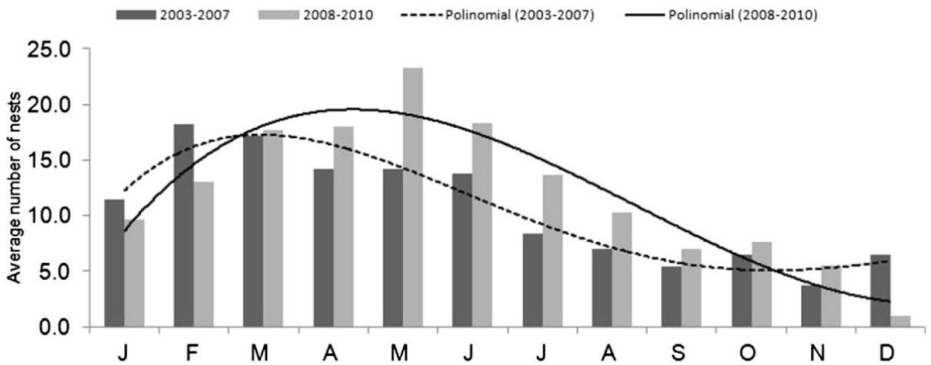

Figure 4. Nesting activity (mean ± SD) by month in sampled beaches combined, in the period 2003 – 2010 with polinomial tendency lines for two periods of time: 2003 – 2007 and 2008 – 2010.

Because Farol and Comissete beaches combined represent 83.5% of the sample, the nesting activity of both beaches was analyzed.

The average number of nests was, higher at Comissete beach between October/November and February/March, which is different from what was recorded at Farol beach (Figure 5), where the nesting activity occurs all year with higher activity between February and July.

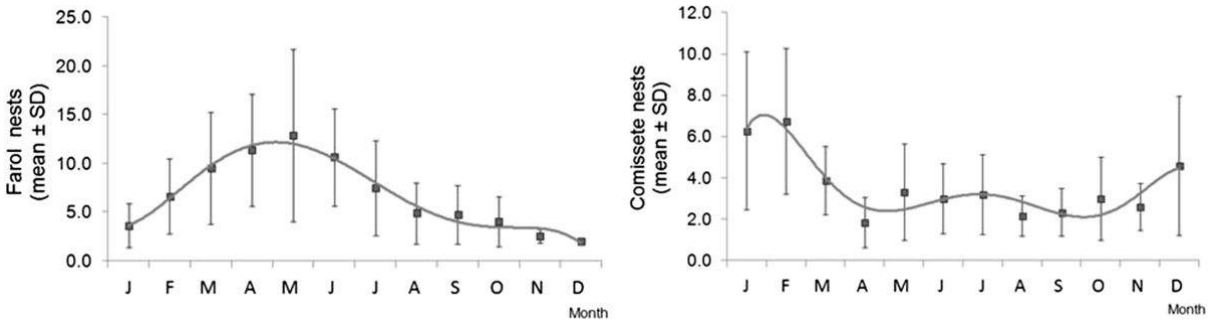

Figure 5. Mean green turtle nests numbers by month in Farol and Comissete beaches for the period from 2004 to 2010 (with polynomial tendency lines).

It's also possible to verify, for Farol (Figure 6), a dislocation of the nesting peak from April (2003 – 2007) to May (2008 – 2010).

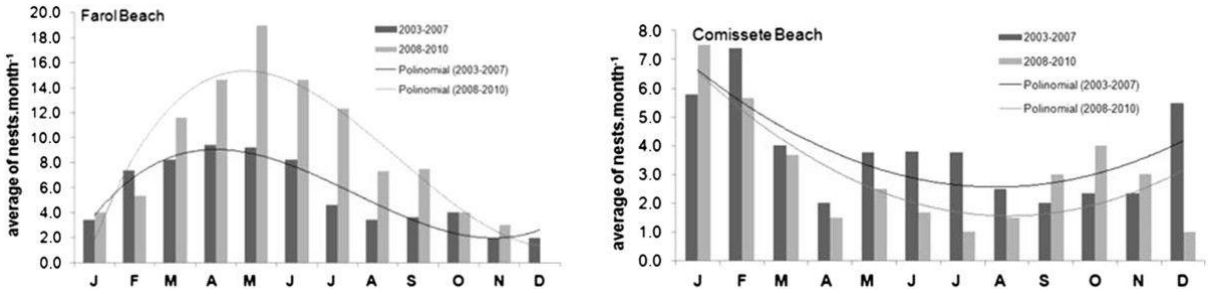

Figure 6. Nesting activity in Farol beach (left) and Comissete beach (right), in the period 2003 – 2010 with polinomial tendency lines for two periods of time: 2003 – 2007 and 2008 – 2010.

When examining nest records over time in Farol and Comissete beaches, a polynomial tendency (Figure 7) demonstrates that since 2005, records diminished at Comissete and increased in Farol. The distribution and reduction of the number of records at Comissete is also shown in Figure 8. After 2005, the majority of nests were concentrated in Farol.

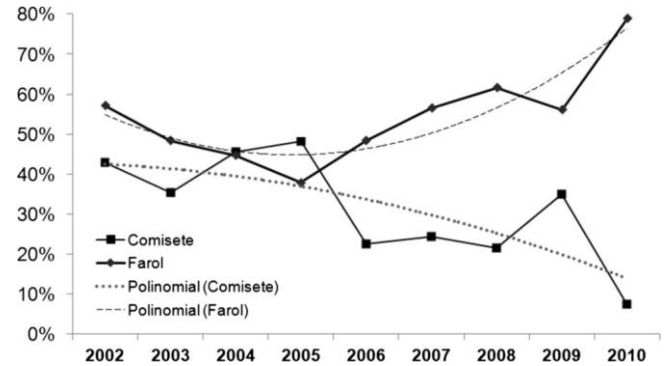

Figure 7.Percentage of records by year between 2002 and 2010. The number of records is proportional to the number of nests and emergences.

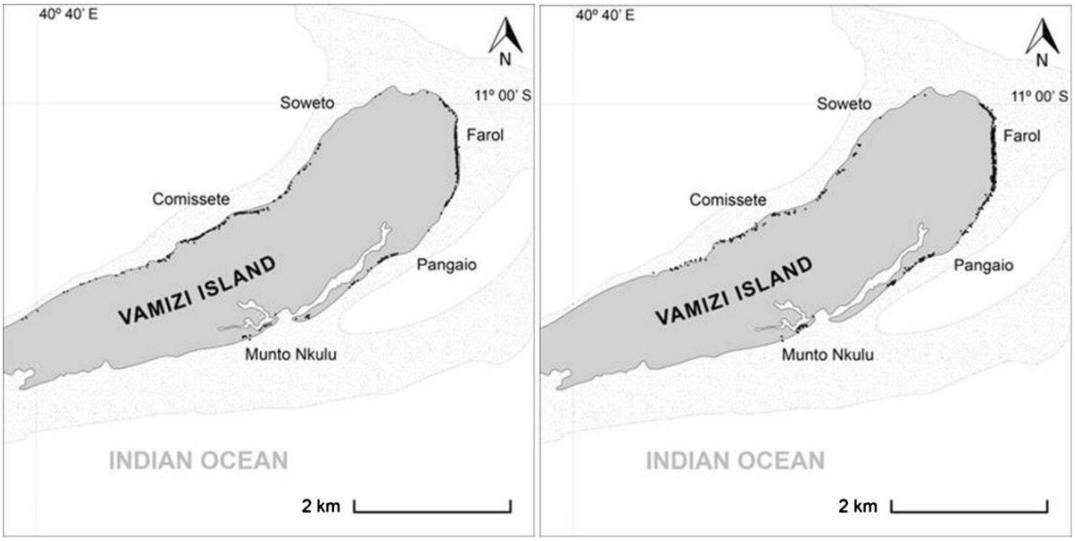

Figure 8. Distribution of nests on Comissete and Farol showing before 2005 (left) and after 2005 (right).

Inter-nesting period and remigration interval: Between March 2004 and August 2010, 161 *Chelonia mydas* turtles were tagged on night patrols. The modal observed inter-nesting interval was 12 days (Figure 9), with a mean interval of 20.3 ± SD 15.8 days (range 8 – 90 days, N = 259). Approximately 88% of the tagged turtles made an emergence at Vamizi in less than 34 days after their first emergence. Approximately 10.8% came to the beach 0 – 2 days after their first emergence. The majority (59.1%) re-emerged between 9 and 18 days after. From our tagged sample, the same turtle emerged at Vamizi between 2 and 7 times (in maximum) per year.

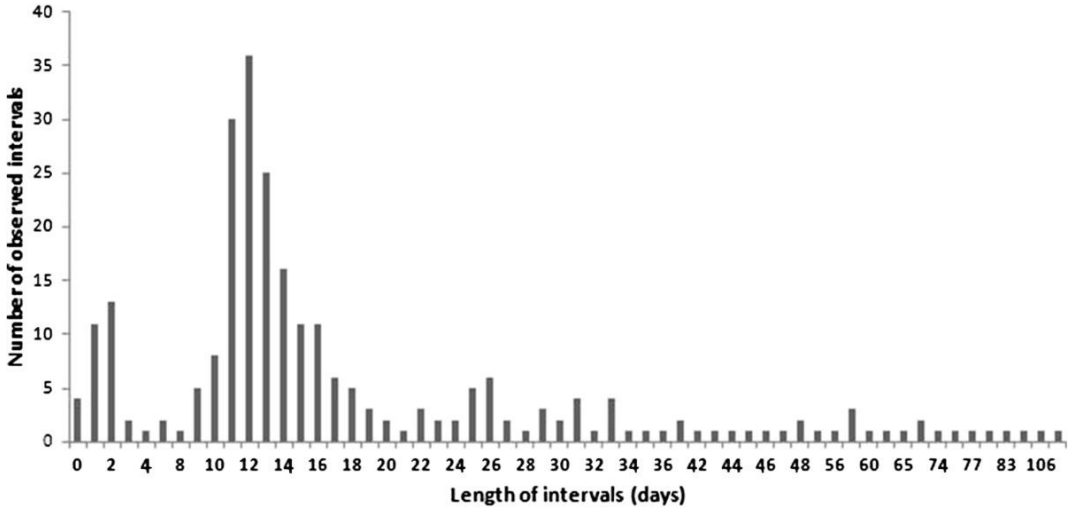

Figure 9. Intervals separating nesting attempts.

Table 2 shows the numbers of emerged/tagged/returned turtles on all the beaches sampled. Of these, 32.9% re-emerged at Vamizi in following years, 84.0% of which did so it on the same beach, thus showing philopatry.

The remigration interval was 2.6 ± SD 1.1 years (range 222 – 1518 days; N = 30).

Table 2. Number (#) of emerged, tagged and returned turtles per year (night patrols)

Year	# Tagged females. Year^{-1}	Returned females marked that returned in subsequent years
2004	13	4
2005	19	9
2006	21	6
2007	23	6
2008	41	–
2009	22	–
2010	22	–

Nesting females and clutch frequency: Table 3 shows the observed clutch frequency for the latest three years of the program. The year 2009 shows the lower estimated value of 33.4 nesting females.year^{-1}.

Table 3. Months of night-time monitoring, number (#) of adult female green turtle tagged, number of clutches laid by tagged females, observed clutch frequency, on beaches combined for Vamizi Island.

	2008	2009	2010	All
Months	**January-August**	**February-September**	**February-July**	
# of nesting females tagged	41	22	22	85
# of clutches laid by tagged females (%)	3.25	3.44	2.65	
	65 (36%)	62 (54%)	53 (30%)	180
Observed clutch frequency (CF)	3.3	3.4	2.7	3.4
Estimated # of nesting females.year^{-1}	55.7	33.4	66.4	

Clutch size, hatching and emergence successes: The average clutch size (all beaches combined, 2003 – 2010) was 116.7 ± 26.5 eggs (N = 649). Comissete beach had an average clutch size of 120.2 ± 31.5 eggs (N = 177), and Farol beach has an average clutch size of 114.2 ± 24.1 eggs (N =371).

The overall mean hatching success was 88.5 ± SD 17.2% (N = 649) and the overall mean emergence success was 84.5 ± 20.4% (N = 649). The year 2003 showed a hatching success of 75.3 ± 33.0%, in contrast with other years, which showed higher hatching success rates (>80%).

One–Way ANOVAs show significant differences in the overall mean hatching success between 2005 and 2009 ($F_{7,595}$ = 3.077 $p < 0.003$), and also show significant differences for the overall mean rates of emergence success ($F_{7,595}$ = 5.017 $p < 0.001$), between 2004/2005 (Games-Howell post hoc test p = 0.033), 2005/2009 ($p < 0.001$), and 2005/2010 (p = 0.013).

For Farol beach there were no differences in hatching success ($F_{7,353}$ = 1.503, p = 0.165). For emergence success ($F_{7,353}$ = 3.489, p = 0.001) the years of 2004/2005 (post-hoc test Games-Howell: p = 0.025), 2005/2009 (post-hoc test: p = 0.004), and 2005/2010 (post-hoc test: p = 0.020), were significantly different.

There were no differences in hatching success ($F_{7,142}$ = 0.884, p = 0.521), and emergence success ($F_{7,142}$ = 0.788, p = 0.598) between years for Comissete beach.

Incubation period: The mean incubation period (i.p.), across all observed beaches was 64.4 ± 12.3 days (N = 687; 2003 – 2010). The overall annual i.p. average reveals a pattern: a smaller

value in a year is always followed by a peaking value in the next year. However, the difference between the last 2 years isn't significant (60.7 ± 7.4 to 61.7 ± 9.3 days).

Significant differences in the overall i.p. mean are almost always consistent, between two consecutive years (2004 and 2005; 2005 and 2006; 2008 and 2009). One–Way ANOVA ($F_{7,631}$ = 6.619 $p < 0.001$) shows no significant differences in the overall i.p. mean between the years of 2004, 2006 and 2008, but they are significantly different from the other years of the study. For example, 2004 is significantly different from 2005 and 2009 (Games-Howell post hoc test p = 0.049; p = 0.014); 2006 is significantly different from 2005 (p = 0.001), 2009 (p < 0.001) and 2010 (p = 0.002), which were hot years.

The overall averages of i.p. in Vamizi beaches are as follows: North facing beaches – Comissete 62.1 ± 11.4 days (N = 182) and Soweto beach, 57.8 ± SD 23.6 days (N = 6); East-South facing beach – Farol beach, 65.5 ± 11.8 days (N = 392); South facing beaches – Munto Nkulo beach, 65.1 ± 13.3 days (N = 42); Pangaio beach, 64.7 ± 15.0 days (N = 65).

At Farol beach the i.p. ($F_{7,372}$ = 4.660, $p < 0.001$) was significantly different between 2005/2006 (post-hoc test Games-Howell: p = 0.049), 2005/2008 (post-hoc test: p = 0.001), 2008/2009 (post-hoc test: p = 0.001), and 2008/2010 (post-hoc test: p = 0.003). There is a small decreasing tendency of the ip of Farol beach over time (Figure 10) indicating possible increases in air/sand temperature. There were no differences in i.p. ($F_{7,147}$ = 2.960, p = 0.006) between years for Comissete beach.

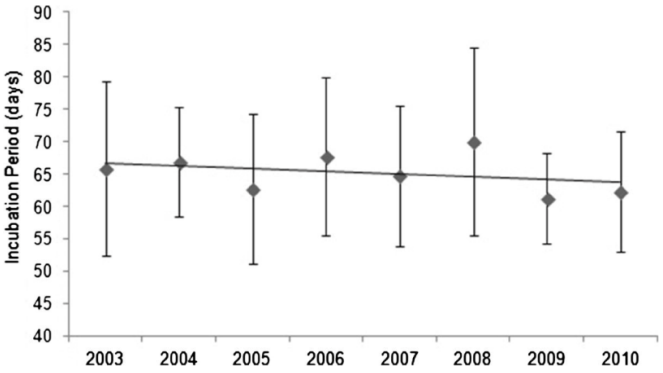

Figure 10. Patterns of incubation period in Farol beach from 2003 to 2010 (N = 392).

Flooded nests: Nest losses occur because of flooding and predation. Predation, however, appears to be very low at Vamizi, since an average of 0.74 ± 2.35 eggs (N = 649) were lost to predation. Conversely nests lost because of flooding were greatest in 2007 (51.2%), 2009 (29.9%) and 2010 (38.0%). Also, February, March, August and September are the months when percentages of flooded nests rise above 25%.

Genetics diversity and phylogenetic analysis

Within the analyzed region, 74 polymorphic sites were found (Additional file 1: Table S1) and 11 mtDNA haplotypes: IND1, IND3, JF926556, JF926557, JF926558, JF926559, JF926560, JF926561, JF926562, CMJ1, CM8, were identified from the 135 samples (Table 4). Four haplotypes described here have been found elsewhere: IND1 and IND3 (GenBank accession n°s. AF529028.1 and AF529030.1, respectively) CM8 (GenBank accession n°. Z50130) and CMJ1 (GenBank accession n°. AB472300.1). JF926556, JF926557, JF926558, JF926559, JF926560,

JF926561 and JF926562 are described for the first time for this region (GenBank accession n°. 1452591).

Table 4. Distribution of observed green turtle haplotypes by beach on Vamizi island

	Total	IND 1	CM 8	IND 3	CMJ 1	JF926558	JF926556	JF926557	JF926559	JF926560	JF926561	JF926562
Farol	81	55	8	7	4	2	1	1	1		1	1
Comissete	37	25	11							1		
Pangaio	9	9										
Kivuri	6	3	2			1						
Aldeia	1	1										
Munto Nkulu	1			1								
Total (*N*)	135	93	21	8	4	3	1	1	1	1	1	1

If IND1 is used as a reference sequence, JF926558, JF926556 and IND3 haplotypes differ by one substitution at base positions 306, 534 and 553 respectively. Haplotypes JF926562 and JF926557 showed three and six substitutions respectively. The remaining five haplotypes are more diverse showing JF926561 one deletion and 10 substitutions, CM8 two deletions and 34 substitutions, JF926560 three deletions and 34 substitutions, JF926559 three deletions and 39 substitutions and CMJ1 two deletions, one insertion and 28 substitutions (Additional file 1: Table S1). Haplotypes CM8 and JF926560 are separated from JF926559 by the same five substitutions, in the base positions 261, 266, 267, 270, 272; only one deletion was detected between CM8 and JF926560.

Vamizi island has high values of haplotype (*h*) diversity, with the most sampled beach (Farol) showing an h value of 0.605.

Among the 135 specimens of green turtles IND1 was the most dominant haplotype (Table 4). IND1 occurs in 68.88% of turtles, IND3 in 5.93%, CM8 in 15.56%, CMJ1 in 2.96% and JF926558 in 2.22%. The other haplotypes occurred in 0.74% each (IND1 > > CM8 > > IND3 > > CMJ1 > > JF926558 > > others).

Farol is the most diverse beach (Table 4), exhibiting 10 haplotypes among 81 samples, followed by Comissete (N = 37), Kivuri (N = 6) with 3 haplotypes each. The remaining places presented only one haplotype.

The network tree of green turtles based on the mtDNA control region sequences (Figure 11) shows the relationships among the identified haplotypes.

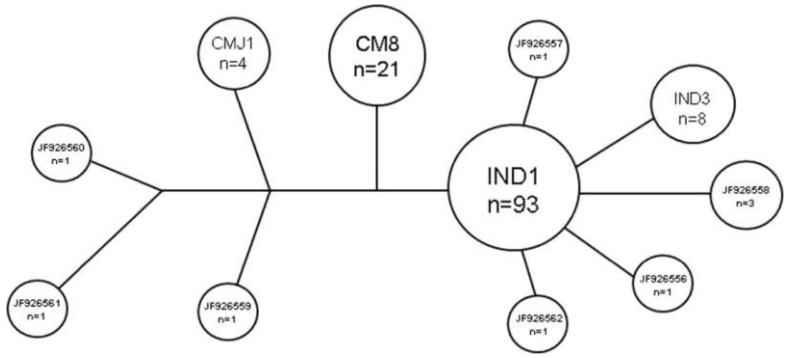

Figure 11. Network tree based on the 11 identified haplotypes.

Turtle biometry

Based on average CCL, the specimens that nest in Vamizi Island were smaller compared with others that nest in the region. For example, at Mohéli the CCL average is 108.1 ± 5.3 cm (range: 92 – 129 cm; N = 742; Innocenzi *et al*. 2010), and at Juani Island (Tanzania) the CCL average is 107.2 ± 4.7 cm (range: 101–118 cm; N = 18; West *et al*. 2013).

Analysis year by year showed a reduction in size of measured specimens and consequently age, as well as a reduction in the expected abundance of each cohort. Among the various threats to marine turtles, fishing techniques are known to contribute greatly to mortality (Lewison *et al*. 2004; Wallace *et al*. 2010). Bycatch has a high impact on marine turtles in the WIO and poaching has been reported to occur in Kenya, Madagascar, Mozambique, Seychelles and Tanzania. All these countries have rookeries or are known as feeding grounds of groups of WIO marine turtles (Bourjea *et al*. 2008). The diminishing of some cohorts in the Vamizi rookery may indicate the presence of anthropogenic pressures on turtles while at the sea, during the inter-nesting period or between nesting and feeding sites.

Reproductive biology

There is variability in several nesting patterns over the years that can be discussed in climatic and intrinsic contexts.

Turtles nest in Vamizi all year long. However, the two main beaches of Farol and Comissete show different nesting peaks, although at the same beach, they differ in duration between years, showing some irregularity. At the Vamizi beaches of Farol and Comissete, green turtles show a similar pattern of nesting seasonality found in the adjacent islands of Eparses. On Grande Glorieuse, the nesting season is longer and shows a more variable peak, which happens in the dry season months (March to June; Lauret-Stepler *et al*. 2007), a similar pattern found for Farol (February-June) during the period 2003 – 2007. This pattern was observed at Juani Island (Tanzania), on its eastern side, where nesting activity happens all year long with a more restrictive peak in April and May (West *et al*. 2013). However, at Farol beach the nesting peak is different in the later study period (2008 – 2010), with the highest nesting activity observed between March and July. The delaying of the nesting period at Farol may be due to behavioral flexibility (Hawkes *et al*. 2009). As noted by several authors, turtles seem to choose nest locations (Cheng *et al*. 2013; Hamann *et al*. 2007) based on sensitivities to changes in their environment and show a biological capacity to adapt to climate crises (Fuentes *et al*. 2010). The nesting pattern observed in Comissete beach is similar to that published by Lauret-Stepler *et al*. (2007) in Tromelin and Europa islands (inside MZC), with a more stable peak at the wet season (November to February).

Inter-nesting period and remigration interval: From published literature, the modal inter-nesting value for green is 12 days (range: 10 – 17 days; Almeida *et al*. 2011), which is similar with what we observed in Vamizi. In Mayotte Island, Bourjea *et al*. (2007a) argue for the existence of three inter-nesting peaks: the first between 1 and 7 days (corresponding to 25% of females that abort their first nesting attempt); the second between 12 and 14 days; and the third between 25 and 28 days (third nest attempt for the same female); though bigger intervals can happen over 150 days. This analysis is very similar to what we observed in Vamizi, though we also find that the second emergence can happen in a longer period.

The standard deviation of the mean inter-nesting period of Vamizi is also bigger compared with values obtained by Bourjea *et al*. (2007a) and West *et al*. (2013). The re-migration interval (2.6 ± 1.1 years) obtained for Vamizi is consistent with data from Bourjea *et al*. (2007a). This result emphasizes that the WIO population maintains an expected behavior regarding migration cycles between foraging and nesting grounds.

***Nesting females and clutch frequency*:** The estimated number of nesting females/year between 2008 and 2010 was low (52), which makes Vamizi a small rookery. Garnier *et al*. (2012) predicted that Vamizi received approximately 50 females per year during 2004 – 2007, which was similar to estimations for the following years; though 2009 had a smaller number of visitors. Associated with the reduction in specimen size, this number can be an indication of regular recruitment needed to maintain the number of reported nesting females. The observed clutch frequency averages (2008 – 2010) were higher than those reported by Garnier *et al*. (2012) for the previous period (2004 – 2007).

Clutch size, hatching and emergence successes: The observed average clutch size (116.7 ± 26.5 eggs) falls between standard published values that range between 110 and 130 eggs (Pritchard and Mortimer 1999). Observed values also fall in the range found for other beaches/locations on the WIO: 78 – 120 eggs.nest-1 (Waqas *et al*. 2011), 116 ± 24 eggs (Innocenzi *et al*. 2010), 134 ± 14 eggs (West *et al*. 2013).

Hatching and emergence successes in Vamizi are higher than in Mohéli (Innocenzi *et al*. 2010) and in Juani Island, at the Tanzanian coast (West *et al*. 2013). Environmental factors, such as temperature (Davenport 1997), rainfall (Matsuzawa *et al*. 2002), erosion (Mazaris *et al*. 2009), and sea level rise (Fuentes *et al*. 2011; Hawkes *et al*. 2009) may influence several nesting parameters like hatching and emergence successes. Yet, erosion and changes in sea level rise are linked with climate change and are enhanced by extreme weather events (Van Houtan and Bass 2007; Hawkes *et al*. 2009). Other intrinsic factors, such as sand type (Hays *et al*. 2001; Fuentes *et al*. 2010), predators (Brown and Macdonald 1995; Mendonça *et al*. 2010), and human pressures (Mazaris *et al*. 2009; Antworth *et al*. 2006) interfere with these nesting parameters.

The rainfall variability of 2004 – 2010 and its influence on sand heat conductivity may play a role in the incubation period differences, especially at Farol beach. Sand characteristics are known to influence the sand temperature, and consequently the duration of egg incubation (Hawkes *et al*. 2009). Vamizi beaches are composed of biogenic sand, which is formed by in situ accumulation of short-distance transportation hermatypic coral reef and other marine organism debris (-0.15 – 0.35 – mm). Compared with to quartz sands, coral sands show different mechanical properties: high grain density, high porosity (ranging from 0.54 to 2.97, which is much higher than quartz sand porosity), high fragmentation and low psephisity (Chengjie *et al*. 2013). Lin *et al*. (2008) show that the water content of soil is one important factor that affects its thermal resistance. Therefore in Vamizi the precipitation may be influencing changes in incubation conditions and affecting its duration, which may explain the statistical differences found between rainy and dry years (like 2005). However, these sands are able to maintain incubation properties that result in high hatching and emergence rates. These variations may be normal, since they are linked to the seasonality created by the monsoons.

Incubation period: In the last years of the study, Farol showed a decreasing tendency of its incubation period and the peak of the number of nests moved from April (2003 – 2007) to May (2008 – 2010). Incubation period is dependent on temperature (see Hawkes *et al*. 2009 and Davenport 1997), and the sex of hatchling is determined by the incubation temperature (Davenport 1997). The pivotal temperature of 29.2°C (Broderick *et al*. 2000; Godfrey and Mrosovsky 2006) will determine the sex, with males being produced below that temperature and females being produced above. A pivotal incubation period has also been estimated to be 56 days (Broderick *et al*. 2000). The observed values for the incubation period are above this pivotal period, indicating that the sex ratio could be male-biased. Models by Fuentes *et al*. (2010) predict that "climate change will increase sand temperature at the nesting grounds", which will result in the feminization of hatchlings by 2030. However, the MZC is very different regarding climatic responses. In their study of the link between the precipitation field and ocean dynamics, Saji *et al*. (1999) report that the air-sea interaction process is different in the WIO, for example, it is independent of the El Niño/Southern Oscillation (ENSO). This means that other climatic-sea water features are possibly affecting the behavioral patterns seen in this study from Vamizi green turtles. Most likely the stability of the NE/SE monsoons is an important factor in green turtle nesting behavior in the northern area of the MZC.

Flooded nests – Sea-level rise and its influence in nesting season at Vamizi: Rising sea-levels may also be influencing Vamizi beaches rookeries. Garnier *et al*. (2012) suggest that nest loss through inundation that occurred in Vamizi in 2007, emphasizes that the phenomena might "be indicative of a regional or global event". The Maziwi Island in Tanga (Tanzania), known for having been "the most important single turtle nesting ground in east Africa", was entirely submerged in 1978 (Mahongo 2009). While clearing the vegetation on the island accelerated the process, other factors such as, erosion from storms, or sea level rise may have also played a part (Mahongo 2009). Through local observations it is clear that Vamizi is suffering from erosion, which means there is an urgent need to monitor sea level trends at the site. This kind of information is lacking not only in Mozambique, but also in the WIO (Mahongo 2009). To mitigate future problems related to global rise in sea-level, it is important to understand the phenomena locally, for example, what will be the extent of nesting grounds being affected in the next 10 years in the rookeries of the north MZC. The observed tendency over 60 years of data collection and data analysis from Indian Ocean showed an average sea level trend rise of 3.4 ± 0.7 mm per year (1953 – 2009; Palanisamy *et al*. 2014). The beaches of Farol and Comissete may provide an important study ground to monitor water/air parameters, and the effects that changes in these may have on female's behavior/choices because they are small but efficient nesting grounds at the present. They seem to be also an important point of dispersal of turtles to the north of the coast, and to the south, entering deeper in the MZC. From 2009 to 2011, Bourjea *et al*. (2013) tracked nesting green turtle females to the nesting peak in the rookeries of Europa, Glorieuses, Tromelin, Mayotte, and Mohéli, using 81 satellite transmitters. Their results revealed the migratory pathways of these females in the WIO, showing that 39.7% of them used Madagascar as a costal foraging ground, and others used Mozambique, Kenya, Tanzania and Somalia coasts. They emphasize that the extreme north of Madagascar functions as an important coastal migratory corridor (Bourjea *et al*. 2013). Garnier *et al*. (2012), using satellite transmitters, showed the migration routes of four green turtle females

tagged in Vamizi, in the direction of foraging grounds situated in Tanzania, Kenya and northwest Madagascar (Nosy Makamby).

Genetic diversity

Haplotype diversity at Vamizi is considered high and similar to that already described for this region (Formia *et al*. 2006; Bourjea *et al*. 2007b). With the use of a 1000 bp fragment of the mitochondrial DNA control region it was possible to identify 11 haplotypes, seven of them new.

Haplotypes IND1 and IND3 are present in Vamizi and were also reported on the Comoros by Formia *et al*. (2006). The Comoros are very near Vamizi, and they play an important role in the currents at the north of the MZC (Ternon *et al*. 2014), where an intermittent gyre is generated around them (Obura *et al*. 2012). It forces water, at intermediate depths, to circulate eastward rather than entering directly into the northern part of the Channel (Ternon *et al*. 2014), perhaps enabling, female turtles to visit nesting beaches around.

The haplotype CMJ1 occurs in the Western Pacific, in a foraging site for green turtles (Hamabata *et al*. 2009). Though its frequency was very low in our study, CMJ1 nevertheless shows a connection between the Eastern Indian (EIO) and Western Pacific Oceans. Formia *et al*. (2006) aligned IND haplotypes with haplotypes from the western Pacific and concluded that they show high similarity, corroborating the link between WIO and the western Pacific.

The CM8 haplotype, detected in high frequency at Vamizi, occurs mainly in the Atlantic (Formia *et al*. 2006). The CM8 haplotype was also identified in southwest Indian Ocean rookeries (Europe, Juan de Nova) and at lower frequencies in Mayotte and Mohéli (Bourjea *et al*. 2007b). Bourjea *et al*. (2007b) found that the CM8 frequency decreases from the south of the MZC towards the north of the MZC rookeries (Bourjea *et al*. 2007b). These authors also suggest that the existence of the CM8 haplotype may be indicative of an active dispersal of green turtles from the Atlantic into the Indian Ocean waters, by the Cape of Good Hope an possibility also raised by Shamblin *et al*. (2014) for loggerhead turtles.

Luschi *et al*. (2006) tracked the journey of post nesting leatherbacks by satellite between 1996 and 2003, from their nesting site at the Maputaland coast of KwaZulu-Natal of southeastern Africa, and showed that two females entered the southeast Atlantic Ocean, which demonstrated that turtles can migrate between MZC and Atlantic Ocean waters.

Despite its high turbulence waters, the MZC doesn't seem to function has a natural barrier because artificial drifters were moved (by currents) northwards, inside the Channel, against the southward migration eddy field (see Hancke *et al*. 2014). This probably explains the presence of CM8 in Vamizi and adjacent islands, being brought by females that migrate northwards. However information is still lacking on Indian Ocean phylogenies and so further research is needed. Obura *et al*. (2012) states that, "genetic differences could result from oceanographic features that affect the movements of juveniles", but how? Part of the juveniles may be dragged by mesoscale eddies towards the south of MZC, and others may be dragged by the EACC, to the north of the WIO (to the foraging areas at Tanzania, Kenya, etc.). The behavior of philopatry may bring some of those juveniles later, as nesting females, to rookeries like Vamizi, which would explain its high haplotype diversity and the existence of haplotypes from the south and from the north of the WIO. It is important to understand the differences between the Vamizi population and populations found by other investigators in the area. For example, does it represent a different genetic sub-population from the females nesting in Europe Island, Mayotte, Comoros, Nosy Iranja, Glorieuses and Aldabra

described by Bourjea *et al*. (2007b)? The observed migratory pathways, both coastal and pelagic, that encompasses the East African coast through Tanzania and Kenya and the Northwest of Madagascar (Garnier *et al*. 2012; Bourjea *et al*. 2013) seem to corroborate this possibility.

Conservation

Our study in Vamizi showed that, despite receiving nesting females in two periods of the year during 2003 – 2010, the distribution of nesting activity has decreased since 2005 at Comissete beach with a proportional increase in Farol beach. This may reveal an adaptation of female behavior towards anthropogenic factors. In Comissete, associated to the opening of a lodge in 2005, beach sand was mixed and cleaned and human presence and activity increased. Turtles are sensitive to human presence on their nesting beaches (Antworth *et al*. 2006) and are known to move to nearby areas, lacking human presence (Weishampel *et al*. 2003). Based on the observed nests, the implementation of the touristic project, including the construction of infrastructures in Farol can change the importance of each nesting beach. Though paleontological records show their resilience and capacity for adaptation to geologic/climatic changes (Fuentes *et al*. 2010), it has not been predicted the effect of human pressures combined with climatic fluctuations on their survival. However, it has been discovered that green turtles are capable of breaking their natal philopatry and choosing alternative nesting grounds (Fuentes *et al*. 2010).

It has been shown that a nesting beach can be abandoned within 40 years (one turtle generation; Fuentes *et al*. 2010), thus changing the spatial distribution of nesting and foraging grounds. It would be important to decipher which pressures are more likely to induce changes in green turtle behaviors in the northern MZC, which will lead to changes in migration routes, and breeding sites.

Vamizi Island is included in the Mtwara-Quirimbas Complex, a priority site for conservation identified in WWF Eastern African Marine Ecoregion (Rosendo *et al*. 2011). As defended by the report “Assessing Marine World Heritage from an Ecosystem Perspective: The Western Indian Ocean” the proposed site with Outstanding Universal Value (OUV) of “Northern Mozambique to southern Tanzania – Nacala – Quirimbas – Mtwara” must be sufficiently assessed to meet the strict criteria to be designated as World Heritage (Obura *et al*. 2012). Also, the World Bank has been supporting projects like the “Coastal and Marine Biodiversity Management Project”, which aim to protec areas in northern Mozambique, by supporting studies to establish a marine protected area (MPA), the Rovuma National Reserve, that awaits government approval (Rosendo *et al*. 2011). Should it be approved, Vamizi will be included in a privileged location where the marine turtle program initiated in 2002. The continuity of the monitoring and conservation program will help to accomplish the goal to qualify it as an OUV area.

Conclusions

Vamizi beaches host approximately 52 nesting females per year, which have been showing a reduction in their length over time. This may be a sign that cohorts of younger turtles are being removed from the population, during the inter-nesting period and/or between the migrations from the foraging to the nesting grounds. This observation is coherent with the need raised by several authors for international cooperation for the protection of marine turtles in the WIO.

This study contributes information on the genetic diversity of a sample of nesting turtles in Vamizi; information that was previously lacking in the literature. The characterization of the diversity based on longer (850 bp) control region sequences enabled a better separation of the haplotypes that

may not have been identified in previous analysis. This information may help to provide a redefinition of regional units of conservation. The genetic diversity and high rates of hatching and emergence success demonstrate that Vamizi Island is an important site for producing and dispersing diverse hatchlings.
This Island is situated in an area with high marine biodiversity and with proven success in incubating turtle eggs. It is possible that the characteristics of the biogenic sand can explain the high rates of hatching and emergence success obtained and is consequently critical for conservation. The sand characteristics may help to minimize ambient changes (e.g. temperature), which are known to affect nesting and incubation parameters.

The main concerns regarding the Vamizi Island rookery are reduction of incubation period values, dislocation of peak nesting activity, increase in the number of flooded nests in the later years of this study and human pressure. Future research is needed to understand the factors that are leading to these changes.
The possibility that turtles react to human activity must be considered in infrastructure planning, especially for touristic purposes, near beaches with importance as nesting grounds, like Comissete and Farol. Some resilience and behavioral plasticity in sea turtles seems to occur regarding human territory occupancy and climate changes.

Ethics
The data was collected according published methodologies (see Eckert *et al*. 1999) and by qualified personnel and in authorized areas.

Additional file
Additional file 1: Table S1. Nucleotide sequences and the 74 polymorphic sites identified on the green turtle.

Competing interests
The authors declare that they have no competing interests.

Authors' contributions
Study design: JG; Study coordination: JF, JG; Field work and data collection: CL, JG; Data analysis: RA, MJP; Genetic analysis: RA, CS, HM, LS, MJP; Wrote the paper: RA, MJP. All authors read and approved the final manuscript.

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Statement

Only the authors have been involved in data analysis and on the decision to prepare and publish this manuscript.

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Eretmochelys imbricata: Lessons to Learn from a Monitoring Program in the North of Mozambique

Abstract

Monitoring programs for nesting turtles around the world have been important to build up a matrix of information for better comprehension of their behaviour and dispersion. The Western Indian Ocean has several monitoring programs that are being used to reveal migration routes, phylogenetic interconnections and nesting behaviour patterns. We determined the nesting parameters for 69 records of hawksbill turtles collected during the Vamizi Island monitoring program. We also determined carapace measurements parameters of the turtles caught by fishermen in the area and give some considerations to improve the conservation of this species. Results show that the island receives hawksbill females all year long. Vamizi is a small nesting ground for this species, with an incubation period of 60.9 ± 10.6 days and a high reproductive rate. The turtles' carapace measurements (SCL 42.0 ± SD 9.0 cm) revealed the existence of young individuals, foraging near the island, and their vulnerability to the fishing practices. This study strongly defends the need to identify more developmental and nesting spots, to be protected near Vamizi, to establish a solid network of marine reserves and corridors in the north of the Mozambique Channel.

Keywords

Eretmochelys imbricata, Nesting Parameters, Mozambique Channel (MZC), Network of Marine Reserves

Introduction

Marine turtles have been of concern of several biologists and conservationists. There are some regions in the world where marine turtles survival continues to be challenged by threats that may lead to their extinction (Broderick *et al.*, 2006) . The hawksbill turtle, *Eretmochelys imbricata*, is listed as critically endangered by the International Union for Conservation of Nature (IUCN) since 1996. In the latest IUCN assessment in 2008, threats like "over-exploitation of adult females and eggs at nesting beaches, degradation of nesting habitats, take of juveniles and adults in foraging areas, incidental mortality relating to marine fisheries, and degradation of marine habitats" are pointed out as the prime causes of "the extensive subpopulation declines in all major ocean basins over the last three hawksbill generations" (Mortimer and Donnelly, 2008).

Considered as spongivorous turtles, the hawksbill are viewed as healthy habitat keepers, especially in coral reef ecosystems (Hawkes *et al.*, 2009) . However in the Indo-Pacific Oceans (review by Bjorndal, 1997) they tend to have an omnivorous diet regime (Mortimer and Donnelly, 2008), having the roles of habitat health keepers and of top consumers. Hawksbill females nest in sandy beaches under vegetation during the night, but sometimes during the day (Mortimer and Donnelly, 2008). This nesting behaviour can be conditioned by anthropogenic disturbances, like human presence, beach-front development and clearing of dune vegetation (Mortimer and Donnelly, 2008). Like other marine turtles, this species shows a seasonal pattern for nesting

activity. In certain locations like Tanzania, their nesting activity is more regular and shows a nesting peak (West, 2010). In other Western Indian Ocean (WIO) locations hawksbill nesting appearances are sporadic and irregular (Lauret-Stepler *et al.*, 2010), possibly as a response to abiotic factors variations. Long term data are scarce for several African eastern countries (Garnier *et al.*, 2012; Obura *et al.*, 2012), and this is the reason why Vamizi's marine turtles monitoring program is important. The Vamizi program generated two papers for green turtles (Garnier *et al.*, 2012; Anastácio *et al.*, 2014) providing information for this part of the Mozambique coast. Other studies conducted in the island bring some insight on the fishery pressures (da Silva *et al.*, 2015) affecting marine turtles. Obura *et al.*, (2012) emphasizes the increase of the fishing pressures in the WIO, due to the amplification of the local populations. Also, the extraction of oil and gas in Kenya, Tanzania, Mozambique, Madagascar and Seychelles (some from very recent discoveries) is increasing (Obura *et al.*, 2012). This will probably lead to a migration of people to these areas in search of better conditions of life, and to an increase in pressures on natural resources and ecosystems. Migrant fishermen are already pointed by Mozambican fishermen as the main cause of resources degradation (Rosendo *et al.*, 2011).

The main objective of this study is to reveal aspects of the monitoring program of the Vamizi Island concerning the hawksbill turtles, *i.e.* the nesting parameters on monitored beaches. It is intended to understand which threats and pressures are felt in the region, and what needs to be accomplished to improve the conservation of this species locally and in other WIO locations. This way, we intend to contribute with more information about hawksbill nesting turtles in the north of Mozambique, an effort requested by several publications for parts of the world from where data is scarce (Wallace *et al.*, 2010, 2011; Hamann *et al.*, 2010; Bagda *et al.*, 2012; Rees *et al.*, 2016). This information can be helpful in providing justified insight to extend the Vamizi's protected area boundaries, or in answering questions seen as global research priorities for marine turtles (Rees *et al.*, 2016) or, even, in determining a conservation unit for this part of the Indian Ocean.

Methods

Study Area

The Vamizi Island is one of the many islands of the East African Coast. It is located in the north of Mozambique (Anastácio *et al.*, 2014) (latitude between 11˚00'S - 11˚10'S; longitude between 40˚30'E - 40˚50'E), belonging to the Quirimbas Archipelago (Figure 1) and to the 95th WIO Ecoregion, following the 2007 Marine Ecoregions of the World (MEOW) classification scheme (Obura *et al.*, 2012). Vamizi Island (Figure 2) has approximately 48 km^2 (da Silva *et al.*, 2015) and its beaches are composed of biogenic sand and some, especially in Comissete and Farol beaches, are used as rookeries by green (Garnier *et al.*, 2012; Anastácio *et al.*, 2014) and hawksbill turtles (Garnier *et al.*, 2012). The west and south sides of the island are occupied by local poor people that live mainly from fishing practices. But this area is also explored by foreign fishermen, especially from Tanzania, who catch marine turtles for meat consumption (Obura *et al.*, 2012). This habitat is known to support populations of nesting and maturing hawksbill turtles, as emphasized by Garnier *et al.*, (2012).

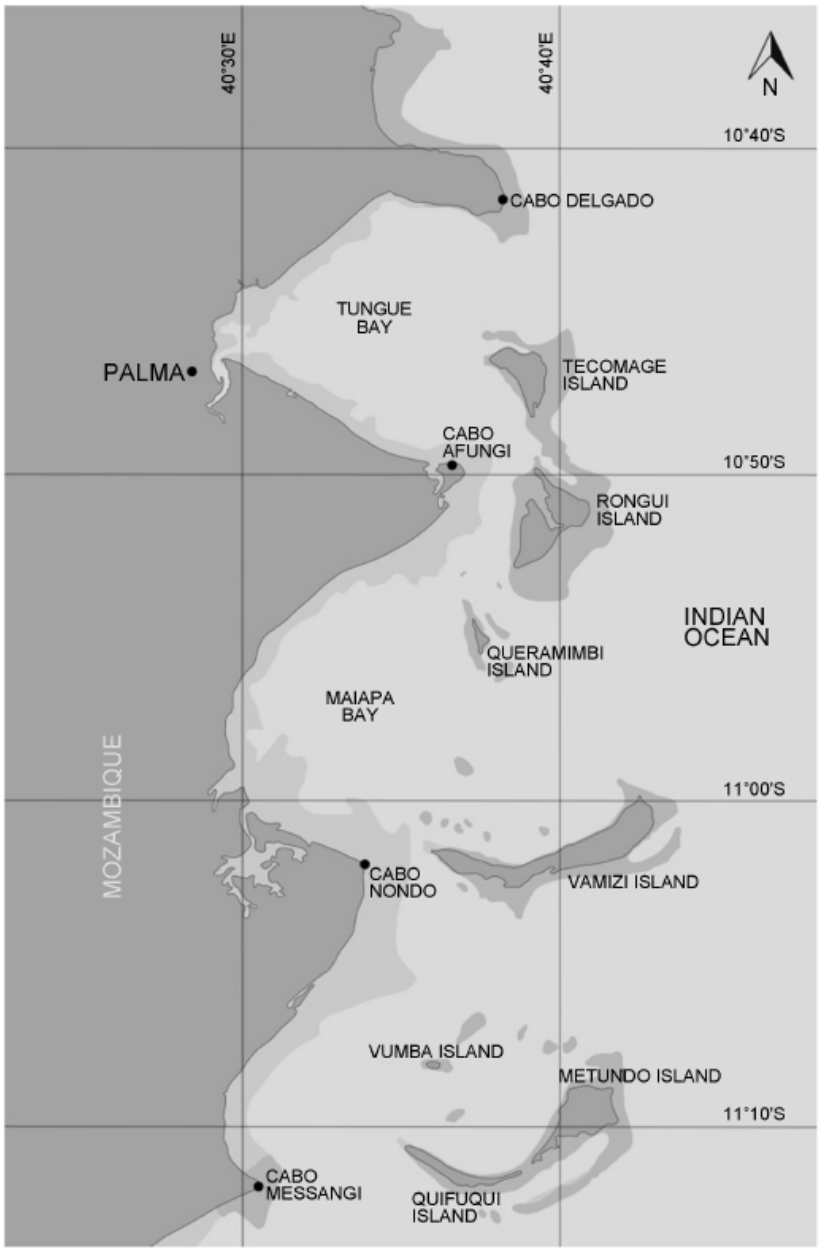

Figure 1. Map of the studied area.

Air temperature amplitude in Vamizi is low but precipitation varies considerably (Anastácio *et al.*, 2014). Between 2004 and 2010 precipitation averages were below 50 mm and 2005 was a particularly dry year (Anastácio *et al.*, 2014). This climate pattern is due to the MZC features since it is a very energetic zone; in the north of the channel, the Comoros gyre and the eddies sustain fertile food webs, with endemic species probably due to the efficient east-west exchange of water contents, enhanced by the many islands inside the channel (Obura *et al.*, 2012) . Also, MZC water speed and variability is strongly modulated by the monsoons seasonality, but also by the Indian Dipole which interferes with the sea surface temperatures, hence with the rainfall (Obura *et al.*, 2012).

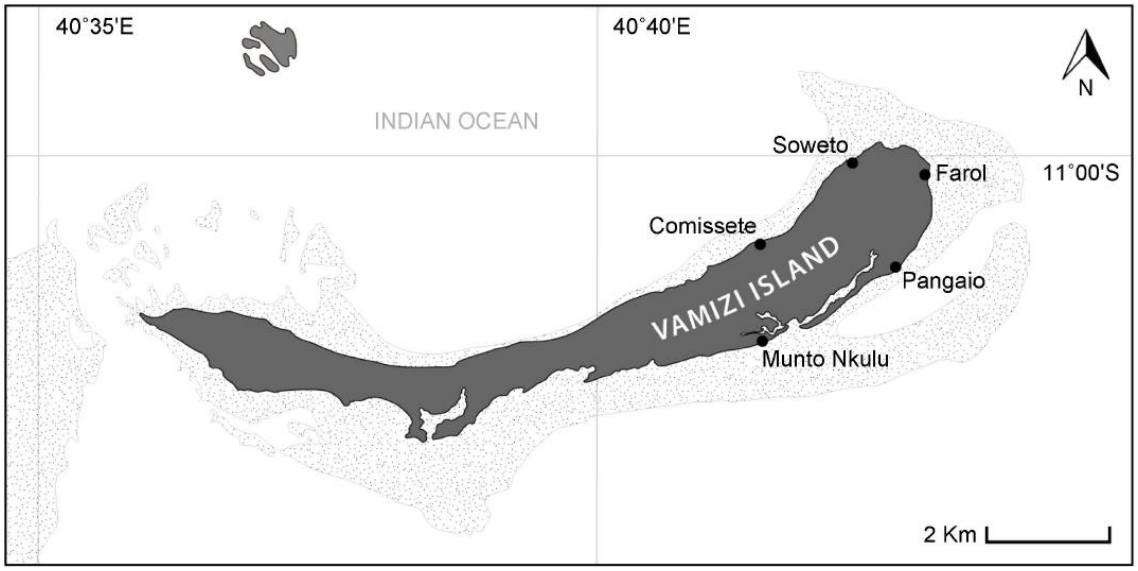

Figure 2. Vamizi Island in detail and location of the monitored beaches.

Monitoring Program and Data Collection

The monitoring program started in September 2002 with foot patrols, conducted daily by a team of prepared monitors (at least three people), who gathered information on paper forms (Anastácio *et al.*, 2014; Eckert *et al.*, 1999). Comissette and Farol beaches were more intensively monitored in day patrols from October 2003 on. Night patrols were conducted every night during the nesting activity peak, from 2004 to 2010 (Table 1).

Table 1. Field effort period (grey areas), per year, of the night-time patrols.

	Month											
Year	1	2	3	4	5	6	7	8	9	10	11	12
2004												
2005												
2006												
2007												
2008												
2009												
2010												

The day patrol monitors had the responsibility for, every morning check turtle activity above the high tide line, such as tracks and nesting marks (differentiating between nesting and non-nesting emergences). Hawksbill turtle's identification (ID) was made following Pritchard and Mortimer description in Eckert *et al.*, (1999); but the thick overlapping (imbricate) scutes of the carapace and the straight bird-like beak of the head are two characteristics of this species.

New nests were identified and marked (with bamboo poles behind the nest) and their global positioning system coordinates (GPS) were taken. In addition to the information of the nesting date, the information of the hatching activity was taken to evaluate hatching success (*e.g.* hatching date, excavation date, number of hatched individuals at the nest and/or undeveloped, not before 90 days after eggs laid, among other parameters). Following Schroeder and Murphy (1999) a crawl was

interpreted as “tracks and other sign left on a beach by a sea turtle”; and a “False Crawl” was interpreted as “a crawl resulting from an abandoned nesting attempt (a non-nesting emergence)”. The teams identified marine turtle species using tracks, or, when captured, using morphometry of the individuals (nesting females at the beaches and other individuals brought by fishermen).

The identification of the turtles (Pritchard and Mortimer, 1999) and their biometric information was given by their minimum curved carapace length, or CCL, and curved carapace width, CCW, lengths following Bolten’s (1999) methodology, and by the size and shape of the tracks (Schroeder and Murphy, 1999; Pritchard and Mortimer, 1999). Each measure was taken three times and recorded. The CCL measures were converted to straight carapace lengths (SCL) following the equation in Teas (1993). Local fishermen were given incentive to bring turtles accidentally captured on fishing techniques. These turtles were also measured for CCL and CCW lengths.

Tagging procedures were made according to Balazs (1999). Titanium tags (www.stockbrands.com.au/titanium.html) (Stockbrands Pty Ltd., Perth, Australia, www.stockbrands.com.au) were used and applied in both proximal front flippers. The first external tags were applied on 18th March 2004 (MZC 0004/ MZC 0005; turtle ID VZ001). The examination for tags in the nesting females occurred during night patrols, but this was also made with the turtles brought by the fishermen. The presence of tags (tag series from MZC 0000 to MZC 0999) was recorded, and missing tags were replaced. For all observed/captured turtles, date, site, tag number and activity was recorded. The individual’s location coordinates were taken with a GPS device, Magellan NAV5000D, used in 2D non-differential mode.

Data Analysis

For the determination of nesting parameters we used samples from Comissete, Farol, Pangaio, Munto Nkulu and Soweto beaches (Figure 2). Nesting parameters averages were obtained using records of all beaches combined and per beach. The nesting success was estimated “as the proportion of nesting activities that resulted in a nest” (Godley *et al.*, 2001). The clutch size, hatching and emergence successes were determined following the methodology described by Miller (1999) using the records of all beaches. The number of eggs laid per year, the average of nests per year, and the average of nests per month were also determined. The hatching success was defined as “the proportion of hatchlings that hatched out of their shells respectively” (Miller, 1999). Emergence success was defined “as the proportion of hatchlings that reached the beach surface” (Miller, 1999). The formulas used to determine the clutch size, hatching and emergence successes were the ones described by Miller (1999).

The incubation period was obtained using all records from all the sampled beaches, and according to the date when the nest was laid.

Our sample included N = 69 records collected in beaches (concerning nesting activity), and N = 103 records of marine turtles captured by fishermen. These records concern data collected between 2002 and 2010. All the statistical analysis was performed on PASW Statistics 18 and on Microsoft Office Excel 2007 software. The significance was estimated at the 95% confidence level. Variables like incubation period, clutch size, hatching and emergence successes were compared for the two main beaches using a t-test (samples with $N < 50$), for which we tested variance homogeneity using the Levene’s Test ($P < 0.05$).

Turtles Bycatch

A total of 103 hawksbill turtles were captured by hand or caught accidently in nets or by other fishing techniques. The captures were reported between May of 2004 and February of 2009. Of those turtles, 79.6% were captured by nets in several places from Mocimboa da Praia to Palma, near Vamizi Island beaches, or in other places located at north ("Baixo" Mepanga-Panga), or at south (Vumba, Metundo, Quissanga) of the island (Figure 1).

Turtles Carapace Measurements and Tagging

The total number of tagged hawksbill turtles was N = 111, being the majority of the measured the ones that were captured, *i.e.* 103 turtles, all of them tagged. The analysis of the records shows that 79.6% of the turtles were captured in nets, 46 of them identified as "jarifas".

The CCL average of the hawksbill turtles measured (2004-2009) was 44.2 ± 9.4 cm (N = 111) ranging from 30 to 88 cm (Figure 3), and the CCW average was 39.6 ± 8.1 cm (N = 111) ranging from 27 to 78 cm.

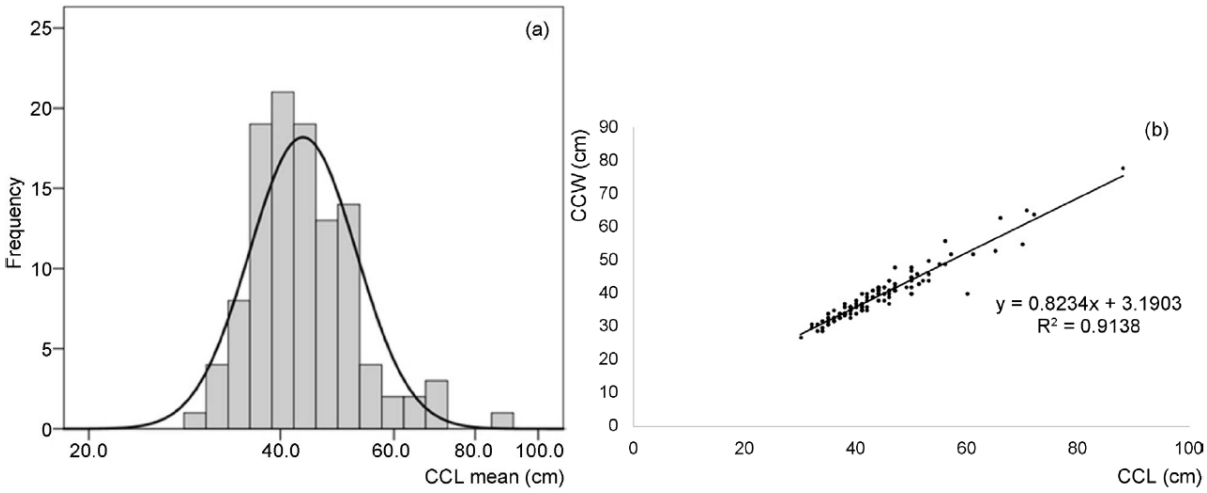

Figure 3. (a) Distribution (logarithmic scale) of the CCL sample (N = 111). (b) Correlation graph between CCL and CCW measurements for the hawksbill turtles of the Vamizi project; the equation y = 0.8234x + 3.1903 shows the correlation between CCL and CCW lengths of the measured turtles. The R^2 value (0.9138) shows a strong correlation between the two variables, as expected.

The turtles captured and measured in 2004, 2007 and 2008 were smaller than the turtles measured in 2005 and 2009. However, 2009 shows a great dispersion of the CCL values, indicating the existence of small turtles in that year. The SCL estimated for our sample is 42.0 ± 9.0 cm. The SCL estimated for the sample of turtles brought by fishermen is smaller, 41.7 ± 8.5 cm.

Reproductive Biology, Nesting Parameters

The number of records for hawksbill nesting turtles, taken on Vamizi beaches, is shown in percentage in Figure 4 (N = 69).

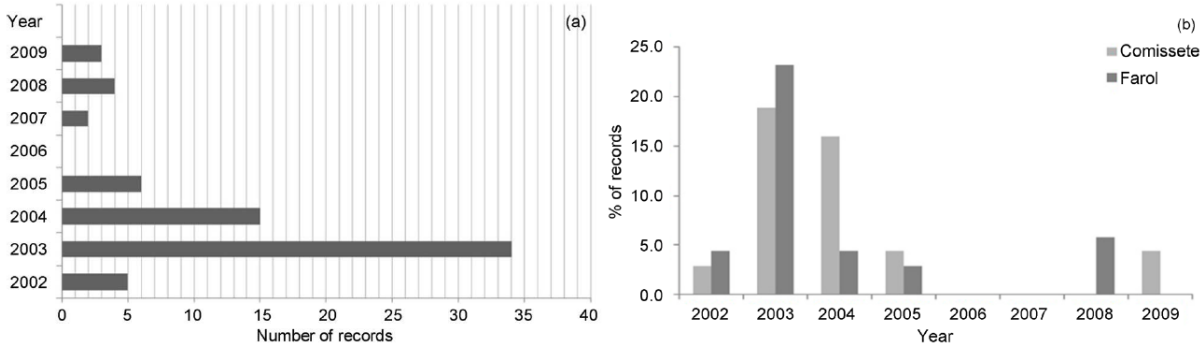

Figure 4. (a) Total number of emergences in Vamizi beaches/year. (b) Comparison of number of records of nesting females in Comissete and Farol beaches per year.

The majority of the nesting activity was recorded in 2003 (34 emergences) and 2004 (15 emergences). There is no data on hawksbill turtles for 2006 and 2010, though there is data in the same conservation program for green turtles. This indicates low numbers of individuals for the hawksbill population for some years and, especially, from 2005 forward.

Recorded nesting activity (N = 69) was, per beach, in percentage, the following: Comissete (46.4), Farol (40.6), Munto Nkulo (8.7), Pangaio (4.3).

The overall nesting success was 73.9%; in average, 4 nests·month−1 (all sampled beaches combined) were laid, being the highest nesting activity observed in December and January. Comissete beach showed the highest value of nests/month in December-January and Farol beach in July-August.

The average clutch size (all beaches combined, for 2002-2005, 2008, 2009 years), was 128.0 ± 30.0 eggs (N = 28). The Comissete beach has an average clutch size of 133.6 ± 31.9 eggs (N = 16), and Farol beach has an average clutch size of 124.1 ± 25.1 eggs (N = 11).

The overall mean hatching success was 86.5% ± 18.9% (N = 28). For Comissete beach the hatching success was 89.2 ± 11.4 (N = 16), whereas for Farol beach was 81.4 ± 26.9, (N = 11).

The overall mean emergence success was 81.6% ± 23.5% (N = 28) (for Comissete: 83.7 ± 18.4, N = 16; for Farol: 77.0 ± 30.5, N = 11).

The incubation period (i.p.), considering all observed beaches was 60.9 ± 10.6 days (N = 35) (2002-2005, 2008, 2009). The overall averages of i.p. in Vamizi beaches are as follows: North facing beachs – Comissete 56.9 ± 4.5 days (N = 16); South facing beaches – Farol beach, 62.7 ± 7.6 days (N = 15); Munto Nkulo beach, 70.3 ± 25.9 days (N = 4). Table 2 summarizes carapace measurements and nesting parameters averages for Vamizi hawksbill turtles.

The t-tests performed to compare means of clutch size, hatching success, emergence success and i.p. between Comissete and Farol, indicated that there are no significant differences between these two beaches for clutch size ($t = 0.83 < 1.96$, for 25 degrees of freedom, i.e. d.f.; variances homogeneity assumed with $P = 0.66 > 0.05$), and hatching success ($t = 1.04 < 1.96$, for 25 d.f.; variances homogeneity assumed with $P = 0.22 > 0.05$). For the emergence successes of Comissete and Farol samples there is no variance homogeneity ($P = 0.04 < 0.05$; $t = 0.65 < 1.96$, for 15 d.f.). And, there is a significant difference for the i.p. on these two beaches (the Levene's Test indicates homogeneous variances, $P = 0.164 > 0.05$, for 29 d.f.; and $t = 2.624$, 29 d.f., >1.96 showing significant difference between i.p. from Comissete when compared with the i.p. from Farol).

Table 2. Summary of carapace measurements and nesting parameters results.

	Average	Range	N
Carapace Measurements			
CCL	44.2 ± 9.4 cm	30 - 88 cm	111
CCW	39.6 ± 8.1 cm	27 - 78 cm	111
SCL	42.0 ± 9.0 cm		111
SCL bycatch turtles	41.7 ± 8.5 cm		103
Nesting Parameters			
Peak of nesting season	December-January		
Frequency of nests	4 nests/month		
Clutch size	128.0 ± 30.0 eggs	98 - 158 eggs	28
Hatching Success	86.5% ± 18.9%		28
Emergence Success	81.6% ± 23.5%		28
Incubation Period	60.9 ± 10.6 days	50 - 72 days	35

Discussion

Turtles Bycatch

Hawksbill turtles are being captured by fishing gear, especially by nets in the Vamizi area. Being omnivorous it is likely that these turtles are attracted by small prays functioning as turtle baits. Hence, the nets function as hawksbill traps. This is a problem already indicated by Bourjea *et al.*, (2008) for the WIO.

There is a need to clear the area of possible abandoned fishing gear, as an important conservation strategy. This could be done by local fishermen, with some monetary incentive.

Rosendo *et al.*, (2011), in a field-based research in the north of Mozambique (at Quirinde, Palma, Mocimboa da Praia and Ulo), analyzed local fishermen opinions about marine resources, who said that a "growing number of migrant fishers" from Nampula Province (Mozambique) and Tanzania, "that use harmful fishing gear", like nets with very small-sized meshes ("cavogo" and "jarifa"), explosives, poisons and scuba equipment, and "the lack of law enforcement" were the main causes for the difficulties lived by locals. Rosendo *et al.*, (2011) found that these migrant fishermen tend to explore marine resources in the north of Mozambique more intensively than the local fishermen. Our results show that 46 of the captures were due to "jarifas", a 6-inch mesh net identified in Tanzania as a "major threat to sea turtles" (Bourjea *et al.*, 2008), hence corroborating Rosendo's findings.

Turtles Carapace Measurements

An aspect revealed by this study is the small dimensions of the turtles measured. Twenty-six juveniles sampled in Ascension Island (Putman *et al.*, 2014) had an average of 47 cm CCL (range: 35 - 60 cm). This means that the measured average of the Vamizi's hawksbill turtles were most certainly juveniles. The estimated SCL average of the hawksbill turtles tagged in Vamizi shows that

they had, possibly, between 4 to 6 years, following growth curves (Snover *et al.*, 2013). It appears that the near-shore benthic habitats between the Tungue Bay and Metundo Island (Figure 1) are used as developmental habitats by the juvenile Mozambican hawksbill turtles. But, could this mean that the hawksbill turtles in the WIO are smaller than other locations? Or that they mature more rapidly? We cannot answer yet these questions, since there is the need to collect more data, but they certainly need to be answered.

Reproductive Biology

Although there are records from all year long on the Vamizi program, the nesting peak occurs between December and January, which is similar to results from a study in Mafia Island, Tanzania (West, 2010). The nesting season occurs between September and April, which is consistent with data from the Republic of Seychelles (Phillips *et al.*, 2014), with an exception to Farol beach, where July and August are also included in the nesting season.

The average value for the Vamizi clutch size is smaller (128.0 ± 30.0 eggs, ranging between 98 - 158 eggs) when compared with the clutch size (110 – 180 eggs/nest) settled for this species (Eckert *et al.*, 1999). In a Seychelles study a mean clutch size of 178.7 eggs was determined for 6 hawksbill nesting females (McCann, 2010). At Mafia Island the clutch size is also higher (143 ± 24 eggs) when compared with Vamizi's results. The results reflect smaller clutches indicating, possibly, smaller or younger females (see Antworth *et al.*, 2006). However, we are inclined to think that nesting hawksbill females were young breeders, with capacity to carry fewer eggs. And this raises other questions: where are the mature turtles? Are they being captured before they have the chance to reach the nesting beaches? Are these results indicating that hawksbill turtles are in decline in Mozambican waters? Are bigger turtles in their migration routes? Despite the small clutches, the overall hatching success rate (86.5% ± 18.9%) is higher than the 73% ± 25% estimated for hawksbill turtles of Mafia Island (West, 2010). This may be due to the sand quality parameters since identical results were obtained for the green marine turtles in the same conservation program (see Anastácio *et al.*, 2014), meaning that Vamizi is one of the places on Earth with the highest estimate for reproductive rates (Lindborg *et al.*, 2016). This result sustains the importance of Vamizi's beaches to incubate hawksbill eggs, but also, the need to ensure a safe route towards the island.

The incubation period is smaller in Comissete than in the eastern or southern beaches of the island. In fact, there is a statistical significant difference between the incubation period of Comissete compared with the incubation period of Farol. This was already expected, since the same pattern was found for green turtle clutches during the same period of time (Anastácio *et al.*, 2014), and indicates a similar pattern for the incubation of eggs of these two species, affected in the same way by the abiotic factors of these two beaches. North facing beaches like Comissete are exposed to higher solar radiation that will heat more the surface of the sand (Fuentes *et al.*, 2010). This will certainly provide warmer incubating environments than in beaches with other orientations, like Farol or Muntu Nkulo. Other aspect shown by Comissete is that since its incubation period is smaller in average, because its sands are warmer, it is most likely that each Comissete nest produces more females, than males (Godfrey *et al.*, 1999). But this is only speculation, since there is no information on nest's shade percentage, or a strategy taken to determine nest temperatures (for example, by placing temperature data loggers inside a sample of nests).

Conservation

The Vamizi Island, though confirmed as a nesting spot for green and hawksbill turtles in the region, is so small that one may consider it to be inefficient in preserving marine turtles. However, even small nesting beaches may be important to recover sea turtles populations. For example, during the project, 57 samples of DNA tissue from hawksbills were collected and analysed. The genetic analysis (mitochondrial DNA control region sequencing of >845 bp) showed 14 haplotypes for the Vamizi's turtles, 12 of which identified (2011) as new haplotypes (isolates 49, 60, 65, 73, 95, 97, 101, 102, 104, 113, 114 and 128 GenBank, JF926554.1, JF926544.1, JF926553.1, JF926547.1, JF926546.1, JF926545.1, JF926548.1, JF926549.1, JF926550.1, JF926555.1, JF926551.1 and JF926552.1 respectively) (Santos *et al.*, 2011). This indicates that Vamizi has high haplotype diversity. Is this an expanding population? Is this a new management unit (MU) or can it be included in a Regional Management Unit (the Indian Southwest RMU, see Wallace *et al.*, 2010) that also considers Seychelles turtles, for example? To address these questions more research and a better protection of the habitats are needed.

The captures reported in this study reveal that the conservation area must be extended to other islands but, especially, to the habitats used by smaller turtles. Moreover, two major threats were identified on Vamizi Island and its proximity: bycatch of turtles in fishing activities (by local and migrant fishermen); and disturbance of the nesting habitats due to anthropogenic presence.

To mitigate the bycatch problem in a short-time period, it is proposed the strategies used by Wang *et al.*, (2010): shark shapes placed along the length of the gill nets, illumination of nets by LED lights, and nets illuminated with chemical light sticks. Perhaps the use of deterrents similar to those described by Wang *et al.*, (2010) may be tested by local fishermen (*e.g.*, Kivuri fishermen were proactive in this study). It would be important to give incentive to local populations, for simple but important measures like searching and clearing the area of abandoned fishing gear. More supervision of fishing activities by local authorities would be essential.

The disturbance of nesting habitats by people may be other important cause for the reduction of nesting females on Vamizi beaches, since hawksbills are particularly sensitive to the presence of people (Mortimer and Donnelly, 2008). Farol and Comissete beaches are two important nesting grounds for green turtles (with higher nesting activity when compared to hawksbill) and have been explored economically, though with conservation efforts and compromises. The results show a coincidence in the decline of nesting female emergence records in these two beaches for green (Anastácio *et al.*, 2014) and hawksbill turtles. This is a sign that the conservation measures applied are not being effective. The low number of emergences of hawksbill females at Vamizi beaches may be due, as well, to increased mortality of turtles as bycatch in the migrating routes, between other feeding grounds and Vamizi surroundings (this is speculative, since it is poorly documented).

The existence of a considerable number of small turtles in the area and the threats identified, plus the existence of nesting females, indicates that the habitats near Vamizi must be effectively protected urgently. In what regards this matter, the strategy of mapping a connection between patches of significant habitats (for feeding, development, nesting and, perhaps mating) used by the WIO hawksbill turtles is largely defended by our team. These patches, and corridors of connection between them, could help to define a network of marine reserves in the north of the MZC. The idea of a network of marine protected areas (MPAs) and corridors connecting them is defended by Gaines *et al.*, (2010), because it is not possible to have reserves large enough for highly migratory and long living species that explore different habitats over their life time. Also, these authors defend

the idea of redundancy (or, as they call it “replication”), *i.e.* “placement of multiple reserves in each habitat” (Gaines *et al.*, 2010). Though more research is needed, the area is already seen as a site with Outstanding Universal Value (OUV) (Obura *et al.*, 2012), hence it needs to be protected.
We believe it could be possible to ensure the preservation of this sub-adult foraging and nesting habitat, since the gas industry already established in the area (at Tungue Bay) is providing the conditions to sustain an informal marine reserve. It retains and mitigates the exploitation of marine resources by illegal fishermen in these areas. Efforts between stakeholders (from luxury tourism and gas industries), government, scientists and local populations are essential to achieve a sustainable development for these habitats, and a preservation of the corals, which are so important to hawksbill marine turtles.

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A Piece of a Puzzle of Haplotypes for the Indian Ocean Hawksbill Turtle

Abstract

The Indian Ocean basin has much to reveal in what concerns marine turtles. Its regional management units (RMUs) are still lacking molecular data to define conservation strategies and priorities. Vamizi Island is one of the best known rookeries in the north of the Mozambique Channel. A mitochondrial DNA analysis revealed 14 haplotypes for the hawksbill turtle's nesting and foraging in/near Vamizi, twelve of which were new in 2011. Though more studies inside the Channel are needed, Vamizi Island possibly contributes with hatchlings for other locations. More knowledge is important to define priorities for management units inside the Indian Ocean.

Keywords

Eretmochelys imbricata, mtDNA, Haplotype, Regional Management Unit, Mozambique Channel

Introduction

Genetic studies allowed (Wallace *et al.*, 2010) the definition of 58 regional management units (RMUs) around the globe, for the seven marine turtle species. The RMUs constitute areas of assessment, since they identify important geographic areas for marine turtle's populations according to indicators like presence, density, and richness (Wallace *et al.*, 2011). The extinction of an entire RMU, or its fragmentation, represents the disruption of species' ecological roles (Wallace *et al.*, 2011). For *Eretmochelys imbricata*, known as hawksbill turtle, 13 RMUs were identified (though 7 are putative RMUs), and some of these, like the Indian-Southeast RMU, are lacking solid data (Wallace *et al.*, 2011). Data gathered in nesting, foraging or even migrating areas for long-term studies, are essential, since marine turtles are long-lived species, and to recognize patterns and tendencies, and make analysis about the causes of changes in population structure and behavior (Eckert *et al.*, 1999). The Seychelles in the Western Indian Ocean (WIO) have a long record of nesting populations for the hawksbill turtles, which have been protected there since the 1970s (Mortimer and Donnelly, 2008). The species uses the Mozambique Channel (MZC) as a migratory route (Obura *et al.*, 2012), and occurs in many places of and near it: Saya de Malha/Banks (feeding grounds), Eparses Islands (Juan de Nova with more than 50 nesting females/year), Mayotte (up to 100 nesting females/year), Reunion Island, Madagascar (nesting grounds), Tanzania (Mnazi Bay, Mafia Island nesting and feeding grounds), and Mozambique (Quirimbas Archipelago) (Obura *et al.*, 2012; Bourjea *et al.*, 2008). Vamizi (11˚01'22.4"S, 40˚41'32.8"E) is one of the many coralline islands belonging to the Quirimbas Archipelago, exhibiting healthy and well-preserved corals (Garnier *et al.*, 2012). It is one of the north MZ well-known turtle's rookeries. But, marine turtle's conservation programs are still concentrated in the south of MZ, in detriment of central and northern parts of the coastline (Louro *et al.*, 2006). With such a vast coastline inside the MZC, and with 5 species nesting or feeding in the area, a greater effort to gather more data is expected. Vamizi's nesting turtle monitoring program began in 2002, and has gathered information on green (Garnier *et al.*, 2012; Anastácio *et al.*, 2014) and hawksbill reproduction parameters (Garnier *et al.*, 2012; Anastácio *et al.*, 2017). The conservation program also provided insight on the coral richness and fishery pressures (da Silva *et al.*, 2015) that also

affect turtles near the island (Garnier *et al.*, 2012). Anthropogenic activity can also contribute to disturb turtles' nesting activity (Anastácio *et al.*, 2014) and impose risks near rookeries or during oceanic migrations (Bourjea *et al.*, 2008). But, though assessments of nesting activities in beaches are important, much is still needed to understand marine turtles' dispersion patterns and behavior in the south WIO, especially in what regards Mozambique's coast (Louro *et al.*, 2006). This is a challenging task due to the complexity and high variability of the MZC water mechanisms (Hancke *et al.*, 2014), but also due to the lack of understanding in what regards marine turtles' behavior in the ocean (in Hamann *et al.*, 2010, see question n^{o}. 2.2., one of the 20 meta questions relating to sea turtle research and conservation). Oceanic currents in the WIO indicate a complex system still difficult to unfold, but the complexity inside the MZC is also under study (Ternon *et al.*, 2014). Inside the MZC, the water circulation is highly variable and eddy driven (Hancke *et al.*, 2014). The MZC eddies have a strong impact on biota (Hancke *et al.*, 2014) with implications on food-webs (Obura *et al.*, 2012). Hancke *et al.*, (2014) hypothesizes that "the frontal zones between mesoscale eddies, and the associated interstitial waters of the turbulence field, create pathways for biological distribution that link the shelf regions, islands and atolls of the Mozambique Channel", all explored territories by marine turtles (IOTN, 2010). The study of the pathways linking these areas could help to understand marine animals' use of the channel (*e.g.* how hawksbill adults move and forage inside the channel during the nesting season), and, by consequence, their distribution inside it.

Water movements may also have an impact on the distribution of young hatchlings (Hawkes *et al.*, 2009; Vilaça *et al.*, 2013) though new insights are being given by recent studies (Putman and Mansfield, 2015). Eddies may be too slow as effective transport vectors of young turtles (1 - 2-year-old), which are active (oriented) swimmers in contrast to what was believed (passive swimmers that were dragged) (Putman and Mansfield, 2015). Due to the difficulties in marking (and recapturing) hatchlings and juveniles, or studying the currents, one alternative for understanding turtles' distribution is by sampling individuals (in foraging and nesting grounds) and sequencing their DNA.

Maternally inherited mitochondrial DNA (mtDNA) studies give insight about the provenience of each turtle (where it was born), even when applied to groups of juveniles (Avise, 2007). The identification of different haplotypes by these studies, enables the definition of populations' genetic structure and phylogeography, and the comprehension of fidelity behavior to nesting and feeding grounds (Lee, 2008). Haplotypes work as "genetic tags" (Blumenthal *et al.*, 2009), especially in what concerns the definition of nesting populations as management units (MUs) (Wallace *et al.*, 2010; Avise, 2007). Genetic tags can be used to understand how diversified a rookery is, and to what extent it is important to manage the area around it (Blumenthal *et al.*, 2009).

Five of the RMUs of the Indian Ocean (mostly in the East) are classified as high risk-high threat (HR-HT) areas, and the Indian Ocean Basin has the lowest availability and quality data concerning marine turtles (Wallace *et al.*, 2011). Many of the Indian Ocean countries are called to provide more data on their sea turtle populations, not only to define RMUs more accurately (Wallace *et al.*, 2011), but also to fulfill the CBD goal of halting biodiversity loss. The sequencing of the mitochondrial DNA (mtDNA) control region (Santos *et al.*, 2011) of samples from hawksbill turtles from Vamizi Island adds information for the Indian Southwest RMU characterization. But it enhances the debate around the connections between Indian Ocean's rookeries and the seaways turtles use in our time, or used in the past of Earth's recent history.

Discussion

The Cenozoic marine turtles lineage (Levin, 2013) endured many climate transformations (Spotila, 2004). Their resilience is shown by their non-extinction through the changes in two completely different oceanic systems: the Pliocene and the Pleistocene oceans (Filippelli and Flores, 2009). From the warmer than today's Pliocene oceans to the cold global climate of the Pleistocene (with glacial and interglacial variations), one can hypothesize marine turtles being confined to southern oceans from the beginning of the Ice Age until the last maximum ice coverage episode. During the Pleistocene Epoch, climatic zones changed (northern and eastern Africa were fertile in consequence of abundant rainfall) (Levin, 2013) but, also, sea level may have dropped more than 100 meters (Levin, 2013), due to the enormous quantities of the planet's surface water added to northern glaciers (Dodson, 2012), changing coastlines in various ways (Graham *et al.*, 2003). Oceanic currents changed (Filippelli and Flores, 2009) and so did migratory seaways (Dodson, 2012) and nesting territories. Were southern Pleistocene oceans full of marine turtles, competing for space and food, whereas northern hemisphere oceans were depleted of these animals? Though many doubts persist, our current knowledge from oceanic changes has the advantage of corroborating (Fuentes *et al.*, 2010) views about turtles' adaptation capacity during changes in sea level rise, nesting sites erosion and modification, and changes in migratory pathways. Human activities have been representing a challenge for marine turtles during the Holocene (Hawkes *et al.*, 2009). When investigators are still lacking knowledge about turtles' behavior (Hamann *et al.*, 2010), how will they manage conservation programs to undo the effects of pollution and bycatch, for example? What do haplotypes reveal? Are marine turtles predictable, when researchers try to understand their past?

Haplotype diversity studies revealed, for example, that natal homing, though "strong", is "imperfect" among females (Avise, 2007), and, in fact "breeding populations may encompass several proximal nesting sites" (Bowen and Karl, 2007). Before attaining the reproduction stage, young marine turtles of different rookeries mix in the ocean (Avise, 2007; Bowen and Karl, 2007). But when females have to nest they choose a specific site (or nearby site) (Hawkes *et al.*, 2009; Avise, 2007). This means that on those sites a prevalent maternal inherited structure of the nesting populations and their hatchlings exists and prevails for long periods of time (if the rookery does not become extinct) (Avise, 2007). The number and variety of haplotypes exhibited by a rookery is its "banner" (Blumenthal *et al.*, 2009).

For Testudines, that appeared in the Late Triassic (Benton, 2005), the mean microevolutionary rate for mtDNA, which is lower when compared with other vertebrates (Avise et al., 1992), is used to build up matrilineal haplotype trees showing sequence divergence estimates in the geologic timescale (Avise et al., 1992). Alterations on haplotype frequencies on a nesting beach are of conservation concern; but knowing the causes implies completely understanding the RMU to which that rookery belongs, which for the WIO is still difficult. This exercise can be done with the published papers about the haplotypes discovered so far (see Vargas *et al.*, 2016). We tried to make the same exercise starting with haplotypes from Vamizi. Hawksbill turtles collected in Vamizi revealed 14 haplotypes, from which two were already discovered, Ei_15 and EIJ4 haplotypes, and 12 were new (Santos *et al.*, 2011) – isolates number 49, 60, 65, 73, 95, 97, 101, 102, 104, 113, 114, and 128 (Anastácio *et al.*, 2017), being introduced in 2011 in the GenBank database accession numbers JF926554.1, JF926544.1, JF926553.1, JF926547.1, JF-926546.1,

JF926545.1, JF926548.1, JF926549.1, JF926550.1, JF926555.1, JF9265-51.1, and JF926552.1, respectively (Santos *et al.*, 2011).

Connection of the WIO with the Indo-Pacific Haplotypes

The detected common haplotypes that linked the WIO with the southern Indian ocean (SEIO) are the Ei_15 haplotype, occurring in Vamizi (Santos *et al.*, 2011) and in Southeast Asia (Mohd Arshaad and Syed Abdul Kadir, 2010), and the EiJ4 haplotype, occurring in Vamizi (Santos *et al.*, 2011), in Southeast Asia (Nishizawa *et al.*, 2016), and in the Pacific Ocean, Japan (Nishizawa *et al.*, 2010). In the SEIO Malaysian rookeries and foraging aggregations, the 20 haplotypes described (Nishizawa et al., 2016) reveal connections not only with the WIO, but also with the Pacific and Northeast Indian populations (Nishizawa et al., 2016). In fact, the haplotype phylogenetic connections made (Nishizawa *et al.*, 2010) postulate that hawksbill turtles suffered an expansion after the last glacial maximum, during the Pleistocene. Considering that evidence suggests a slowdown in mean microevolutionary rate for turtle mtDNA (Avise *et al.*, 1992; Duchene *et al.*, 2012), it is expected that the link between the actual Indian and Pacific Ocean populations will be clarified, since it is preserved in the form of an ancestral identity-tag. But these are only assumptions. Nishizawa *et al.*, (2010), following Avise (2000), Encalada *et al.*, (1996), and Reece *et al.*, (2005), suggested that hawksbill and green turtle's populations suffered late-Pleistocene expansions from nesting and foraging equatorial regions to higher latitudes, hypothetically due to climate and sea-level fluctuations. That expansion occurred "from multiple sources following a bottleneck" (Reece *et al.*, 2005; Rogers and Harpending, 1992, *in* Nishizawa *et al.*, 2010). Shanker *et al.*, (2004) goes further, postulating that the radiation of turtles began in the Indian Ocean, and developed into the Pacific and the Atlantic Oceans. Even though Duchene *et al.* (2012) emphasize that "divergence dates as old as 5.63 Million years", Miocene epoch (23.7 - 5.3 Mya), "are needed to explain geographic genetic variation in *E. imbricata*", haplotype distribution conjugated with slow mutation rates might explain why recent populations retain ancient molecular sequences from different and geographically separated rookeries.

There is no doubt that both haplotypes Ei_15 and EiJ4 link the Pacific and Eastern Indian populations with the WIO populations. Still, more data will bring insight, especially the analysis on the connections between the Arabian/Persian Gulf and the Red Sea rookeries and foraging sites, where important concentrations of hawksbills are found (Pilcher *et al.*, 2014; NOAA, 2013), and the MZC populations with other Indo-Pacific rookeries and foraging grounds (Vargas *et al.*, 2016). The Persian hawksbill subpopulation mtDNA analysis revealed endemism, with seven specific haplotypes discovered so far (Tabib *et al.*, 2011, 2014). The Persian haplotypes are related with haplotypes from the Southeast Asian Region (Ei_1, and Ei_6 haplotypes, submitted by Mohd Arshaad and Syed Abdul Kadir (2010), after a study for the Department of Fisheries Malaysia), as emphasized by Tabib *et al.*, (2014).

Connection of the WIO with the Eastern Atlantic Haplotypes

With the purpose of giving insight into population connectivity among Ascension Island turtles, and the ones from other parts of the globe, Putman *et al.*, (2014) used a paired approach. With genetic analysis and dispersal simulations they identified possible sources for juvenile hawksbill populations from the Atlantic island, where it is known that they do not nest. Their analysis showed that Vamizi's haplotype

113 belongs, alongside the identical sequences Okayama 24-Seychelles FG, EiA48, and EATL (found in Cape Verde Islands FGs and Principe Island nesting females), to the Clade "Western Indian Ocean foraging grounds (FGs) and Eastern Atlantic nesting and FGs" (Putman *et al.*, 2014). The same study showed that Vamizi's haplotype 104 belongs to the "Indo-Pacific nesting and FGs" Clade (Putman *et al.*, 2014). These results corroborate Shanker's *et al.*, (2004) hypothesis of the Indian Ocean being the source of expansion of marine turtles.

Other questions are being posed, such as: is there a connection between Indian and Atlantic Ocean basins nowadays? Are hatchlings from the north of MZC being driven by currents towards the Eastern Atlantic Ocean? Is the Indian Ocean serving as "a source of at least a small portion of hawksbill juveniles in the Atlantic basin" from locations as far as Seychelles (Putman *et al.*, 2014) or Vamizi? Or, are these genetic connections resulting only from past migrations that, alongside with slow mtDNA mutation rates conserved Indian haplotypes in the south Atlantic populations?

We are inclined to think that the hypothesis of connections between different ocean basins nowadays is less likely; hence, the second hypothesis, *i.e.* past migrations and slow mutation rates, is more likely to explain the haplotype distribution (Bowen and Karl, 2007; Avise *et al.*, 1992). Like Vilaça *et al.*, (2013) emphasize, "because nesting aggregations in eastern Atlantic exhibit EATL haplotypes, the presence of this "typical" Indo-Pacific haplogroup in Atlantic areas does not necessarily mean that *E. imbricata* individuals are currently migrating among oceans". This discussion is used to explain the provenience of the São Tomé e Príncipe nesting and foraging hawksbill's populations (Monzón-Argüello *et al.*, 2011), since the EATL haplotype is so abundant in these rookeries, whereas it is less abundant in other Atlantic locations revealing a strong past connection with the WIO. But the connection between East Atlantic EATL and the WIO identical haplotypes will only be clarified with more studies (molecular, telemetry, nesting monitoring) in other locations, especially from the MZC (Monzón-Argüello *et al.*, 2011).

Haplotype and Nucleotide Diversities

Finally, the importance of the north MZC rookeries is emphasized by the haplotype diversity values in Vamizi Island. The highest value for haplotype diversity (h) is 0.8950 ± 0.0020 for Vamizi. The highest nucleotide diversity (π) is 0.0743 ± 0.0021 (Santos, personal communication). Haplotype diversities described for the Atlantic Ocean (Ascension Island) are h = 0.333 ± 0.124 for juveniles (Putman *et al.*, 2014), for Brazil h = 0.358 ± 0.069 (Lara-Ruiz *et al.*, 2006), and for the Cayman Islands (Caribbean) h = 0.72 ± 0.04 for a mixed-stock of foraging juveniles (Blumenthal *et al.*, 2009). The 32 samples (embryos) collected in the Kish and Qeshm Islands in the Persian Gulf revealed five endemic haplotypes with values of h = 0.69 and π = 1.56 (Tabib *et al.*, 2011). For feeding populations in Yaeyama Islands in Japan, eleven haplotypes were found, for which h = 0.783, and π = 0.018 (Nishizawa *et al.*, 2010). All these results corroborate that Vamizi's rookery, and most likely other locations inside and near the MZC, is genetically important for conservation, with high haplotype and nucleotide diversities.

Conclusion

The WIO puzzle concerning the genetic variation of hawksbill turtles and the connection with other oceans is still unsolved. More research in the Indian Ocean is demanded, to enlarge the conservation effort and to comprehend which spots must be connected in the migratory pathways of marine turtles. In what concerns the MZC particularly as a source of information to understand

the mechanisms that explain current distribution of haplotypes between different ocean basins, more molecular studies will bring more certainties. The establishment of protected corridors inside the MZC is crucial, due to the connectivity that it exhibits for its biota (Hancke *et al.*, 2014). More protected MUs in the continental shelf regions of Madagascar and Mozambique, with new monitoring programs for foraging and nesting grounds, are also needed. Mozambique is reported as having less than 10 females/year (NOAA, 2013), when Anastácio *et al.*, (2017) reported 34 emergences for the 2003 nesting season in Vamizi alone. This last example shows the need for more reporting, since Mozambique is thought to have a bigger population for nesting hawksbills. The fact is that it is urgent to ensure the maintenance of pristine habitats inside the MZC that nurtures a vast genetic richness, not only to recover the densities of marine turtles in these locations, but because turtles have significant economic value that can be managed to alleviate poverty. While researchers are trying to solve many questions concerning marine turtle's adaptation and distribution patterns, human activities still strongly jeopardize populations and their own well-being. The future of marine turtles depends on the ability of conservationists and governments to actively engage poor people in the management of wild life.

Conflict of Interest

Authors declare that they have no conflict of interest.

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Software for improved field surveys of nesting marine turtles

Abstract

Field data are still recorded on paper in many worldwide beach surveys of nesting marine turtles. The data must be subsequently transferred into an electronic database, and this can introduce errors in the dataset. To minimize such errors, the "Turtles" software was developed and piloted to record field data by one software user accompanying one *Tortuguero* in Akumal beaches, Quintana Roo, Mexico, from June 1st to July 31st during the night patrols. Comparisons were made between exported data from the software with the paper forms entered into a database (henceforth traditional). Preliminary assessment indicated that the software user tended to record a greater amount of metrics (*i.e.*, an average of 18.3 fields ± 5.4 sd vs. 8.6 fields ± 2.1 sd recorded by the traditional method). The traditional method introduce three types of "errors" into a dataset: missing values in relevant fields (40.1%), different answers for the same value (9.8%), and inconsistent data (0.9%). Only 5.8% of these (missing values) were found with the software methodology. Although only tested by a single user, the software may suggest increased efficacy and warrants further examination to accurately assess the merit of replacing traditional methods of data recording for beach monitoring programmes.

Introduction

Considering the need for global commitment and engagement, science and technology currently play an important and a probably decisive role. Conservation means eternal vigilance regarding an ecosystem (Meffe and Carroll, 1997). Ecologists have multiple strategies to implement conservation; some of them are exciting, new and technological. Monitoring ecosystems has become the centre of attention due to pressures that affect their equilibrium, such as climate change, disturbances in the mass-energy flow from producers to top consumers (Anastácio *et al.*, 2012), and competition for resources between wild species and humans (Anastácio *et al.*, 2014a). Monitoring is also labour intensive due to the number of variables that must be measured and the speed at which analytical delivery must act (Joppa, 2015; Pimm, *et al*., 2015). Different high-performance technologies that improve daily life have been developed for citizen use during this century, for example, smartphones, apps, laptops, tablets, and drones. These technologies can be or are associated with wildlife protection based on a real-time survey, for example, of rhinoceros (www.cisco.com/c/m/en_us/never-better/csr-1.html) or elephants (www.savetheelephants.org/). These technologies can also be used by investigators to facilitate field work (Marvin *et al.*, 2016) or to help advance current knowledge (*e.g.,* about elephant communication (Stoeger and Baotic, 2016).

Marine turtles have been the target of numerous conservation projects that require monitoring and data collection to understand population dynamics and trends (Bjorndal *et al.*, 2010; SWOT 2011; Hamann *et al.*, 2010). This in turn requires a large amount of data and several years of monitoring, particularly for long-lived species such as marine turtles (SWOT 2011) (see Chaloupka and Limpus, 2001; Troëng and Rankin, 2005; Antworth *et al.*, 2006; Lauret-Stepler *et al.*, 2007; for examples of monitoring studies). The monitoring of marine turtles particularly poses considerable challenges due to their behaviour during their early years (oceanic stage) or in the juvenile and

adult phases because the turtles travel between breeding and feeding areas (transoceanic migration) (Troëng and Rankin, 2005; Sims *et al.*, 2008; Godley *et al.*, 2010). Additionally, adult males do not visit beaches during the nesting season (Eckert *et al.*, 1999; Hawkes *et al.*, 2009), and distinguishing between male and female hatchlings requires invasive techniques (*e.g.*, a histological analysis) (Eckert *et al.*, 1999). Such complexities have required the development of a range of monitoring strategies, such as capture-mark-recapture using metal or plastic tags (Eckert and Beggs, 2006a), or more advanced technology, such as PIT tags (Eckert and Beggs, 2006a), satellite and molecular tracking (Godley *et al.*, 2010), and molecular techniques (Lee, 2008). Still, considerable questions remain unanswered (Hamann *et al.*, 2010).

Many conservation projects monitor nesting beaches where a group of females come every year to nest. Monitoring the nesting females, their nests and hatchlings (the nesting beach surveys) is not sufficient for characterizing a population, but such surveys provide important indicators of the population status and assist in the development of local conservation management measures for those individuals at the beach or in the surrounding area (*i.e.*, in the neritic habitats and corridors). Standardized procedures are important because many projects provide basic data for conservation measures. The State of The World's Sea Turtles (SWOT, 2011) provides information on global standards for data reporting. SWOT intends to build an improved data collection by relying on a global network of data providers for all aspects of sea turtle biogeography (SWOT, 2011).

The current trend is the assembly of all information in a single database, especially for globally distributed migrating species (Scholes *et al.*, 2008) such as marine turtles. The study of multi-scale Regional Management Units (RMUs) by Wallace *et al.*, (2010) exemplifies both the asymmetry in data worldwide, which are biased towards areas in which monitoring and reporting are high, and issues with the data quality provided. Wallace *et al.*, (2010) conclude that the efficacy of applications using RMUs is dependent on the accuracy and quality of the data contained in the files, including the difference between the true absence of a species and an apparent absence due to a lack of monitoring or reporting. Similarly, other studies have shown that the scientific effort is skewed, and some programmes lack scientific guidance (Bjorndal *et al.*, 2010; Godley *et al.*, 2010; Lee, 2008; Obura *et al.*, 2012; Formia *et al.*, 2006).

It is necessary to develop a global database for marine turtles in order to understand their distribution and population trajectories. Information for the Western Indian Ocean (WIO), for example, is lacking (Mortimer, 2002). The *IUCN East African Regional Office (EARO)* and the *IUCN/SSC Marine Turtle Specialist Group* (Bjorndal *et al.*, 1996) have previously emphasized a need to improve monitoring efforts in this region to achieve more and better reporting.

Following the recommendation made regarding the WIO (Mortimer, 2002), and as a consequence of previous work (Anastácio *et al.*, 2014b), a software tool was developed to help teams in remote areas gather and report information to entities such as SWOT. A software tool used to record field information that uses adequate methodology for a certain nesting season and follows SWOT (2011), Eckert *et al.*, (1999), Sims *et al.*, (2008), and WIDECAST (Eckert and Abreu Grobois, 2001) recommendations may provide an enormous benefit for conservation projects compared to existing monitoring that employs paper.

The premise was that, in order to enhance data quality, it is important not only to choose adequate protocols and methods (SWOT 2011; Sims *et al.*, 2008; Eckert *et al.*, 1999; Eckert and Abreu Grobois, 2001) but also for field ecologists to use field technology, such as software prepared for a specific purpose, to collect variables.

A new way of executing field ecology has arisen due to the development and use of software applications for ecological monitoring. Some projects, such as iNaturalist (www.inaturalist.org/), iBats (www.bats.org.uk/pages/ibatsprogram.html), and iBird (ibird.com/), can serve as examples. Actually, the window of opportunity is open for ecologists to create and test monitoring software for many species. The Bruna Lab (brunalab.org/apps/) has a list of free applications for ecologists. More importantly, this indicates that traditional methodologies will be replaced by digital tools in field ecology for the monitoring of many species.

Sims *et al.*, (2008) emphasize that counting errors by an observer and environmental stochasticity have an impact on trend determination for marine turtles. Software that standardizes the way a field ecologist saves data also enables the possibility of comparing information over time, since it helps reduce errors due to manual data re-entry (Marvin *et al.*, 2016). The same can be said for the use of integrated tools; instead of recording GPS coordinates manually on a paper form, a field ecologist can use a GPS app to save that information and avoid errors.

To examine the previous assumptions, a software package named "Turtles" was developed and piloted in the field as a method for data recording for subsequent statistical analysis. Its performance was trialled in conjunction with the traditional methodology (*i.e.*, paper forms and entered into a database). Our goal is to replace traditional data recording methodology with dedicated software, such as an app for a tablet or a smartphone, that provide significant benefits for monitoring of marine turtles nesting.

Results and Discussion

Two months of field work from June 1st, 2016, to July 31st, 2016, were recorded and analysed comparatively. During this period, *Centro Ecologico de Akumal* (CEA, see Methods section) kept their traditional methodology of data collection on paper forms, while the software-user used the developed software for the same task. Then, the data collected by the 3 main *Tortugueros* (a specific designation given to field monitors that work only with turtles, which in Mexican are called "tortugas") from CEA was used as benchmark to assess the performance, effectiveness and benefits of the software tool for field work.

Table 1 shows that the software database contains a total of 171 records (the effort of one person in the field). The paper forms database contains 561 records (the effort of three people in the field). These records were scrutinized in terms of "missing values" and "errors" amounts and percentages.

The percentage of missing fields in the software database is 5.8%, whereas the number of missing fields in the paper forms database is higher, at 40.1% (see the "Methods" section for the definition of "record" and "field" in the databases). For example, 9.4% of the paper forms database did not contain the hour (when the record was made) (Table 1), and one record had a missing nest tag. The software always showed a list of nest tags (the tag is introduced at the moment the nest is identified during the field work, though the software generates a redundant automatic tag for it, enabling the user to check the nest codes and avoiding the duplication of nest tags, which is an advantage). The missing fields in the software database related to the GPS location were due to the fact that the coordinates were introduced manually. This issue will be addressed in a software upgrade to reinforce and automate the capture of these data. Although there is a significant effort to revise the software source code, the use of software and technological tools provides the benefit of continuous improvement of the process, with a minor impact on the field effort performed by the

Tortugueros. Therefore, when the software database is compared with the information collected on paper forms, the absence of data on relevant fields is higher in the traditional paper approach. Thus, the software performed better and added a benefit.

Table 1. Analysis of missing values and "errors" of the paper forms and software databases. The total number of records with errors is not a sum of the values of the column above but rather the total number of records that contain that error. For example, if a single record contained multiple errors, they were counted as a single error.

Description	Paper forms database		Software database	
	Records	Percentage	Records	Percentage
Total amount of collected data (from 01/06/2016 to 31/07/2016)	561	100.0%	171	100.0%
Field effort	3 People		1 Person	
Total amount of collected data per person	187		171	
1. Missing value for relevant fields:				
1.1. GPS location of the Nest	176	31.4%	10	5.8%
1.2. Time (hh:mm) of the record	53	9.4%	0	0.0%
1.3. User name	5	0.9%	0	0.0%
1.4. Nest ID	1	0.2%	0	0.0%
Total	**225**	**40.1%**	**0**	**5.8%**
2. Error "different answers for the same value":				
2.1. Different texts for the same user	49	8.7%	0	0.0%
2.2. Different texts for the same turtle false crawl reason	6	1.1%	0	0.0%
Total	**55**	**9.8%**	**0**	**0.0%**
3. Error derived from "inconsistent data":				
3.1. Mismatch between total number of eggs and the sum of the partials	2	0.4%	0	0.0%
3.2. GPS data out of the range of that region	3	0.5%	0	0.0%
Total	**5**	**0.9%**	**0**	**0.0%**
Total number of records with errors	**262**	**46.7%**	**10**	**5.8%**
Total number of records without errors	299	53.3%	161	94.2%
Total number of records without errors per person	**99.7**		161.0	

No errors derived from "inconsistent data" were found in the software database. On the other hand, 0.9% of data inconsistencies were found in the paper forms records. Hence, the total number of paper forms records that were error-free was 299. Although the number of records per person was higher for *Tortugueros* (16 more field form records than in the software database), the software user generated fewer misses (5.8% versus 46.7% on paper forms) and 0% errors (errors type two and three in Table 1). This translates into a greater number of valid records per person (161 software records versus 99.7 records by traditional method), which is a similar efficiency of absolute data recorded in the field. However, the data recorded by the software user was more reliable and of higher quality.

The errors found frequently originated in the traditional methodology (as expected from previous experience), which is prone to errors due to higher process exposure to potential sources of error than in the software approach. These derive from 1) different field content that represents the same information, *i.e.*, the same result was given different designations (for example, the names of *Tortugueros* were given different designations, or empty fields were identified by different symbols, which causes problems and requires time-consuming work to prepare the file for statistical

analysis); 2) missing information requiring another result; or 3) typing errors that implied an unrealistic data range, the wrong coordinates, or duplicated nest tags. These "errors" were negligible in the software database, since several mechanisms were introduced in the application to avoid them. The mechanisms of the software were multiple choice fields (weather conditions in several variables, species ID), mandatory fields (the user can only proceed if certain variables are filled in), scrolling information (for example, a list of the introduced nest tags is presented to the user when it is necessary to introduce new coordinates for the nest, when it is moved, and when the nest is excavated, after eggs hatched), and auto-filled information fields (date, time).

Time is an important variable when comparing the performance of the traditional methodology with the software. The standardization of the paper forms database (correction of "errors", when possible) required three working days. However, when the software database was ready for analysis, the paper forms database had to be prepared by entering information on paper forms into a computer, which required several weeks.

For the results in Tables 2 and 3, the analysis of the two databases was divided into four categories: "turtles seen or not seen (false crawls)", "turtles seen", "nests seen" and "nests moved". The software user filled in 18.3 fields ± 5.4 sd on average in a single record with data of marine turtles, versus 8.6 fields ± 2.1 sd on average for *Tortugueros* (Table 2). This is because the software allows more data to be recorded if the user so desires (the average number of fields recorded by the software user was higher or similar in all four categories in Table 2). For example, the software user always recorded weather variables (which are not indicated in Table 2), while *Tortugueros* rarely collected weather information. This reveals the power of the digital tool *versus* paper forms.

Table 2. Average number (±standard deviation sd) of fields filled in per record according to the category of analysis. Notice that not every field must be filled in every record for each category. The software was created taking into account the possibilities of every monitoring project; for example, it has fields for passive integrated transponder (PIT) tags information, and not every monitoring project uses PIT tags. In the Akumal Project, measurements of total tail length (TTL) and post-cloacal tail length (PTL) are not taken, though the software has an entire window to insert that information. This is the reason why the total number of fields to fill in is always greater than the averages presented.

	Category of analysis			
	Turtles seen or not seen (false crawls)	**Turtles seen**	**Nests seen**	**Nests moved**
Average number of fields (±sd) filled per record in the paper forms database	8.6 ± 2.1	10.5 ± 1.1	13.9 ± 7.2	14.9 ± 6.0
Total number of fields in the paper forms	15	15	15	19
Average number of fields (±sd) filled per record in the software database	18.3 ± 5.4	22.9 ± 4.7	25.7 ± 5.1	14.0 ± 0.8
Total number of fields in the software Turtles	23	57	49	22
fields / variables considered for this analysis (examples)	Species id; Tag number; CCL (curved carapace length); CCW (curved carapace width); Track width; Activity of the turtle.	Species id; Tag; CCL (curved carapace length); CCW (curved carapace width); Track width; Activity of the turtle	Nest tag; GPS coordinates; Temperature inside the nest;Temperature of the sand; Nest depth	GPS of the new location; Nest tag; Number of eggs; Number of broken eggs

Upon analysing the average number of records per category (four categories considered) of the entire databases (Table 3), it is possible to find that the software user made more records of "turtle activities" and of "turtles seen" when compared with the top three *Tortugueros* averages (74.5 ±

13.5 records *versus* 65.2 ± 20.5 records and 34.0 ± 5.0 records *versus* 33.3 ± 3.7 records, respectively). This shows that the software does not disturb the work of the user or even diminish its performance. The average of the two categories involving nest variables was lower (Table 3) for the software user compared to the *Tortugueros*. The reason that fewer records were shown for nest variables has more to do with the field division of tasks than with the capacity of the software user to record them, as well as with the hatching dates of the eggs (after the final stage of the pilot study).

Table 3. Number and averages (±standard deviation sd) of records of the entire databases, collected in two months, by the Tortugueros and the software user. 1Includes false crawls.

Categories of analysis	Number of records of turtles[1]	Number of records of turtles seen	Number of records of nests	Number of records of nests moved
Averages ± sd of CEA Top 3 *Tortugueros*	65.2 ± 20.5	33.3 ± 3.7	36.7 ± 9.7	4.0 ± 2.0
Averages ± sd of software user	74.5 ± 13.5	34.0 ± 5.0	25.0 ± 2.0	2.5 ± 1.5

The functionality of the software on a tablet on the beach at night proved to be very reliable. Both methods are practical; both are functional for field data recording. However, Table 4 shows the specific differences between them.

Table 4. Characteristics of the traditional methodology compared to the software.

Traditional methodology – paper forms	"Turtles" software
After the data are recorded on paper forms, they must be entered in an Excel file.	After data about a turtle, a nest or a crawl have been recorded, a table containing that information is automatically provided.
Does not introduce date and hour automatically.	Introduces date and hour automatically.
The user must write the same thing repeatedly, even if it is the same information.	Has selectable, predefined answers, and new entries can be added.
The user must write in each paper form for every variable.	Enables the collection of several weather datasets only once per night (at the beginning of the recording), but more information can be added at different times (changes, for example). If no changes are observed, the software automatically replicates the weather information entered in the beginning in each record.
Does not have a mechanism to avoid the duplication of nest tags; the last record must be consulted before going to the field.	Avoids the duplication of nest tags.
A red light is necessary for recording on paper.	No red light is necessary - the light of the tablet/smartphone is sufficient.
It is not dependent on a battery source, but a pencil or pen (that the user sometimes loses) is necessary.	Needs a battery (prior charging required) or power bank.
If all the paper forms are used, more are necessary to continue recording data. *Tortugueros* use their smartphone or a notebook in these situations.	No need for backup. Works until charge runs out.
Cannot be used if it rains (the paper gets wet).	Can be used in light rain.
Difficult to use in windy conditions.	Not difficult to use in windy conditions.

The results suggest that the software has several advantages compared to the traditional methodology. First and foremost, it avoids the need for data entry on a computer after it has been collected on paper. The dataset provided by the software is immediately available for analysis by a statistical tool because data consolidation is not required.

Another aspect in favour of replacing paper forms with the Turtle software is that the *Tortugueros* use a smartphone on the beach to communicate with each other and even to record data after all of their paper forms have been exhausted. Thus, *Tortugueros* were at ease with the software and

were satisfied with the idea that they did not have to type the information on the office computer. It is important to emphasize that the user can manipulate the database produced by the software at any time, even on the beach.

Methods

Akumal Project

The Sea Turtle Protection Program of the Akumal beaches was created in 1993 (www.ceakumal.org), and its development is carried on by the CEA. Although this protection programme focuses on nesting and feeding grounds (DOF 2016), nesting site preferences of female green sea turtles (*Chelonia mydas)* and loggerhead sea turtles (*Caretta caretta*) were the focus of this study.

CEA is the local Non-Governmental Organization with permission for managing the natural resources of the newly created marine protected area and beaches. As of March 7th, 2016, an agreement that establishes "Bahía de Akumal" as "Área de Proteccion de Especies Marinas" in the Tulum Municipality of Quintana Roo State (DOF 2016) was decreed by the Mexican Government. This refuge area was created for the protection of the following species of sea turtles: *Chelonia mydas*, *Caretta caretta*, *Eretmochelys imbricata*; corals: *Acropora palmata*, *Acropora cervicornis*, *Plexaura homomalla, Plexaura dichotoma*; mangrove and dune species: *Laguncularia racemosa, Rhizophora mangle, Conocarpus erectus;* and seagrass species: *Thalassia testudinum*, *Syringodium filiforme, Halodule wrightii* (DOF 2016).

The research objectives of the nesting part of this project were 1) to determine the physical characteristics of the beach female sea turtles preferred for nesting at Akumal; 2) to determine how the physical characteristics of the nest relates to the ambient temperature inside the nest; and 3) to use these results to predict the sex ratios of the hatchlings in Akumal (Slater, 2015). The results can then be used to determine if adaptive management of the nests should be implemented in the future (DOF 2013). This work was carried out in collaboration with CEA and Operation Wallacea under the *Sea Turtle Protection Program* based in Akumal, Mexico.

Turtle Surveys

The nesting season in Akumal occurs from May to November or December (Slater, 2015; DOF 2013; CEA 2016). During those months, the *Tortugueros* patrol the beaches every night from 9 p.m. until 4 a.m. or longer, depending on the nesting activity. They also check the nests during the day at 6 a.m., when the clutches start to hatch. Each patrol is composed of 1 or 2 *Tortugueros* per beach (Figure 1) at Half Moon Bay, Akumal Bay, Jade Bay, and South Akumal. Each beach is divided into sectors marked with a divider every 100 metres.

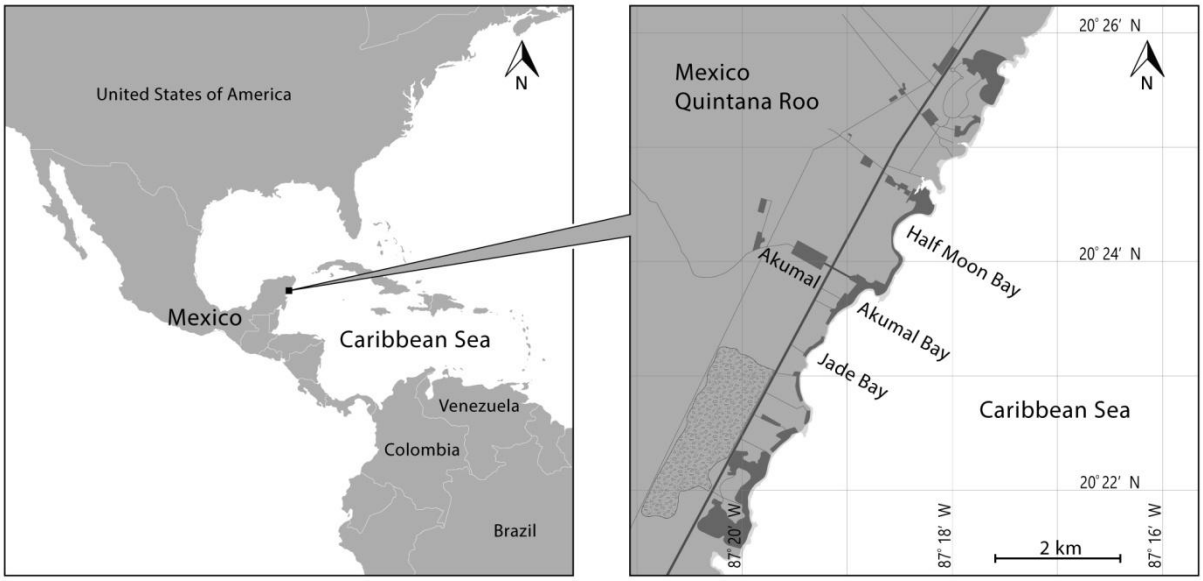

Figure 1. Location of Akumal and the beaches. The field work occurred primarily on Half Moon Bay beach, which was divided into 7 sectors, and Jade Bay beach, which was divided into 5 sectors. Left image designed by Freepik (http://www.freepik.com) and modified with Adobe Illustrator CC2017. Right image designed with Adobe Illustrator CC2017 from Landsat image; Landsat imagery courtesy of NASA Goddard Space Flight Center and U.S. Geological Survey.

The number of *Tortugueros* varied during the season, but CEA had 4 permanent *Tortugueros* and hired one more permanent *Tortuguero* in July. In June and July (2016), 7 volunteers helped during the night patrols, so the field effort encompassed 4-12 people distributed on the four beaches. During each night patrol, the *Tortugueros* patrolled the beaches and specifically identified nesting attempts, nesting turtles and nests. The variables collected during the 2016 nesting season (the same variables reported in CEA-OpWall report (Slater, 2015)) were the weather conditions, the tide level, moon phase, cloud cover and artificial light for each night. For each nesting female, *Tortugueros* recorded the species of turtle, the time and date when the female began to lay eggs, the nest number, the curved carapace length (CCL) and width (CCW), the presence of neophytes on the carapace, and the number of the tag located on the front flipper, where applicable (Slater, 2015). The *Tortugueros* collected the following nest variables: the nest depth (with a hard measuring rule) and the nest temperature (with a pen thermometer, 0.1 °C) at 2 cm into the sand and at the bottom of the nest (usually at 40 cm deep using a hard tape measure that was inserted inside the nest) (Slater, 2015). The *Tortugueros* also collected variables from sites in the zones where nest densities were low and at sites rejected for nesting. These variables were primarily the sand temperature at 2 cm depth, obstacles in the potential nest zone (*i.e.*, none, natural, or man-made), obstacles in the tidal zone, artificial light, human disturbance (*i.e.*, none, man-made obstacle, human obstacle, human voices, human presence) (Slater, 2015). The CCL measured was the CCL notch to tip (n-t) according to Bolton's (Eckert *et al.*, 1999) methodology, *i.e.,* the length "from the anterior point at midline (nuchal scute) to the posterior tip of the supracaudals" (Eckert *et al.*, 1999) of the carapace. GPS UTM coordinates were taken with a Garmin e Trex® 10, written on paper forms and entered into the software manually.

The turtles were tagged according to the Eckert and Beggs (2006) methodology. The project used Monel tags (Eckert and Beggs, 2006) that were generally applied to the front left flipper after

checking the flipper and the paddles for tags and scars. Turtles with obvious fibropapilloma (FP) disease were documented but not tagged (Eckert and Beggs, 2006).

"Turtles" Software

The "Turtles" Software was developed as a tool to monitor the activity of nesting females from several species, the leatherback (*Dermochelys coriacea*), the hawksbill (*Eretmochelys imbricata*), the green (*Chelonia mydas*), the loggerhead (*Caretta caretta*), the Kemp's ridley (*Lepidochelys kempii*), and the olive ridley (*Lepidochelys olivacea*) turtles, following recommendations by the "Research and Management Techniques for the Conservation of Sea Turtles" (Eckert *et al.*, 1999) and others (Bjorndal *et al.*, 2010; SWOT 2011; Anastácio *et al.*, 2014b; Eckert and Abreu Grobois, 2001). The software, designed and built with the mission of simplifying the data recording task on field and improving the quality of the data collected, was used in this scenario as a "proof of concept" tool.

Its functionality was tested with simulations by navigating it (testing buttons and paths) and fulfilling every variable. Databases generated during the simulations were carefully analysed to detect malfunctions, errors, and mismatches. The development process and tests took six months. After the development process, the software was used and tested in Akumal during two months of field work. The software was built to satisfy the need to enter as much data as possible, following the methods of Eckert *et al.,* (1999). However, each project has only a part of those variables, and the Turtles Software can be adapted to those specifications. For example, the software window about the turtle species gives the possibility of recording information on Leatherbacks'; however, it was not necessary to record information about that species. In the future, a version of the software can be provided for each project, according to the specifications and needs of the users.

A version to record information only on tracks or only on nests is possible; the version used is the most complete, with all the possible variables so far. The software can record a total of 104 variables, concerning weather conditions, abiotic variables (such as the sand temperature in the nest, sand humidity, sand temperatures), the GPS coordinates of the tracks and of the nests, all the variables concerning nesting turtles (CCL, CCW, track width, post-cloacal tail length PTL, total cloacal tail length TTL, head length, new tags, old tags, health conditions, among others), nest (depth, number of eggs per category, number of nests in its proximity, tag, obstacles near the nest, predators) and track variables (type, width, causes of false crawl).

The software was developed using Microsoft Visual Studio Community 2015, in Visual Basic language. The source code was compiled and installed on two 7-inch tablets running Windows 10 Operating System, which were used during the field work. The software records the data in a local Microsoft Access file. Its interface consists of several windows with relevant monitoring variables.

The tool guides the user according to the work flow of the field teams, as shown in Figure 2. It is possible to make several records in sequence after the R0 box that comprises all windows concerning weather and disturbance factors. The R1, R2, R3 and R4 fields allow several data types to be recorded; for example, if an investigator has a turtle laying eggs, and if those eggs have to be moved, the software will allow that to be recorded in sequence in the R1, R2 and R3 fields. However, if the investigator chooses to save only information about the nest or to enter that information before entering information for a turtle, he can use that approach. More importantly, at the end of each box of variables (R1, R2, R3 or R4), it is mandatory to save information before going to another box.

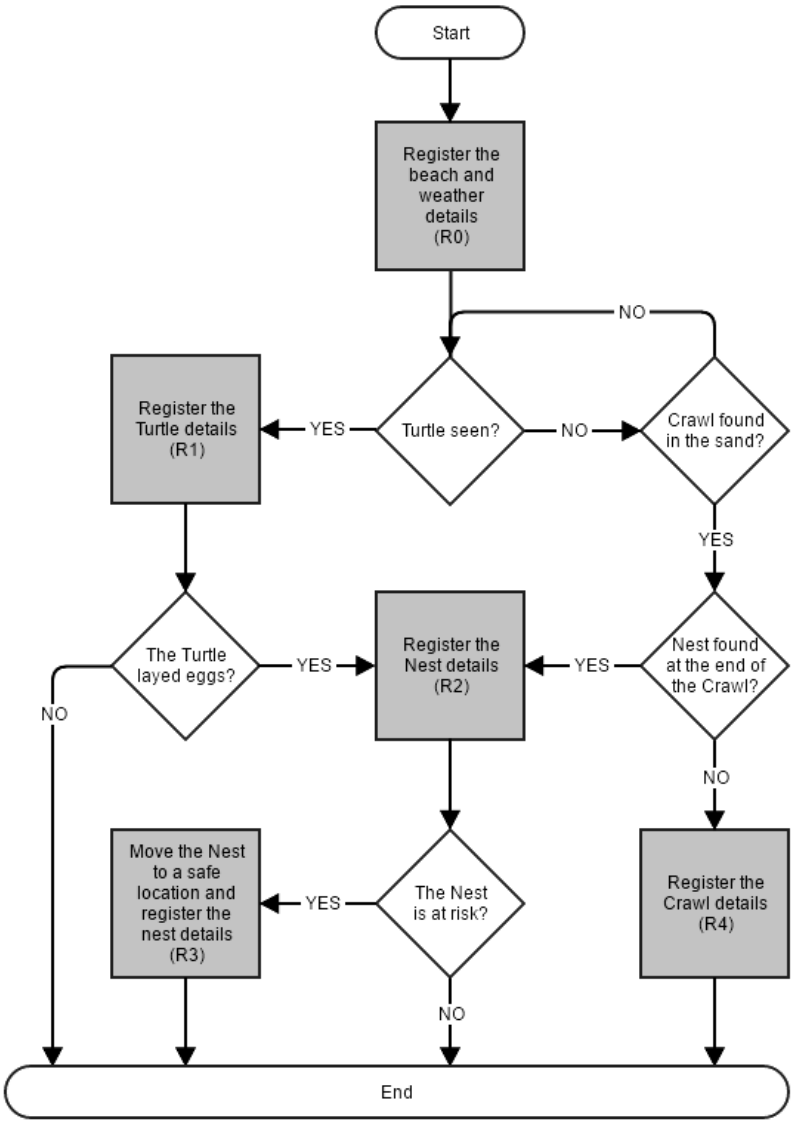

Figure 2. Workflow for the field work of a nesting turtle project. The software was built with the same logic.

The flow of windows shown to the software user is demonstrated in Figure 3, which is a complement of Figure 2. When started the software, the user will find the “1. Login” window to type in identification and password code. After authentication, the user will find the “2. Beach Details” and “3. Weather Details” windows to fill in the generic information of the place. Then, in window 4, the user must select the type of record according to the situation on the field. As shown in Figure 3, the selection made in window 4 will direct the user to the corresponding set of windows. Between windows 2 “Beach Details” and 5 “Save data”, the user can move forward and backwards along the multiple windows. For multiple records (*i.e.,* turtle seen and nest found), the software allows the user to “Continue Collecting Data” after completing and saving a record.

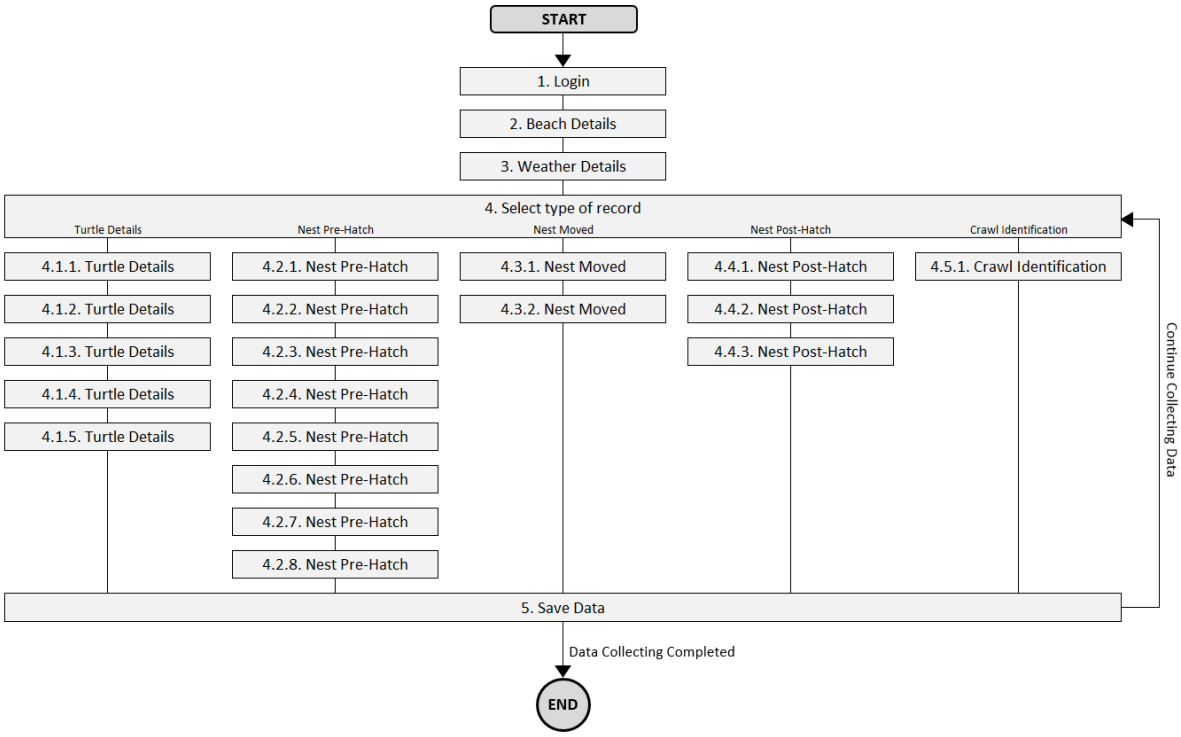

Figure 3. Software structure of windows offered to the user.

Each window has several variables. Window 4 “Select type of record” is shown in Figure 4 and provides a menu of five buttons, since the user must decide which kind of record ought to be filled.

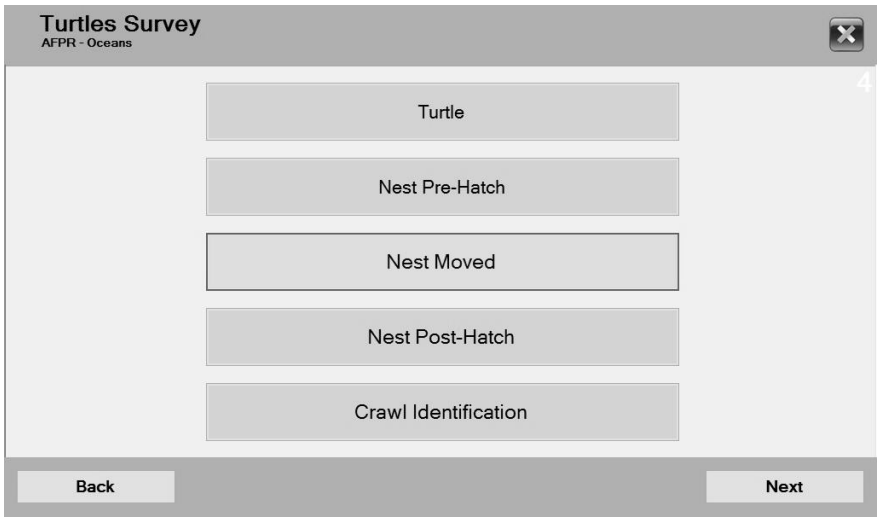

Figure 4. Window with menu buttons to select the data type for each case. This window enables the user to decide between boxes R1 (Turtle button), R2 (Nest Pre-Hatch button), R3 (Nest Moved button) or R4 (Crawl Identification) in the diagram in Figure 2; each box had a set of specific variables concerning the case. A new button, “Nest Post-Hatch,” that could be a R5 box, enabled the recording of nest variables after hatching. This button and the variables concerning a nest evaluation after eggs hatched exist in the software version that was tested (see Figure 6).

The set from 4.1.1. to 4.1.5. is about female turtles’ characteristics: 4.1.1. is the window where the user identifies the species (information for identification is provided); 4.1.2. has several fields where the user inserts information about old tags (kind, number, where it is applied), and new tags if they

are applied; 4.1.3. has a diagram of a turtle's plastron with the measurements is provided, and PTL and TTL measurements can be inserted; 4.1.4. provides a diagram of a turtle with the measurements: CCL, CCW, and track width can be inserted (for each, three fields are shown, since references (Eckert *et al.*, 1999) advice taking each measurement three times); weight, head length and width can also be inserted (this window is shown in Figure 5); and 4.1.5. asks for turtle activity, its health conditions, date (generated automatically), hour (generated automatically), information on additional experiments (*e.g.,* codes of sample taken for DNA analysis), turtle status after leaving the beach, and distinctive marks or characteristics of the turtle and provides a field for notes (free text).

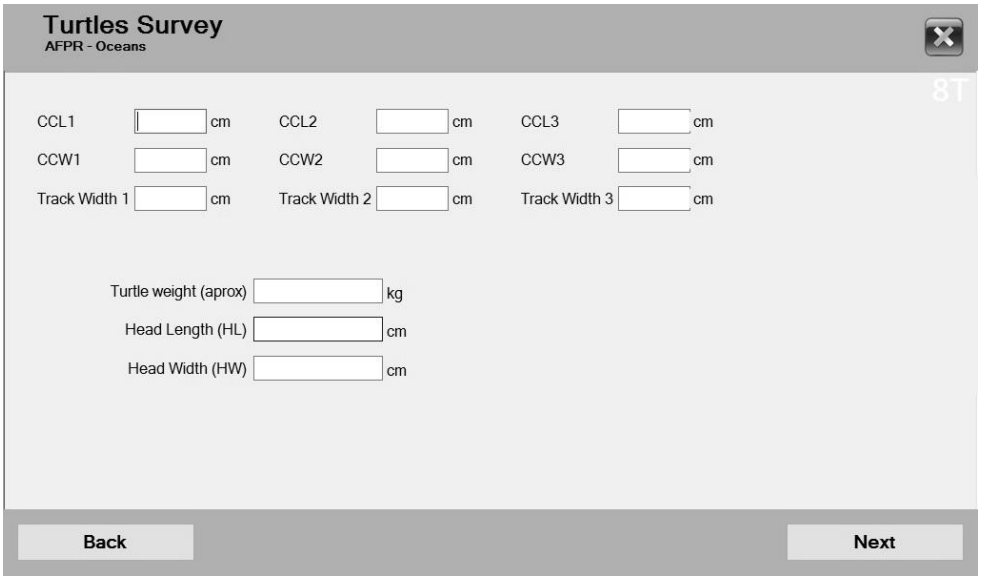

Figure 5. After choosing the R1 variable set (see Figure 2), several windows appeared in sequence, such as the window shown (which corresponds to window 4.1.4. from Figure 3). Turtle measurements, such as CCL, CCW, track width, weight, head length and head width, can be recorded in this window.

Windows 4.2.1. to 4.2.8. show a sequence of variables to record information about a nest that is found. Window 4.2.1. generates an automatic code for that nest (its tag), but the user can insert a different code after the automatic code. This code is generated with a code for the location and a number. Window 4.2.2. inserts the date (automatically). Window 4.2.3. asks for the name of the beach and area where the nest is seen (because many projects divide beaches per sections) and provides a third box to add more references. Window 4.2.4. allows the introduction of latitude and longitude of the nest and asks for type of mark that is used to identify the nest. Window 4.2.5. asks if the female is present (yes or no); if the user chooses the "yes" button, the software asks for the tag of the female. Window 4.2.6 collects information about the clutch size and automatically inserts the date of the eggs laid (redundancy); the user is asked for total number of eggs laid; if it is a partial or a complete clutch; number (#) of incubated eggs (with embryos), # yolkless eggs, and # multiyolked eggs; and time of deposition (inserted automatically but can be typed also). Window 4.2.7. is the nest data window, where the user inserts temperature of the sand (°C – measured at 50 cm of depth), sand humidity (%), location of nest along the beach (selects, or types), distance of nest to the high tide mark (selects) and inserts a value (meters); and measurements of depth of the nest (A) from the sand surface to the top of the first egg and (B) until the bottom of the egg

chamber. Finally, in window 4.2.8. the user can select the kind of vegetation, disturbances and obstructions around the nest; also, the user is asked about the dune height (m).
If the software user decides to move the nest to a hatchery, windows 4.3.1. and 4.3.2. are important to record the new information; first in 4.3.1., the user selects the nest from a list of nest tags, and then the user inserts the new GPS coordinates for the nest.
After the eggs hatched, the user will add information in windows 4.4.1. to 4.4.3. Window 4.4.1. allows the user to select and recover the nest tag. Window 4.4.2. allows the user to set the hatching date (generated automatically but can be typed), time of emergence; # of emerged hatchlings; # of live hatchlings in the nest; # undeveloped; # unhatched; # shells, # dead hatchlings; and the # of predated eggs/hatchlings. The species of the hatchlings is also selected (see Figure 6, which is a print screen of window 4.4.2.). Window 4.4.3. has fields for genetic sample codes (if necessary), and the user can choose what was the fate of the nest (flooded, invaded by predators, dislocated, or other); finally, the last field is the date of conclusion (automatically generated). If the user testimonies a “false crawl” behaviour or if the user only finds a crawl, the information can be added in window 4.5.1. choosing the type of track (buttons with images for green, loggerhead and hawksbill crawls and a button for other type); track width (cm) is asked; nest deposition (yes or no); and information about disturbance factors (from a collection of answers). If the user finds a nest, after fulfilling information in window 4.5.1., the user can skip to the “nest pre-hatch” windows.

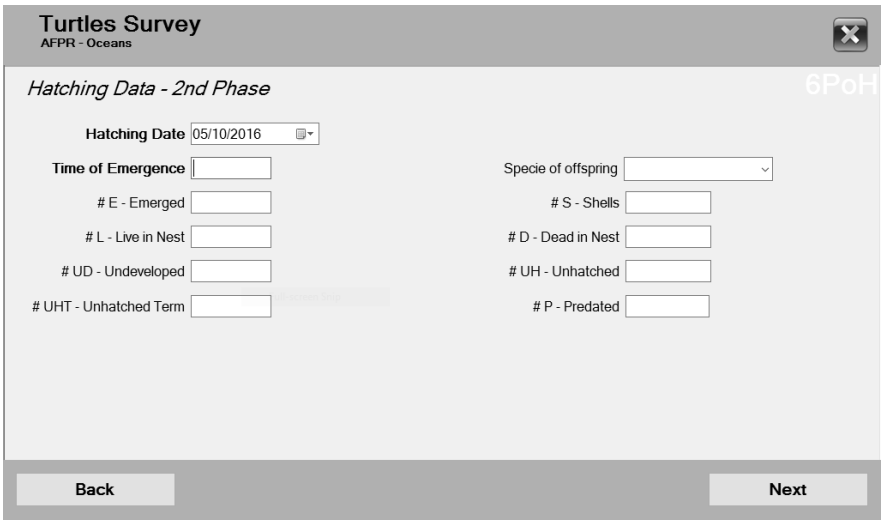

Figure 6. If the user had a chance to record data in box 5 (Figure 2), the variable set to fill in after the hatchlings left the nest; the user could use this window to choose the date, type the time of emergence, and select the offspring species and the count related to the excavation categories. By filling in all the fields, the software automatically computes the emergence and hatching success rates.

As shown in Table 5, the fields that are pre-filled or that required one-click selection represent 41% of all fields in the software. This means that the largest portion of fields is intuitive, fast to answer and enables the reduction of potential errors in the database by narrowing the answer to a set of pre-defined options. The number of buttons and fields does not indicate the number of variables necessarily. The type-in number fields are the more numerous (40%), which is justified by the need to take measurements (carapace, depth of nests, distances to high tide watermark, etc.) and

readings (of temperatures, of moisture, of tag numbers). The remaining 19% of the fields of the software are of type-in text and more prone to errors.

Table 5. Amount and type of fields per section and window (windows ID are the same as shown in Fig. 3).

Section	Login	Beach Weather		Record Type	Turtle Details					Nest Pre-Hatch								Nest Moved		Nest Post-Hatch			Crawl ID	Save	Total by Field Type	
Window ID	1.	2.	3.	4.	4.1.1.	4.1.2.	4.1.3.	4.1.4.	4.1.5.	4.2.1.	4.2.2.	4.2.3.	4.2.4.	4.2.5.	4.2.6.	4.2.7.	4.2.8.	4.3.1.	4.3.2.	4.4.1.	4.4.2.	4.4.3.	4.5.1.	5.		
Multiple Buttons	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	4	3%
Checkbox Option(s)	0	0	0	0	0	5	0	0	0	0	0	0	0	2	1	0	2	0	0	0	0	1	0	0	11	9%
Drop Box	0	2	6	0	0	5	2	0	3	1	0	1	0	0	0	2	0	0	0	0	1	0	2	0	25	22%
List Box	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	2	2%
AutoFill	0	0	0	0	0	0	0	0	2	0	1	0	0	0	1	0	0	0	0	0	1	1	0	0	6	5%
Type-in Number	0	3	2	0	0	1	2	12	0	1	0	1	2	0	4	5	1	0	2	0	9	0	1	0	46	40%
Type-in Text	2	4	1	0	0	2	0	0	3	0	0	1	1	2	0	0	1	0	0	0	0	5	0	0	22	19%

The version that was tested allowed the user to navigate with few restrictions. However, it is intended that the following versions have more restrictions. For example, to skip to the variables about the turtles, the user must previously fulfil data concerning weather conditions. The idea is to avoid creating databases with missing fields.

Though it is a proof of concept, the software is available by contacting the authors. The strategy is also to adapt the tool for each project focus, *i.e.*, each project can set the group of variables they need in their software version.

Pilot Study

The Turtles software was tested from June 1st to July 31st during the night patrols by one biologist (software user). The patrols were done between 9 p.m. and 2:30 a.m. (time varied until 3 or 4 a.m., depending on the nesting behaviour) from Monday to Friday by one biologist that accompanied one *Tortuguero*. Each night, one beach was patrolled by the pair. The two main beaches (with higher densities of emergences and nests) were patrolled alternately (Half Moon Bay and Jade Bay) by this pair during each week. Each night, the tasks were divided on the field, but all records were made by the two workers. The biologist used the software in the field, while the *Tortugueros* entered the data manually on paper forms followed by CEA staff entering the recorded data into an Excel spreadsheet (paper forms database). Comparisons were then made between exported data from the software with that provided by CEA.

Samples and Variables for Data Analysis

The data focused on *Chelonia mydas* and *Caretta caretta,* the two species that nest in Jade Bay and Half Moon Bay (Figure 1). After completing each record in the field (for example, per turtle, or per nest), the software allows the user to save (and add) the information to the Access table. This information is available to the user to be transferred to other programmes, such as Microsoft Excel.

From each method (traditional with paper forms and the software), samples for a variable set were chosen, since the original databases were different in organization and number of variables. Then, the two related samples (the paper forms sample and software sample) were compared without subsequent modification.

The two complete datasets were compared to assess the potential benefits and drawbacks of the software compared to the traditional methodology when building tables for statistical analysis. Information that disturbed data analysis was found (*i.e.,* different texts concerning the same thing

for the same variable). It implied standardization and correction of information on those variables (in the paper forms database), before statistical analysis/tests were performed. Variables of the paper form database were standardized using the Microsoft Excel 2007.

To determine whether the software methodology would interfere with the user's performance in the field, the averages for records and data collection were determined. A field in the database is a cell fulfilled (or not, which is the concept of missing value) with information concerning a variable. A record is a complete row of fields concerning a single turtle or a single nest.

The average number of records was determined using the paper forms database as a reference to determine the performance and impact of the software in the field work. The average of fields fulfilled was also determined; the variables were gathered by categories (four categories in total, *i.e.*, "Turtles seen or not seen (includes false crawls)", "Turtles seen", "Nests seen", and "Nests moved"). These averages are indicators that allowed concluding if the software is suitable for field work in terms of quantity and quality of data recording. This work was done in Microsoft Excel 2007.

For the records of both databases, several data consistency parameters were analysed, such as the mismatch of content, the lack of dependent variables, and the amount of unrealistic data, which were indicative of data integrity. The analysis implied determination of the percentage of missing fields on records; GPS location of the nest; time of the record; user name and nest ID; and percentage of errors in the fields (an error implied correcting it when possible, or discarding it when the value was absurd). Errors were divided into two categories: "different answers for the same value", and "inconsistent data". For "different answers for the same value", information that fitted one of the following two groups was included: "different texts for the same user" and "different texts for the same turtle false crawl reason". The error "inconsistent data" includes the "mismatch between total number of eggs and the sum of the partials" (meaning errors in formulas that the software avoids), and "GPS data out of the range of the region" (see Table 1 in the "Results and Discussion" section).

Conclusions

Our pilot study of the Turtles software suggests it to be a more efficient and reliable method in comparison with the traditional paper forms recording methodology and the subsequent data transcription for nesting marine turtle conservation programmes. The software can help to increase the reliability of estimated trends. Moreover, it can contribute to the global standardization and sharing of recorded information. It should be made available online so it can be adopted by nesting turtle projects that are interested in replacing paper records with an easier and a more reliable solution that uses tablets or smartphones.

A software *per se* will not ensure data quality. However, if combined with a well-delineated methodology, it will certainly improve field data collection, specifically because data will be added to a database the moment the software user in the field saves the information. Additionally, software applications can use code and predefined answers, making databases intelligible. The principle that a "collective focus should be to achieve comparable, replicative results with accuracy and precision" (Eckert *et al.*, 1999) was considered. Following this principle, an easy-to-use solution was designed to generate data that can be easily sent to statistical analysts, so that results about the collected field data can be generated but also increase the power of the field work.

Ethics

All methods were carried out in accordance with relevant guidelines and regulations imposed by CEA (2016) and SEMARNAT (DOF 2013). Additionally, all experimental protocols were approved by the same entities.

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Author Contributions

This work was developed solely with the authors’ financial resources. R.A. and M.J.P. conceived the software, K.S. coordinated the Opwall operation in Akumal, R.A. coordinated the Opwall student’s field work, J.M.G. coordinated the Tortugueros team for CEA, and R.A. and M.J.P. analysed the results.

Additional Information

Competing Interests: The authors declare that they have no competing interests.

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Capítulo IV

Educating on global perspectives

Anastácio, R.S.S., Azeiteiro, U.M.M., Pereira, M.J.V. (2012) Climatic Changes, Nutrient Imbalance and Primary Productivity in Aquatic Ecosystems. Tropical Oceanography, 40(1): 1-16. ISSN: 1679-3013, 10.5914/1679-3013.2012.0060

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Climatic Changes, Nutrient Imbalance and Primary Productivity in Aquatic Ecosystems

Abstract

Purpose – It's the aim of the authors, based on a minireview of published information, to present a view of possible consequences of climatic changes associated with biogeochemical cycles and nutrients availability to phytoplankton and primary productivity. *Approach* – In this paper the authors assume the possibility that changes associated with climate will determine the disappearance of many species, a redistribution of that prevailing, and the change of the environmental quality, as well as of the quality and quantity of mass and energy, established and available to consumers. *Findings and Social implications* – The dependency of the primary productivity on several factors, and their change, the quality and quantity of electromagnetic energy, the proportion of atmospheric gases and dust, the change of temperature patterns, the acidification of water bodies, the introduction and/or remobilization of nutrients and toxic substances associated with biogeochemical cycles and a non-sustainable exploitation of resources, could reduce the flow of energy to higher trophic levels, and may result in problems associated with food security at a local, regional or global scale. *Originality* – The authors highlight the consequences of possible changes on ocean primary productivity due to pH lowering, due to the increase of carbon dioxide solubilization and associated nutrient imbalance.

Keywords

Phytodiversity, phytoplankton, ocean acidification, metals, nutrient imbalances, food chain.

Introduction

Productivity associated with phytoplankton depends on several factors, such as light and associated flow of energy, temperature, pH and quantity and quality of nutrients.

The diversity of optimum rates and amplitudes tolerated by many species allow the assumption that each organism will occur in a multidimensional vectorial space, away from the origin of axes, the more extreme value or set of parameters that prevail to its existence as a vegetative form. Changes of the equilibrium, which prevail during speciation, will provide the redistribution of phytoplanktonic species in before prohibited latitudes, but will also be responsible for disappearance or non-occurrence of many species. The decrease of phytodiversity is largely illustrated in eutrophic environments, or where toxicity, due to several elements, ions or substances, exceeds autochthonous species tolerance. The quantity and quality of light available to primary producers depend not only, of the path till it reaches the aquatic medium surface but also of its hydrodynamism, transparency and depends on the energy associated with the wave length that composes visible light spectrum. Nutrient rich environments frequently present low diversity and high turbidity due to excessive production. The apparent resultant benefit of the high fixation of energy brings problems in the recycling process of matter. This changes the organoleptic characteristics of water which is used in several activities, like cooking and drinking, agriculture and

industry. Another problem is that it depletes water from nutrients, facilitating the growth of species with competitive advantages, due to the ability to store these nutrients or mobilize them from other compartments (such as atmospheric nitrogen, fixated by other groups of filamentous cyanobacteria), or to the production of biotoxins against its competitors. Changes of pH in several aquatic formations, due to carbon dioxide concentration and the increase of global temperature, is enabling the redistribution of species (*vide* invasive species). This change affects metals speciation and chemical equilibrium of the different chemical species present in aquatic environments (fresh, brackish and marine). Ocean acidification will change concentrations and proportions of dissolved ions, complicating, for example, calcium precipitation, essential for several species and groups of phytoplankton and coral reef formations. The increase of solubility of many metallic species, essential as macro or/and micronutrients, will enable the achievement of toxic concentrations. This will promote a reduction of phytodiversity and the prevalence of less sensitive species.

Inherent to the decrease of plankton diversity is an abundance alteration of several organisms, as well as their capacity to live. Interactions in and between trophic levels will show disturbances. These will be due to the quality and quantity of edible mass and available energy. Blooms of toxic species, such as those belonging to dinoflagellates and cyanobacteria, associated (among others) to higher temperatures will reduce also the space-temporal availability and quality of food. These last factors, frequently referred as lower quality food, will contribute to the change of mass and energy available for higher levels of the trophic chain. These reductions (also associated with extensive fishery) will affect/reach higher levels (human level) and will jeopardize food security in a period in which the debate about alternative energies overcomes the necessity to find an alternative to petroleum and its derivates.

Climatic changes and primary productivity

Phytoplankton contributes to half of the production of organic matter on the planet (Field et. al., 1998). This corresponds to 96% of the annual carbon production by oceanic plankton (23.9 x 1015gC) (Buffle, 1990). Coastal regions contribute with 25% of that production (Murray, 1994), representing, in average, the double (100gC/m2/yr) of that estimated for the remaining ocean (Ryther, 1969). This productivity is limited by the quantity and intensity of light (Ryther, 1954a) and nutrients (Ryther, 1954b).

Oceanic organic matter can be considered as a derivate of inorganic materials converted into algal biomass via photosynthesis (Murray, 1994). This process (carbon fixation and resulting organic flow of energy in aquatic medium) can be presented by the sequence atmosphere/ (light + CO_2 + nutrients) – phytoplankton – trophic chain (Buffle, 1990), and by the equation: $106CO_2 + 16HNO_3 + H_3PO_4 + 122H_2O \rightarrow (light) \rightarrow (CH_2O)106(NH_3)16(H_3PO_4)$ (Redfield et. al., 1963).

The Electromagnetic spectrum and the quantity of energy which reaches rivers, lakes and ocean surfaces and that will be available to be used by primary producers depend on the latitude and time of year (Kimball, 1928), of its path (Pike, 1962), of the interaction with atmosphere components, of particle quantity (Kimball, 1928; Drummond *et al*., 1958), of diverse gases (Drummond et. al., 1958) including water vapor (Kimball, 1928; Drummond *et al*., 1958), carbon dioxide, oxygen, nitrogen, ozone by absorbing and diffusing it (Drummond et. al., 1958).

In the surface (Sverdrup et. al., 1946; Strickland, 1958) and through the water column (Morel, 1991, Johnsen; Sosik, 2004) the penetration of light depends on factors like its wavelength energy

(the most energetic reaches higher profundities), obstacles (Ohlmann et. al., 1996), pigment concentration (Baker; Smith, 1982), organic matter and particles in suspension (Murray, 1994).
The concentration of carbon dioxide in atmosphere has been suffering an increment since the beginning of the Industrial Era (Murray, 1994), and it has been showing an evolution from 280ppm, existent before that period (and which remained for a large period in earth's history) (IPCC, 2001), to 389 ppm in September 2011 (NOAA, 2011). In 2005, it was of 380 ppm (Raven et. al., 2005), which corresponds to an average annual increment, to our period of 1.7 ppm. Annual emissions contribute with 7 X 109 t C, in the form of carbon dioxide, to the atmosphere (Schlesinger, 2004) and some projections indicate the possibility of reaching 1000 ppm in 2100 (Raven et. al., 2005).
The concentration of carbon dioxide and of species present in ocean waters depend, not only, of the salinity, but also, at a similar salinity, of the pH of the medium, showing itself, according with that last one and in different percentages, in its molecular form or in the ionic forms of bicarbonate or carbonate (Buch, 1951). The modification of the partial pressure of that gas in the atmosphere allows its dissolution in aquatic medium at a greater quantity, till it reaches equilibrium. Its reaction with water allows, by carbonic acid dissociation, the formation of bicarbonate and carbonate. If the buffer capacity of the conjugate acid/base pair exceeds a limit, hydrosphere acidification will take place.
The 'Ocean acidification due to increasing atmospheric carbon dioxide' (Raven et. al., 2005) report summarizes the possible effects of the increase of the carbon dioxide in atmosphere, in oceans acidity before and for the XXI century. In the last 200 years has been occurring, due solubilisation of carbon dioxide in the ocean, a reduction of 0.1 units in the pH value (Caldeira; Wickett 2003), corresponding to an increase in the hydrogen ions concentration of 30% (Raven *et al*., 2005). It is estimated that the increase will reach 0.5 units in the following 90 years. To ensure the average value of 8.2 ± 0.3 can be reduced to 7.5 – 7.4 (Caldeira; Wickett 2003; Raven et. al., 2005), with consequent reduction of hydrogen and carbonate ions in superficial waters. This will affect also metals speciation and its adsorption to organic matter and increment of its free forms (Millero et. al., 2009).

The Metals Factor

In addition to environmental factors such as light, pH, and carbon, is also known the importance that many elements have in algae development. Many elements are known as essential to a balanced development of phytoplankton, that when scarce can limit its development, or, due to its toxicity, condition phytoplankton development (when in excess). Plants and algae need several elements and substances at different rates of abundance/ availability/ concentration to express entirely their life cycle. Elements and substances contribute to the manifestation of each stage of the cycle in plenitude. These nutrients are (besides phosphorus and nitrogen) vitamins, amino acids and vestigial elements, resultant of biogeochemical processes, but also, and in several cases in great part, of human activity at a local or
global scale (domestic, agricultural and industrial); these processes disperse nutrients between and through biosphere compartments.
It is possible to find 90 chemical elements in nature (Greenwood; Earnshaw, 1995), 25 in biological systems (C, O, H, N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Mo, B, Cl, Na, V, Cr, Si, Co, Ni, Se, F, I) (Silva; Williams, 1991) being, at least, 20 used by plants (Santos, 1991).

In what is concerned to vegetal nutrition, elements can be separated in three groups: essential, beneficial (essential elements to some plants, only) and toxic. In the essential group are: C, O, H, N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, Mo, B, Cl; in benefitial group are: Na, Si, Co e Al; and in the toxic group can be considered: Pb, Cr, Cd, Hg, I, Br, F e Se (Santos, 1991). In algae nutrition requisites also is included these essential elements and some of the beneficial referred, such as Na to Cyanoprokaryota, and Si to diatoms (Gaur; Rai, 1994), as well as to Chrysophyceae and some Xanthophyceae, where they appear as component of scales, schist's or of cell wall. These elements, constituents of organic molecules such as proteins and nucleic acids (N) (Vincent, 1992), enter, like phosphorus, in NADPH and ATP compositions, as well as in less energetic forms, nucleic acids, phospholipids and phosphoproteins. Potassium is involved in sugar and nitrogen metabolisms, and in protein synthesis, in the organic acids neutralization and in enzymes activation. Magnesium is a constituent of chlorophyll and acts as stabilizer particle of ribosomes, maintaining the necessary configuration to protein synthesis. It is indispensable for the maximum functioning of enzymes, intervening in sugar metabolism and it is a cofactor of enzymes which activate phosphorylation process. Sulfur is a component of aminoacids as methionine and cysteine, in vitamins as biotin, thiamine and in ferredoxins. At the micronutrients level it stands out iron (Fe^{2+} e Fe^{3+}), Mn^{2+}, Zn^{2+} e Cu^{2+}. Iron is absorbed in the less oxidized forms. It participates in oxi-reduction reactions due to oxidation states +2 and +3, being part of cytochromes and ferredoxins. Manganese enters in the constitution of enzymes, where it acts through mechanisms of oxi-reduction. It is absorbed in the divalent form.

Also zinc is absorbed in the divalent form. It intervenes in enzymes connection to the substrate (Santos, 1991). In algae, like it happens to other organisms, some elements (Fe, Zn, Cu, Mo, V, Cr, Co, Ni, Se, As, Sn) are only necessary in vestigial quantities, participating in enzymatic processes (Wilde; Benemann, 1993).

As a result of human activity, many elements have been introduced in biosphere, in a scale that does not permit to biological systems, connected to the biosphere, easy and fast adaptation. The actual exploitation of energetic resources has been changing quantities, proportions and distribution of gases (CO_2, O_3, CH_4, nitrogen oxides) (Silva; Williams, 1991). Also, a great number of metals has been introduced in nature (atmosphere, lithosphere, hydrosphere) by the very diverse human activity. The sources of heavy metals are the natural erosion and the human activity, domestic or industrial.

The industrial influence is noticed in the increase of the Cd, Cr, Pb, Hg and Zn levels (Meybeck et. al., 1989; Filippis; Pallaghy, 1994); also the case of copper levels, present in water, can be due, partially, to non treated domestic effluents, industrial effluents, car exhausts and open incineration (Shibert; Shatila, 1979). These can be associated to car use (Ba, Cd, Cu, Ni, Pb, Zn) and associated to consumption of fossil energy sources, petroleum derivates (Cu, Mn, Pb, Sb, Sr, Zn) (Lin et. al., 2005, Wang et. al., 2003) (Ag, Cd, Ba, V) (Lin et. al., 2005) (Al, Ca, Co, Cr, Fe, Mg, Mo, Ni, Si, Ti) (Wang et. al., 2003) and coal derivates (As, Se) (Manoli et. al., 2002; Swietlicki et. al., 1996). The development of new technologies, like nanotechnology, can contribute in the future to the biosphere introduction of those or other elements that are nanoparticles constituents (e.g. Au, Co, Ti (Li et. al., 2007), Zn (Yang; Xing, 2009).

Oceanic waters show, in average, 0.120 mg/Kg of Cu, 0.390 mg/Kg of Zn, 0.480 mg/Kg of Ni and 0.001 mg/Kg of Pb, having, the majority of elements, an atomic number above 21 with concentrations inferior to 1 mg/Kg (Quinby-hunt; Turekian, 1983) and occurring in the form of ion

pairs or complexes, particularly constituted with carbonate, chloride or hydroxide ions (Turner et. al., 1981; Murray, 1994). These elements can be concentrated by phytoplankton (Sorentino, 1979; Pereira et. al., 2003b). Metals can be rapidly sequestrated by cells or portions of these cells (Volesky, 1990). The

capacity of biosorption is being dependent of a number of external factors: pH, temperature, bicarbonate and suspended solids (Wilde; Benemann, 1993) as of the metal type, ionic form in solution and of the particular type of active site responsible for the metal capture (Kuyucak; Volesky, 1988; Volesky, 1990). Other factors can be added to those: light, salinity, cations and anions, sulphur in aminoacids and colloids (Filippis; Pallaghy, 1994). In metallic complexes bio-absorption by algae, can occur an interaction between functional groups from the surface cellular matrix, allowing substitution processes between metal ligands and algae, or verifying and interaction between ionic metal complexes with polar or charged groups of algae (Watkins et. al., 1987).

The bio-remove of metals involves active and passive transport processes. Initially a fast and passive process occur, resultant from the metal bond with cellular surface, extracellular matrix, wall and membrane, followed by an active process (Wong; Pak, 1992). Metals capture by cells or its constituents can be made by: adsorption, ionic change (Stokes, 1975), complexation, coordination, chelation and inorganic microprecipitation (Volesky, 1990). Each one or the combination of the mechanisms above referred, can contribute to the immobilization of one or several metallic elements.

Metallic cations are attracted to sites in cellular surfaces negatively charged (Volesky, 1990). From the moment when metal reaches cellular surface, it interacts with the cell wall or membrane (Kuyucak; Volesky, 1990), and it bonds to sites of that surface that show affinity to the metal (Wilde; Benemann, 1993). A number of anionic ligands participate in the metal sequestration: phosphate, carboxyl, sulfhydryl and hydroxyl groups from protein membranes (Volesky, 1990). This process, normally, is fast and reversible. Bio-absorption is followed, generally, by a slowdown in the process of adsorption. This slowdown can be due to several mechanisms which include: covalent bonds, surface precipitation, oxi-reductions reactions, crystallizations in cell surface and diffusion to cell interior, with sequestration of the metal by cellular proteins and to other intracellular sites (Wilde; Benemann, 1993). The two principal mechanisms responsible for bio-absorption, referred by Wilde and Benemann (1993) are ion-exchange, in which ions like sodium, magnesium and calcium, are dislocated by metallic ions, and complexation processes between metals and several functional groups, such as carboxylic acids, amines, thiols, hydroxyl groups, phosphate and carbonyl.

Cell wall composition plays an important role in metals adsorption (Lorch, 1986), capture and bonding (Kuyucak; Volesky, 1990), considering the pectins and other substances with capacity to bond with metals present in cell wall; there is a capacity of the cell to store metals (Lorch, 1986), even when the organism is dead (Kuyucak; Volesky, 1988; Volesky, 1990; Pereira et. al., 2003).

Algae cell walls are constituted by microfibrils, responsible for giving form and rigidity. These microfibrils are embedded in unshaped material of diverse nature. They are constituted by cellulose in Chlorophyta (Volvocales, Chlorococcales, Ulothricales, Desmidiales), Chrysophyceae, Xanthophyceae, Dinophyta, Phaeophyceae and in Rhodophyta. Hemicelluloses can also occur (Chlorophyta - Oedogoniales), showing substances of pectin embedding them (Chrysophyceae, Volvocales, Ulothricales, Zygnematales, Rhodophyta). Some groups show other polymeric chains,

constituted by mannans, galactans, sulphated fucose, or by uronic acids like algine (mannuronic and glucuronic acids). Rhodophyta show a diverse polymer carrageenan besides agar and, sometimes, $CaCO_3$ mixed with cellulose and pectins. Many forms produce polysaccharides which make part of the sheath, as in a Cyanoprokaryota, Xanthophyceae and Volvocales (Bourrelly, 1968, 1970, 1971, 1972; van den Hoek *et al*., 1995). Euglenophyta mucilage also shows particular composition (mucopeptides – amine glucose, sulphated glucose, cysteine) (Pereira; Azeiteiro, 2003b). These walls and mucilaginous material can appear impregnated by calcium carbonate (Chrysophyceae, Volvocales), by silica (Bacillariophyceae, Xanthophyceae) and most frequently by iron salts (Chrysophyceae, Desmidiales) conferring rigidity to envelopes (lorica) in Chrysophyceae, in certain Volvocales or, in larger scale, in *taxa* of *Trachelomonas* and *Strombomonas* genera. Few are the constituent monomers of these molecules, whether they are neutral, whether they are oxidated: glucuronic and galacturonic acids. In them we can find frequently forms such as *N*-acetylglucosamine, constituent of the cyanoprokariota walls (Bourrelly, 1968, 1970, 1971, 1972). Species from the *Trachelomonas* genus also possess a very diversified organic matrix (Pereira et. al., 2003b) mineralizable (Rino; Pereira, 1991a, b). That process is reversible, pH dependent (Pereira et. al., 2003b), and the quantity and type of ions, particularly of Fe and/or Mn (Rino; Pereira, 1991a, b; Pereira et. al., 2003), determining the quantity and quality of energy that crosses the external matrix and reaches photosystems. Some Chrysophyceae have envelopes in a certain way uniquely organic, constituted by cellulose or chitin associated with other polysaccharid or proteins, frequently occurring, in this last case, mineralization due Fe, Mn, Ca, carbonate and silica compounds (Dunlap et. al., 1987). The study of species like *Kephyrion* and *Pseudokephyrion* (chrysophytes) showed the presence, in their lorica, of iron in the form of manganese spicules and granules, verifying a spatial segregation of these components when both are present (Dunlap et. al., 1987).

The calcium carbonate, common mineral present in biological systems (Silva; Williams, 1991) component of many scales (cocoliths, Coccolithophorids) (van den Hoek et. al., 1995) and loricae of phytoplanktonic species (Phacotaceae) (Hepperle; Krienitz, 1997), precipitates to calcium concentrations of 5×10^{-3} M, and in $1^{-10} \times 10^{-3}$ M for HCO^{3-}, being that process sensitive to pH, temperature, pressure, ions and salts concentrations (Silva; Williams, 1991). Precipitation of calcium carbonate in *Phacotus lenticularis* loricas mineralization, also depend on environmental factors, as pH and saturation of calcium carbonate of the medium (Hepperle; Krienitz, 1997). Species of *Phacotus* (*P. lenticularis* e *P. sphaericus*) use in their loricas construction calcite ($CaCO_3$), removing it from the medium. Its occurrence depends on several environmental factors such as temperature (17-22 ºC), pH (8.30-9.65), nutrition (N/P > 7) (Krienitz et. al., 1993). Although calcium is the predominant element, other elements can be found, besides sulphur, in *Phacotus lenticularis*, such as P, Cl, K, Na, Al, Si and, sometimes, As and Ba (Procratsky, 1982). Other Volvocales, belonging to the *Dysmorphococcus* genus (*D. globosus*), have a lorica composed of one part where calcium is a secondary element, occurring iron and manganese as the principal elements (Dunlap; Walne, 1993).

Physico-chemical parameters like temperature (Wong et. al., 1978), pH, oxireduction potential, ions composition, mineral particles, organic matter content, light and hydrostatic pressure, influence the chemical form, mobility and availability of elements and substances, and their toxic effects to the biota (Babich; Stotzky, 1980).

Individual or combined metals toxicity, in relation with algae, will depend on the type of metal (Verma et. al., 1993; Pereira *et al*., 2005), $Hg^{2+} > Ag^{+} > Cu^{2+} > Pb^{2+} > Cd^{2+} > Zn^{2+} > Tl^{-}$ (Canterford; Canterford, 1980) of its concentration $Hg^{2+} > Cu^{2+} > Cd^{2+} > Ni^{2+} > Cr^{2+} > Zn^{2+} > Cs^{2+} > Pb^{2+}$ (Pereira et. al., 2005), and of biotic and abiotic factors (Vymazal, 1990). Metals toxicity, combined or not, will depend on the type of its form (metal species), concentration, pH of the medium and of the presence of natural (phosphate) (Verma et. al., 1993) or artificial ligands (EDTA, citrate, glycolic acid), being more toxic in its ionic form (Starodub et. al., 1987) and acid medium (Michnowicz; Weaks, 1984; Starodub et. al., 1987; Lee et. al., 1991). As a whole include: the concentration of metal, affinity for binding sites, electronegativity, duration of exposure, concentration of other ions (other heavy metals, phosphorus, calcium, magnesium), pH, complexing and chelating agents, redox conditions, temperature, light, turbidity and species characteristics (cell wall, mucilage, cell composition), concentration of algological biomass, extracellular products, stage of development, cellular activity (Vymazal, 1990) as well as the capacity/ impediment that has to access the site at the cellular level (nucleus, mitochondria, chloroplasts), where it exerts its effect. Extracellular matrices and nature of its composition (Vymazal, 1990; Pereira *et al*., 2003) membranes (Mierle; Stokes, 1976) are important barriers, conditioning the motility of those elements to cell interior (Silva; Williams, 1991).

Metals exert larger toxic effects on algae if its concentration increases (Pereira et. al., 2005); these effects include reduction in growth rate and death (Sorentino, 1979; Kerry; Laudenbach, 1988; Mallick; Rai, 1989, 1990; Lee *et al*., 1991; Winner; Owen, 1991; Asthana *et al*., 1992; Pereira *et al*., 2005; Rodriguez, 2011). Metals affect the shape, morphology (Sorentino, 1979; Lazinsky; Sicko-Goad, 1983), the biovolume (Thomas et. al., 1980; Lazinsky; Sicko-goad, 1983; Tornqvist; Claesson, 1987; Gensemer, 1990; Visviki; Rachlin, 1992; Rodriguez et. al., 2011), and ultrastructures (Gupta; Arora, 1978; Shehata; Badr, 1980; Heumann, 1987) of algae. They changed (Cu, Cd, Cr, Ni, Zn) photosynthetic activity (Singh; Singh, 1987; Rai; Raizada, 1988; Gupta, 1989; Wong; Chang, 1991), respiration (Cu, Ni), carbon dioxide and other nutrients absorption (Peterson et. al., 1984; Mallick; RAI, 1990) and its incorporation (Ni, Cu, Hg, Cd) (Sastry; Chaudhary, 1989), pigment content (Pettersson et. al., 1985), ATP (Stauber; Florence, 1987), and DNA (Sorentino, 1979; Sastry; Chaudhary, 1989). The various groups of algae have different sensitivities to the effects of metals (Takamura et. al., 1989). The planktonic communities are affected by metals such as Hg, Cu, Cd, Zn and Pb, which causes a decrease in photosynthetic activity (Singh; Singh, 1987; Rai et. al., 1991), in productivity, diversity (Gachter; Máres, 1979; Foster, 1982; Genter et. al., 1987; Chapin III et. al., 2000) and structure (Foster, 1982; Worm; Duffy, 2003). This changes the community and favors the survival and abundance of less sensitive species (Thomas; Seibert, 1977; Gachter; Máres, 1979; Sorentino, 1979).

Benthic communities (Williams; Mount, 1965; Dickman et. al., 1990) and phytobenthos are also affected (Reese, 1937; Dickman et. al., 1990). Immobilization of nutrients such as phosphate by precipitation with aluminum, also changes that diversity. Associated with its toxicity, determines an indirect effect on the abundance of zooplankton (Hornstrom et. al., 1984).

Conclusion

Productivity associated with phytoplankton (Mendes et. al., 2009; Resende *et al*., 2005, 2007) and other trophic levels (Abrantes et. al., 2006; Azeiteiro et. al., 2006; de Figueiredo et. al., 2007, 2009,

2010; Marques et. al., 2007; Lopes et. al., 2009) depend on several abiotic factors. The alteration of equilibriums which have been prevailed to its occurrence, (Figueiredo et. al., 2006; Pereira; Rino, 2001; Pereira; Azeiteiro, 2003a; Pereira et. al., 2010), will able a redistribution of phytoplankton species, but also will preside to the disappearance, or non occurrence, of several species.

The decrease of phytodiversity is largely illustrated in eutrophic mediums, or where toxicity due to certain elements, ions and substances exceed tolerance limits of autochthonous species (Pereira et. al., 2005; Gerhardt et. al., 2008; Rodriguez, 2011).

The excessive growth of algae (due to a natural or artificial introduction of nutrients in the aquatic environment), leads to deterioration (Figueiredo et. al., 2011; Thompson; Rhee, 1994), expressed by higher levels of organic matter, reduction in transparency, color, pH, conductivity / salinity (interior mediums), dissolved oxygen and its percentage saturation, sometimes with its absence in the water (Abrantes et. al., 2006).

The occurrence of periods of anoxia allows the formation of sulphides and the release, from sediments, of iron, nitrates and phosphorus. The increase of biological productivity, which characterizes the eutrophication, has negative effects on the remaining biota (Thompson; Rhee, 1994) reducing diversity and changing relative abundance (Abrantes et. al., 2006; Figueiredo et. al., 2006, 2007; Lopes et. al, 2009; Marques et. al., 2007). The production of allelopathic substances (Figueiredo et. al., 2004a, 2011), biotoxins (Hallegraeff, 2003; (Figueiredo et. al., 2004b) and of chemical contaminants in the environment has a toxic effect (Abrantes, 2008) on many different types of organisms and affects the organization of biological processes at a cellular level, population level, communities level and ecosystems level (Boyle, 1984).

Changes in productivity of aquatic ecosystems may also result, admit the authors of this study from the presence of metallic nanostructures, such as those described by Halas (2010). These metallic nanostructures possess the ability to interact with electromagnetic radiation, and may be responsible, if present in abundance in the medium, not due to toxicity of metals by itself (these are inert and/or are not found dissolved) but because they act as chromophores, absorbing and selecting wavelengths that will be available for primary producers. The reduction in primary productivity over the last century associable to: the climate, temperature of surface waters (Boyce et. al, 2010), the atmospheric temperature range, the quantity and quality of light, the nutrient levels in which each phytoplanktonic species develops, and pollutants that are able to tolerate, will originate, also, changes in diversity and relative proportions of species of the phytoplankton community, and it can lead to a change in phytogeography, in the quantity and quality of mass, and in energy available (in space and time) for the primary consumers.

Ecosystem services, food, protection provided by coral reefs (Duraiappah et. al., 2005) may be compromised (Raven et. al., 2005). Associated with this phenomenon, the fully exploited or overexploited stocks of fish (FAO, 2009) collected by industrial fishing fleets (Watson; Pauly, 2001), or the artisan fishing communities that, in the intertidal zone, collect these resources for daily subsistence, can contribute in a significant way to the reduction of energy that may be available to man. The effective management of fisheries resources (Mora et. al., 2009), the catch of ichthyoplankton, of juveniles and non-target species, and the loss of matter and energy transfer to top consumers will certainly carry severe consequences at local, regional or global scale, associated with food security for a world population that continues to grow and has a geographical distribution that is not consistent with the resources generated and/or available.

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Global Science Teaching for Human Well-Being

Abstract

A *curriculum* framework for seven years of science education is delivered as a proposal for discussion, for the nine years of schooling that the Incheon Declaration defines as compulsory (ID UNESCO 2015). Every child should learn Science in their mother tongue, hence at least one global science curriculum should be provided for free, translated for free, and posted in a public site. The materials derived from the same *curriculum* should be provided with the same perspective: translated into the child's mother tongue, easily available and free. These derived materials should address as well the traditional/local knowledge, respecting indigenous cultures.

We strongly believe that, to achieve the 2030 goals for education, a massive global act of passion altruism that puts each teacher and pedagogue's creativity at the service of global science teaching. For other subjects, the feeling and convictions are the same. But, because we all depend on ecosystems that sustain us, to deliver that message using a science *curriculum* is an obligation.

Sharing a global science *curriculum* open to change and debate that conjugates Biology, Geology, Physics, and Chemistry, while having in consideration the sustainable development goals, is the aim of this manuscript.

Keywords

Science *Curriculum*, Human Well-being, Sustainable Development Targets

Introduction

"Education is the most powerful path to sustainability. Economic and technological solutions, political regulations or financial incentives are not enough. We need a fundamental change in the way we think and act." (Bokova, 2012)

Ethics is, according Savater (1995), the art of living well, of knowing how to live. To have, practice, and manage the art of living well is ought to provide a good life. A good life implies choosing, which for those with less academic resources is more difficult (see http://idsn.org/key-issues/education/).

Our well-being depends on the existent biodiversity and on ecosystems' prosperity (MEA 2005). However, people still choose to deplete natural resources, affecting other species, hence reducing biodiversity (Rands et al., 2010), and even annihilating it (see Ceballos et al., 2017).

The 2000-2010 decade was productive in ideas, congresses and documents about how the loss of biodiversity jeopardizes our future. It is the decade of the Millennium Development Goals (MDGs), and of the Millennium Ecosystems Assessment (MEA). The MEA (2005) highlights the fact that society does not understand completely how biodiversity and well-being are linked. Most people recognize that their lives depend on natural functions, which provide fresh water, food, shelter, fibers; but people take the benefits they take from Nature for granted (MEA, 2005).

In developed countries, schools teach how important it is to preserve biodiversity. Of course, in these countries, native biodiversity has been deeply affected by the development of societies through centuries (Despommier, 2010). We became aware of the importance of preserving forests, dealing with waste, and purifying water to drink (Despommier, 2010). Schools in developed countries have projects like ECO-SCHOOLS, http://www.ecoschools.global/, and most (if not all) subjects (English, Geography, History, Informatics, Mathematics, Natural Sciences, etc.) incorporate themes related with the Brundtland Report (1987) and the Agenda 21 (1992) themes. Whereas developed countries have been improving their school systems and acquiring experience in teaching and creating experiences related with biodiversity and sustainability, debating about science and ecology, which are complex issues for kids, teenagers and even adults (Vale, 2013; Nordlund, 2016), developing countries are struggling to bring more children to school, to build better schools, to train more teachers and to improve subjects' *curricula* (see "progress of goal 4 in 2017" at https://sustainabledevelopment.un.org/sdg4). Because people's future will depend on how they relate to ecosystems, it is urgent to provide strategies to empower teachers and learners on a global basis.

"Biodiversity change is (…) inextricably linked to poverty, the largest threat to the future of humanity identified by the United Nations (Díaz et al., 2006)."

The contribution done here addresses the concern of empowering society to understand the link between biodiversity and human well-being in such a way that almost every aspect of people's lives could be conducted by a better philosophy of choosing healthier ways of relating to ecosystems' functions, services and species. Our way of living is not yet oriented towards sustainability, and the only way to improve it is by reaching as many people as possible through education.

"(…) education is a public good, a fundamental human right and a basis for guaranteeing the realization of other rights. It is essential for peace, tolerance, human fulfillment and sustainable development." (ID UNESCO 2015)

Science, as an institution, has been concerned with these issues and debates a way to "translate economic and socio-cultural values of ecosystems services into monetary values" (de Groot et al., 2010) to make people understand better its importance (Constanza et al., 1997). Science is still deciphering how biodiversity is linked to ecosystem services (Díaz et al., 2006; Rands et al., 2010), while the United Nations (UN) assesses governments on their efforts to reach Sustainable Development targets related to climate (SDG 13), biodiversity on land (SDG 15) and sea (SDG 14) goals, among others (https://sustainabledevelopment.un.org/?menu=1300).
Planetary citizenship is also a well-known concept that emerged from a post-globalization world (Bindé, 2004) that is still being developed (by the SDGs). UNESCO established the creation of four contracts to build planetary citizenship values: The social contract, in which education should be viewed as a priority through life; The natural contract, which aimed at serving the human development, respecting ecosystems and species; The cultural contract, which debated cultural impacts; and The ethical contract, that aimed for the emergence of a global philosophy, in what concerns human well-being and sustainable development (Odhiambo in Bindé, 2004).

Philosophers like Popper (1999), years before, struggled to build a global framework to end poverty and violence. Many (UN, UNESCO, UNICEF) believe that education is a strong tool to make a difference in building up a better planetary citizenship (ID UNESCO, 2015).

In this paper, it is aimed to make a specific contribution of a basic science global *curriculum* for seven years of school (from primary 3 to the ninth grade). It is also intended to debate the importance of providing a basic framework to guide science teaching from the third grade to the ninth grade; sometimes, instead of establishing an unachievable goal, to begin with a simpler solution can be better.

Education through life is also an ambitious goal, and, perhaps, still far from reach in many parts of our world. But, the effort of providing information to adults will help people ask more questions and search for answers. A basic *curriculum* for children can be used and adapted to adult's need of learning more about science.

"Education transforms lives and is at the heart of UNESCO's mission to build peace, eradicate poverty and drive sustainable development" (http://en.unesco.org/themes/education-21st-century)

A Global Science *Curriculum*: a framework for the first nine years of school

The Incheon Declaration (ID UNESCO, 2015) emphasizes the need for "relevant teaching and learning methods and content that meet the needs of all learners, (…) using appropriate pedagogical approaches and supported by appropriate information and communication technology (ICT)", among other important issues. ICT, for example, are not available in every school, but education systems can deliver information to remote schools. Because of the urgency of providing "relevant content that meet the needs of all learners", we believe that a basic framework to teach and engage children, teenagers and adults (people are never too old to learn) in Science learning is fundamental. This *curriculum*, proposed here as a non-closed document, *i.e.* open to discussion, is ought to be translated and downloaded by any country that desires to use it. Also, the pedagogical approaches and materials derived from the *curriculum* should be available and translated for free in every language. This is the perspective we advocate.

We are mostly concerned with an "education for sustainable development" (ESD) that prepares children for problem solving, critical thinking and reflecting about issues that condition their lives (Vale, 2013). We want them to be aware of the fact that human beings are connected and depend on ecosystems and other species. We want them to be able to criticize and predict the consequences of human actions for the environment.

The framework shown here tried to intertwine information from several fields of Science, especially for the 7th, 8th and 9th grades of the *curriculum*. Repetition of information was avoided, thinking on the importance of providing a basic set of information to children that face the risk of quitting school earlier. We strongly recommend teachers to see this *curriculum* not as a "list of required topics and information" to pack in each school year (Vale, 2013), but as a guide to adapt to the context of each situation. We also emphasize the importance of the views shown in Vale's (2013) perspective, since allowing children to ask questions is allowing them "to promote independent learning".

The framework for the first years of school is shown in Table 1. We consider that Natural Sciences should be introduced as soon as possible. In fact, primary education in Singapore comprises

Science as one of the core subjects for primary education, and they introduce it in primary 3 (Tan et al., 2016). The recommendation of starting with 8 years old is just because many schools do not have the means to keep young children for many hours learning, so they engage in teaching first native languages and mathematics. However, Science can be introduced even earlier (*i.e.* pre-school education). A connection between the themes and some of the SDGs was also taken in concern, and is pointed out in Table 1 and Appendix A.

Table 1. Natural Sciences *curriculum* themes for the first four years of school; Themes were distributed for the third and fourth years of primary school, but they can be distributed in other ways.

Content	Intended outcomes
Ages 8-9 (3rd grade, or primary 3) Sustainable development goals (SDG) taken in consideration: 3, 4	
1. Introduction to the study of Natural Sciences 1.1.From a house to a planet 1.2.Living things (from macroscopic to microscopic scales) (biodiversity) SDG 14, 15 1.3.Natural Habitats for living things (species) SDG 14, 15 1.4.Transformed Habitats (crop fields, fish farms,) SDG 14, 15	**Theme 1.** The idea is to explore different levels of nature occupancy, from what is familiar (house) to the explanation of where it belongs (Planet Earth). Then, it is aimed that children explore the different kinds of living things living in their environment, and develop their knowledge from that. It would benefit the development of the concept of biodiversity. Exploring, for example, that there are tiny living things like bacteria and protozoa; even if they cannot see them with microscopes, knowing the existence of microscopically living things opens the door for knowing and asking more.
2. Our relation with Nature SDG 11, 12 2.1. Living in rural areas versus living in urban areas 2.2. How to use habitats and nature causing less harm to other living beings?	**Theme 2.** The idea is to explore the different habitats near the school, and develop knowledge about different habitats for animals. It will set the basic ideas to explore the differences between living in rural areas and living in urban areas, and what that imposes to other species (plants and animals especially), like water, soil and air pollution, and habitat fragmentation. It is aimed to develop an "ecological conscience", or a "care moral" towards Nature and its living things.
Ages 9-10 (4th grade or primary 4) Sustainable development goals taken in consideration: 2, 3, 4, 5, 6, 11, 12	
2. Our relation with Nature (cont.) 2.1. What are ecosystems? 2.2. Benefits and goods derived from ecosystems 2.3. How do we affect ecosystems? 2.4. How does Nature affect us? SDG 3, 4, 6, 11 (… sustainable), 12	**Theme 2. (cont.)** After understanding that people belong to Nature, like every other species, and knowing the variety of natural habitats, the word "ecosystem" is ought to be explored. Showing examples of how abiotic and biotic factors influence each other, and how they become part of bigger units – the ecosystems. What is intended is not the rigid use of the correct words (like ecosystem, abiotic factor, etc.) but to

3. Human health and care 3.1. The human body: how it grows (baby, child, teenager, adult) and gender characteristics 3.2. Hygiene 3.3. Food and nutrition 3.4. Tackling diseases 3.5. What is needed for human well-being? SDG 2,3, 5, 6, 12 (…sustainable consumption)	mobilize ideas like: light affects animals' behavior (and explore examples), water is essential for all living things (animals drink fresh water, plants need water and it is an important part of the water cycle); people need to extract wood from the forest, but what does that entail, etc. **Theme 3.** We advise focusing on human beings, by studying their body only after the previous themes have been explored. The theme "how it grows and gender differences" is ought to explore reproduction, development and differences between boys and girls adequately to this level. This is an opportunity to empower girls. It is important to emphasize that each person has different abilities that should be respected, addressing also that some children have special needs (creating awareness and tolerance). The "Hygiene" topic should explore the importance of water security, disinfection of hands, bathing and cleaning. But also, how water can be disinfected or even not polluted. The "Food and nutrition" theme ought to explore food security, but also strategies to help children feed better and make better choices for their health. The "Tackling diseases" subtheme should prepare children in poor countries with poor sanitation facilities to cope with that context, and deal with strategies to avoid being ill. The importance of vaccination, hygiene and protective behaviors should be taught. The categories of human well-being should be explored in the end as a goal to reach through every person's life and because it relates to the World Health Organization's (WHO) "human health" concept.

For the 5th and 6th grades the complexity increases. The *curriculum* we propose is focused on understanding how science works and how ecosystems function. Conservation biology topics are explored (see tables A.1. and A.2. in appendix A).

For the 7th, 8th and 9th grades abstract notions are added like: what were dinosaurs, how mountains are built, what is matter and energy, etc. Evolution, cell structure and metabolism, are examples of themes that should be developed (see table A.3., A.4., A.5. in appendix A).

To develop materials for or derivations of this (or other) *curriculum*, we emphasize the importance of learning in a "safe, healthy, gender-responsive, inclusive and adequately resourced environment" (ID UNESCO, 2015), as much as possible. What is encouraged is a state of mind of "Teach Less, Learn More", following Singaporean ideology (Tan et al., 2016).

Discussion

Education about conservation ecology is important to improve human relation with natural goods and benefits. Only through education will it be possible to improve the human relationship with ecosystems. The public and governments' interest in reverting the pressures on wild species is increasing, as Rands *et al.* (2010) emphasize, but not effectively to halt biodiversity loss (Ceballos *et al.*, 2015, 2017). Perhaps due to the fact that, like climate change, ecology's complexity demands more understanding and compliance from governance and policy, sponsors, markets, education systems, and from common people.

"Education systems must be relevant and respond to rapidly changing labour markets, technological advances, urbanization, migration, political instability, environmental degradation, natural hazards and disasters, competition for natural resources, demographic challenges, increasing global unemployment, persistent poverty, widening inequality and expanding threats to peace and safety." (ID UNESCO, 2015).

Marine turtles, for example, subjects of many conservation projects have a strong impact on tourists and local people, especially children. But the local children are confronted with mixed feelings: turtles must be protected to ensure monetary revenue by tourism (upon which many families rely), but turtles are also explored and pressured by being advertised by locals. This is what happens, for example in Quintana Roo, Mexico despite the efforts of non-governmental organizations like "Centro Ecológico Akumal" (http://www.ceakumal.org/), that develop environmental education activities for children. And this is only an example that involves emblematic species and their delicate habitats and niches (the nesting beaches used by females, the sea grass beds and the corals explored by the juveniles in the coast).

Human-wildlife conflicts – another example – show the complexity of the human need to use ecosystems and compete with other species. For humans, other species have different value. Some are just to contemplate, while others provide material goods (many of which have been prohibited to collect).

Elephants are poached because of their ivory (Goldenberg et al., 2016), and though it is prohibited to hunt them, many poachers still take the risk, because of the profit generated in the market (Goldenberg et al., 2016). Many elephants are also killed because they are feared and destroy goods (Taruvinga & Mushunje, 2014; Anastácio et al., 2014). But in all cultures they are seen as symbols of nature, used as flagship species (Lee & Graham, 2006). Beyond the problems they cause, elephant's species are gardeners of the ecosystems (Douglas-Hamilton et al., 2005), and they are classified as keystone species (Meffe & Carroll et al., 1997; Thouless et al., 2016), hence, they play an important role in the ecosystems, which humans cannot afford to lose. The example of elephants' relation with humans poses a great challenge to all of us. How can poor people live and share resources with these big and charismatic creatures? Elephants' spots and home ranges are being invaded by people in worryingly increasing numbers, and conflicts happen frequently, ending in people or elephant deaths (Douglas-Hamilton et al., 2005; Pinter-Wollman, 2012; Taruvinga & Mushunje, 2014), even inside protected areas (Craig, 2013). So, how can this problem be dealt with from an educational perspective? Can it be separated from an ecological/conservation perspective? Can the biological perspective be separated from the social point of view? It seems like it cannot

(Bradshaw & Bekoff, 2001). Conservation ecology is a multidisciplinary field that depends on understanding peoples' beliefs and needs (sociology, anthropology), how ecosystems function (ecology, biology), and how society experiences their time and space (economics, political science, communication science, education science) (Meffe & Carroll et al., 1997).

What can we do, as a global society, to help preserve species like elephants, and people? What can we teach and inform people about that would make a difference? We can prepare people to debate the dilemma by going to school. The Incheon Declaration (ID UNESCO 2015) has the ambition of ensuring "the provision of 12 years of free, publicly funded, equitable quality primary and secondary education, of which at least nine years are compulsory, leading to relevant learning outcomes." A general science *curriculum* for the first nine years of school that emphasizes themes related with human well-being and ecosystems conservation, that enables the debate of complex questions like "what can we do to mitigate ivory poaching?" is, in our belief, a strong strategy. It is expected to be available online, but also in the form of didactic materials, for teachers to use them. Instead of waiting for each country to define standards and review curricula, UNESCO can provide, for each subject, a basic curricula for each grade, and from it, each country can adapt it to "ensure quality and relevance to the context, including skills, competencies, values, culture, knowledge and gender responsiveness" (ID UNESCO 2015). For example, in the absence of a solution, the Ministry of Education of each country can start to translate and adapt the basic science *curriculum*, for every language spoken in the country, and upload their versions in the web. Only by sharing educational resources and experiences is it possible to transform lives in an effective way. And the attitude of sharing freely and offering pedagogical materials can help achieve a holistic development of competencies, like critical thinking, creativity and divergent thinking, communication, collaboration, independent learning, lifelong learning, and the most important of all, active citizenship (Tan et al., 2016), and global citizenship, and critical questioning (Vale, 2013).

Singapore, one of the most successful stories of growth, invested in its educational system in such a way that it constitutes an example that is still seeking, today, ways of improving and of breaking with a homogeneous rigid system (though effective) to become more heterogeneous, enabling their students to discover themselves by also developing soft skills (OECD, 2010; Gopinathan, 2011; Tan et al., 2016).

UNESCO has started the "sharing" effort with the "open educational resources" (http://www.unesco.org/new/en/communication-and-information/access-to-knowledge/open-educational-resources/what-are-open-educational-resources-oers/), or by creating the International Bureau of Education (IBE) (a global center of excellence in *curriculum*, at http://www.ibe.unesco.org/en/who-we-are). Also, initiatives like PISA4U (https://www.pisa4u.org/), which started in 2017, and even sites like https://www.oercommons.org/, or http://www.bbc.co.uk/education/subjects/zng4d2p constitute solid examples of what is intended. We believe that these platforms and projects would benefit from more simplicity (pages are a bit confusing, with immense information). Sharing what we know and how we know it for free is one of the most valuable gestures for the future of all living things.

Other aspects are needed, like improving the preparation of teachers, or supervising pair work, choosing the most gifted for the job. However, considering that a country does not have enough teachers, at least every person with university or even secondary graduations can, if guided, help in the first years of education to expand the network of schools and achieve the SDGs 4, 5, and 10. In Portugal many engineers started to teach Mathematics, Physics or Chemistry in public schools after

the 1974 Revolution, and many found a passion for teaching. It also happened with Biologists, who became great Biology teachers. Later, these "teachers" had to become specialized in education, and they embraced the teaching career, instead of the technical and industrial purpose for which they were prepared. If people have the proper orientation (*e.g.* clear *curricula* and materials), and the values that guide a teacher's activity, many can transform themselves into marvelous teachers. How many retired engineers, industry leaders, attorneys, investigators etc. in many countries can help teaching children as volunteer work? We comprehend that a country without enough teachers has to make a plan. Other measures have to be taken: if there is no money to train teachers, is it possible to train people in a specific area, whilst providing knowledge for that same person to be able to teach in a public school? Is it possible to have more than one profession in our lives? Is it possible to invest more in education and train more teachers? Is it possible to, after that, take the step of increasing teachers' payment? Poor countries need to be creative in finding solutions. Rich countries need to be supportive and share know-how. For now, our concern is delivering a *curriculum* for seven years of schooling that conjugates Physics, Chemistry, Biology and Geology in one single subject: Natural Sciences.

Conclusion

To make a difference in a child's life is to empower that child to become free to choose and act, feel and seek security in the environment, have access to basic materials, healthcare and information in a society that enables good social relations among people and that respects ecosystems and other species (MEA 2005). Educating children from an early age in Science themes will increase their capacity to ask important questions, and to seek answers through their adult life. The Incheon Declaration has the goal of providing nine years of quality education to every child in the World. Whereas some countries have the means and the experience of good practices, underdeveloped countries struggle with many problems, including having a task force which is either unprepared or not large enough to guarantee nine years of studying for every girl and boy.

Appendix A

The global Natural Sciences *Curriculum* is open to discussion and it is not a perfect scheme. It intends to conjugate Biology, Geology, Physics and Chemistry in a single framework. This framework was built having in consideration the SDG 4, through which it is possible to achieve the SDG 1.

To build up the following *curricula* the authors studied the science *curricula* from Portugal (RA applied the Portuguese Natural Sciences *Curriculum* several years, as a teacher – 5th to 9th grades and 10th – 12th grades biology/geology *curriculum*), Mozambique (to which the authors had access), United States and U.K. (K-12) – available in the internet.

Several recent Biology, Geology, Chemistry and Physic books were used, to prepare a logical perspective of the themes.

Table A1. Proposal for fifth grade Natural Science *Curriculum*.

Theme	Subthemes	Intended outcomes
5TH GRADE		
Sustainable development goals taken in consideration: 4, 5, 13, 14, 15		
Science and its principles	**Unit 1. Science and scientists** 1.1. Fields of Science: Biology, Geology, Chemistry, Physics, and other fields 1.2. Brief history of Science 1.3. What are the characteristics of investigators, researchers, and scientists? 1.4. Words in Science (*e.g.* Latin use in Biology)	**Unit 1.** To show what Science is, and examples of its fields; To tell the story of Science, showing that it is always evolving and that there were obstacles; To show that Science and Technology made the world easier for human beings to live in, but brought problems; To show that researchers are common people with curiosity (a researcher can be invited to talk with children, for example). To explain the difference between species' common and scientific names.
Lab and Field work	**Unit 2. Working in a Laboratory and in the Field (Nature)** 2.1. Rules to work in a Lab (show and/or practice) 2.2. Lab equipment (show and/or practice, if possible) 2.3. Rules to work in the field (show and practice) 2.4. Field equipment (show and practice)	**Unit 2.** To prepare children to work in small groups with simple experiments To develop lab and field work skills by collecting plants, or organizing an experiment, or observing bugs with magnifying glasses, etc. The idea is to develop autonomy, joy of observing and experimenting, organization, and communication skills (by drawing, explaining, etc.)
Biology **Biodiversity** **Taxonomy** **The cell** **Monera** **Protista** **Fungi** **Plantae**	**Unit 3. Diversity of life** 3.1. Living things are grouped into Kingdoms: Monera, Protista, Fungi, Animalia, Plantae 3.2. Unit of living things: the cell 3.3. Cell Theory (basic principles) 3.4. Knowing about bacteria (using a microscope) 3.5. Knowing about Protista (in a drop of water, for example; observe Algae) 3.6. Knowing about Fungi (yeast cells, molds, mushrooms, etc.) 3.7. Different plants	**Unit 3.** To create awareness for the diversity that exists around us, even if we do not see it, and the need for organizing it in groups. To show examples of species from all kingdoms. To explain what is a cell and that there are 3 different types of cells (prokaryotic and eukaryotic animal and plant cells); Show examples of cells (with images, experiments, etc.); To explore notions like unicellular, multicellular organisms, and biological levels of complexity (cell – tissue – organ – system of organs – individual). To observe living beings from the children's context and knowing about their diversity. To make experiments and record observations (see examples): -infusion to observe protozoa, -collect algae and observe, -observe molds, -use yeast to make bread, -collect and observe plants and their parts (root, stem, leaves, flowers, fruits, seeds), -collect little bugs and drawing them without harming (pill bugs, for example), or dead bugs to observe and draw (bees, …).

Animalia	3.7.1. Structure of a plant (angiosperm, for example) 3.8. Knowing about animals (sponges, cnidarians, mollusks, arthropods, fish, amphibians, reptiles, birds and mammals) 3.8.1. Structure of a mammal	To explore videos, the internet and books about living beings.
Human beings: a particular case	**Unit 4. The Human Body** 4.1. Body Systems and their roles 4.1.1. Circulatory 4.1.2. Respiratory 4.1.3. Skin and Excretory 4.1.4. Nervous and Endocrine 4.1.5. Reproductive 4.1.6. Digestive	**Unit 4.** To explain the human body and its systems (using figures, schemes, videos, etc.) To explain the menstrual cycle to boys and girls (at this age it is of major importance, especially for girls).

Table A2. Proposal for sixth grade Natural Science *Curriculum*.

Theme	Subthemes	Intended outcomes
6TH GRADE **Sustainable development goals taken in consideration: 2, 3, 4, 5**		
Ecology **Ecosystems services**	**Unit 5. Home for the living things** 5.1. Ecosystem definition and examples 5.2. Abiotic factors (wind, water, substrate, temperature, pressure, light, salinity) 5.3. Habitats and niches 5.4. Atmosphere, hydrosphere, geosphere and biosphere 5.5. Ecosystem services (food and water provisioning, air quality regulation, climate regulation, waste regulation and treatment, soil formation, climate regulation, pollination, etc.)	**Unit 5.** To understand what an ecosystem is, and study examples. To explore different abiotic factors (and make simple experiments). To acquire the notion of habitat and niche of a species. To understand the connectivity between ecosystems, and the atmo/geo/hydro/biospheres. To explore simple examples of important services provided by ecosystems.
Ecology: Flow of energy and matter in an ecosystem	**Unit 6. Food and Energy** 6.1. Producers (phototrophs and chemotrophs)	**Unit 6.** To learn the role of organisms in the flow of energy and matter circulation inside the ecosystem. To explore how human activities interfere with the food webs and how that jeopardizes food security and human well-being

	6.2. Consumers (heterotrophs) 6.3. Decomposers 6.4. Food chains, food webs, trophic levels, and energy flux, and matter cycle. 6.5. How can human activities disrupt food webs? 6.6. Consequences of energy and matter flow disruptions for the ecosystems 6.7. Farming and Fishing – the "dos" and the "don'ts"	To know and debate the fragmentation of habitats. To know farming practices used in the region, and sustainable farming practices. To know fishing practices used in the region, and sustainable fishing practices.

Table A3. Proposal for seventh grade Natural Science *Curriculum*.

Theme	**Subthemes**	**Intended outcomes**
7TH GRADE **Sustainable development goals taken in consideration: 4, 5, 13, 14, 15**		
Evolution **Palaeontology** **Tectonics** **Geologic time** **Mass Extinction**	**Unit 7. Earth's evolution and Biodiversity** 7.1. Why are livings things so diverse? 7.2. Were there different living things on Earth? 7.3. Charles Darwin and the Evolution theory 7.4. Fossils and sedimentary rocks 7.5. Why did such an amount of species become extinct? 7.5.1. The sixth Mass extinction: causes and consequences 7.6. Earth's age and geologic time divisions 7.7. Earth's transformations through time: - atmosphere - surface dynamisms (volcanoes, earthquakes) - interior of the Earth 7.8. Plate tectonics 7.9. The diversity of landscapes, and their	**Unit 7.** To learn about the diversity of species and develop questioning and debate about it Introduce Darwin and Wallace, and their process on developing evolution theory. To learn what a fossil species is To debate and question about natural extinctions, and anthropogenic causes that lead to species' extinction. To develop the notion of geologic time. To explore Earth's dynamism with atmosphere, surface and interior phenomena. To explore Plate tectonics (geology science), that explains the importance of geographic barriers for the evolution of species. To show and study the richness of different landscapes, and their importance.

	biological and aesthetic values	

Table A4. Proposal for eighth grade Natural Science *Curriculum*.

Theme	Subthemes	Intended outcomes
8TH GRADE		
Sustainable development goals taken in consideration: 4, 5, 12, 13, 14, 15		
Astronomy **Physics**	**Unit 8. Gaia is Stardust** 8.1. The Universe - how is it constituted and organized? - recycler of matter and energy convertor - distances in the Universe 8.2. Planet Earth - mass and weight - gravitation - rotation and translational movements - moon phases and tides - forces and pressure - magnetic field 8.3. Planet Earth's characteristics that allow Life to exist	**Unit 8.** To introduce Physics and Chemistry with Astronomy topics. It is important to let students ask their questions and feedback their curiosity with the information; also, they can research about their questions. To explore Earth as a Planet among other objects in the Universe and its characteristics and peculiarities. To explain concepts with simple experiments, whenever possible. To ask students which characteristics are important to maintain life – exploring the importance of resources (things species need to survive). To learn about groups of rocks and examples of minerals, their applications. To study the Oceans and their peculiarities, understanding that when they change they interfere with global changes. To study the atmosphere and acquire a basic understanding of its dynamics, and the difference between climate and weather. To study how humanity explores biological resources.
Natural Resources	8.4. Natural resources: rocks and minerals 8.5. Natural resources: water deposits and water cycle 8.6. Ocean dynamics (water characteristics: currents, salinity, upwelling, etc.) 8.7. Atmosphere dynamics (wind, climate, weather) 8.8. Species as biological resources 8.9. Energy sources 8.10. The problem of	To study different types of energy sources (wind, sun, fossil fuels, etc.) indicating advantages and disadvantages for each. To lead the students to debate about human activities and their impact on the environment; To show examples, like ocean acidification, acid rains, deforestation, and other disturbances To debate creative ideas to cope with waste and pollution in the future. To debate how future generations should deal with consumption of natural goods and services.

	extraction of natural resources, pollution and waste production 8.11. How to preserve natural resources in an overpopulated world	

Table A5. Proposal for ninth grade Natural Science *Curriculum*.

Theme	Subthemes	Intended outcomes
9TH GRADE		
Sustainable development goals taken in consideration: 3, 4, 5		
Physics **Chemistry** **Cell Structure and Metabolism**	**Unit 9. The complexity of Nature** 9.1. Energy 9.2. Light and colour 9.3. Sound 9.4. Matter - Periodic table - Elements, atoms and molecules - Chemical reactions - Chemistry of Life 9.5. The cell structure 9.6. Cell metabolism: what is it? -Photosynthesis purpose -Fermentation purpose -Aerobic respiration purpose -DNA expression 9.7. Cell cycle and mitosis 9.8. Meiosis and fecundation 9.9. The Immune system	Recommendations: Themes should be developed to provide the basic information to understand how nature works. It is not intended to massacre students with formulas and definitions, but to let them hear and ask about what is energy, light (why are plants' foliage green), etc. The ideal would be for natural sciences to have 3 to 4 hours per week in students' schedule, but, that is not the reality of many places, so teachers need to seek the best way to explain the topics as efficiently as possible, but without suffocating students. This applies to all the themes shown. For example, if teachers have time, they can explain the implications of meiosis and fecundation for the diversity of life, and even explore different life cycles; Otherwise, they can show meiosis as a different process for genetic material division of the cell. An idea is to use the Immune system as the central theme to mobilize the information taught in Unit 9. To learn concepts of Physics like energy, light, and sound. To learn about the organization of matter. To learn the cell structure: organelles and their functions and interactions To study some metabolic pathways/purposes, like photosynthesis, fermentation, cell respiration and genetic expression. To learn the cell cycle and mitosis (with microscopic observations whenever possible). To learn meiosis and fecundation, and the implications of them. To study the human immune system, as a complex interaction between tissues, cells, molecules of a wide variety.

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Capítulo V

Discussão Geral e Conclusão

> "Any optimism must be tempered by the enormous challenges of making food production sustainable while controlling greenhouse gas emission and conserving dwindling water supplies, as well as meeting the Millennium Development Goal of ending hunger" (Godfray *et al.*, 2010).
>
> "(...) economic transformation is crucial to the project of sustainable development" (Jackson, 2011).
>
> "87. Sustainable development is a complex challenge, with urgent requirements, resulting in enormous financing needs (…)" (UN, 2014).

O conservacionista aprendente está em crise, pois o seu trabalho é cada vez mais vasto (tem de dominar muitas tecnologias, técnicas, metodologias ou ter conhecimento delas), complexo (lida com muitos interesses e vontades), e cheio de dificuldades (há poucas oportunidades para entrar no mercado de trabalho; há pouco financiamento). Alguns jovens conservacionistas chegam mesmo a desistir da área e a enveredar por outras profissões (por exemplo, o ensino). Na verdade, fazer conservação é dispendioso, não gera resultados imediatos, e são necessários muitos recursos, muitas pessoas e tempo. E há muito para fazer. O conservacionista é também realista, não tendo um "pensamento mágico acerca do futuro" (Jackson, 2011). Sabe que a única coisa que pode fazer é trabalhar para convencer outros a aderir à sua causa, com as evidências que reunir. Tem-se assistido a uma revolução lenta desde os anos 70/80 do século XX; a revolução pelo querer cuidar e preservar primeiro as espécies emblemáticas e depois os seus habitats, ecossistemas e serviços.

A internet e as tecnologias associadas a ela estão a trazer alguma vantagem para a investigação: a modernizá-la, a torná-la mais eficiente a produzir as tais evidências que os outros necessitam para se convencerem daquilo que os cientistas já sabem, sobre a decadência do meio natural em função das necessidades rudes do ser humano.

Mercados de carbono ("green" e "blue carbon"), acordos de clima, convenção da biodiversidade, Aichi targets, SDG, entre outras estratégias, resultam do esforço dos conservacionistas oficiais e dos "não oficiais" (todos aqueles que se importaram) em marcar uma posição sobre a importância de se utilizar a biosfera de uma forma mais inteligente.

Mas estamos ainda no arranque (só há pouco saímos da linha de partida). Seria importante que o ser humano vivesse mais do que algumas décadas (diria alguns séculos) para que lhe fosse possível perceber a transformação gigante que cria à sua volta, nos ecossistemas. Só os mais atentos e os mais velhos têm memória das alterações. Mais uma vez, a tecnologia pode ajudar muito a construir uma memória de impacto nas gerações recentes: fotografias, vídeos, e redes sociais rápidas que divulgam num clique as transformações a milhares de pessoas. Ao ler os diários de bordo dos capitães de embarcações que navegaram nas Caraíbas pós século XVI, é possível constatar que havia um mar de tartarugas (Spotila, 2004). Mas como se pode fazer perceber a mudança causada de séculos de exploração e explosão demográfica? Só fazendo perceber é que, talvez, se possa transformar a atitude das pessoas. O talvez implica que para fazer emergir uma moral do cuidar (da Natureza) não basta apenas mostrar (com textos, imagens,

vídeos, teses), tem de se apostar numa educação livre, democrática, crítica, de qualidade para os mais novos, mas também para a sociedade em geral.

Os artigos apresentados nesta tese mostram um caminho abrangente e pretendem apontar algumas soluções. Estas soluções podem contribuir, entre outras medidas, para a preservação dos ecossistemas do norte de Moçambique. A pressão demográfica, imposta pelo crescimento económico que a região tem exibido, exercida sobre os ecossistemas delicados (*e.g.* corais, mangais) e sobre as suas espécies emblemáticas (elefantes, tartarugas marinhas, dugongos, mabecos, leões, leopardos, etc.) e não emblemáticas, obriga-nos moralmente a propor a proteção urgente da área costeira desde o Parque Nacional das Quirimbas até ao Rovuma. Esta ideia não é nova, já Obura *et al.*, (2012) a defende, mas necessita de concretização. Esta é uma das metas que derivam da finalização deste trabalho de doutoramento.

Far-se-á uma retrospectiva do trabalho desenvolvido, começando com os objetivos iniciais.

Conseguiu-se apresentar um plano de gestão do território e dos recursos naturais para a "Messalo Wilderness Area" (MWA) de Quiterajo, tendo este sido apresentado às entidades locais e publicado num "open journal" de cariz científico. Os resultados dos questionários digitais (N=189) permitiram a definição de uma listagem de indicadores do Human Wellbeing Assessment. Esta informação tradicional acoplada à pesquisa bibliográfica sobre a região e ao conhecimento da área confirmaram a elevada dependência dos locais sobre os recursos terrestres e marinhos na MWA. Confirmaram também a existência do conflito severo com elefante africano. Permitiu, ainda, perceber as causas do conflito que acaba por ser generalizado em África, sempre que pessoas se cruzam com elefantes. Assim, os questionários digitais mostraram-se como uma ferramenta útil para a recolha da opinião das pessoas e permitir o seu envolvimento na construção da proposta de gestão dos recursos da região.

Do plano de gestão da MWA definiu-se como prioridades encontrar uma solução para o HEC instalado, tendo-se desenvolvido essa mesma solução – sensores – ao longo destes últimos anos e que permitirão continuar a pesquisa nos próximos anos. Foi feita uma candidatura à "International Elephant Foundation" para testar os primeiros protótipos, mas o projeto que se construiu não foi um dos escolhidos para ser financiado pela organização. Esta oportunidade surgiu por intermédio de outra entidade, mas cujo conteúdo já não coube nesta tese.

No que concerne aos testes aos sensores de movimento, os espectrogramas mostraram que as ondas mecânicas produzidas pela massa utilizada (8 Kg) captou sinais de baixa frequência com intensidade adequada. Estes sinais foram consideravelmente mais fortes que o ruído de contexto ("background noise") o que lhes confere a sensibilidade pretendida para detectar animais de massa elevada (elefante), ou média (leão, mabeco, leopardo, macaco, entre outros). Os dados dos testes de campo demonstraram que com os dispositivos é possível detectar uma fonte de vibração pelo método da triangulação e usando informação GPS. Também demonstraram que é possível criar uma malha com os dispositivos, separados 25 metros entre si, para monitorizar os movimentos dos animais e discriminar padrões entre sinais. As aplicações possíveis para os dispositivos desenvolvidos são várias, porém o objectivo de provar que detectam elefantes em movimento foi atingido e o próximo passo é acoplar-lhes um mecanismo simples de aviso de presença, evitando assim conflitos.

Da análise das bases de dados do programa de conservação de Vamizi para as tartarugas "green" (N=1303), descobriu-se que as praias de Comissete e Farol, principalmente, albergam um número de fêmeas nidificantes de tartaruga verde de, aproximadamente, 52 fêmeas/ano, com uma

tendência para diminuir. Porém, as taxas de sucesso quer para a eclosão (88.5±17.2%) quer para a emersão das crias dos ninhos (84.5±20.4%) são elevadas quando comparadas com outros locais no Índico. Também o número de haplótipos de tartaruga verde encontrados (11 no total, dos quais 7 são novos) fazem de Vamizi um local a proteger. Observou-se uma redução do período de incubação no intervalo estudado, uma deslocação do pico da atividade nidificante (figura 4, página 114) e um aumento do número de ninhos inundados nas praias (ver figura 8, página 116), que revela a provável influência das alterações climáticas e da presença de actividades antropogénicas. O que corrobora isto é o facto da actividade de nidificação se ter deslocado para praias mais desertas em detrimento daquelas que começaram a ter turistas (figura 7, página 115).

Os parâmetros da biologia reprodutiva foram apresentados também para as hawksbill de Vamizi. Porém, para esta espécie, o número de registos foi inferior ao estudo das green (N=69). As hawksbill nidificam em Vamizi durante todo o ano, com uma média de 4 ninhos/mês, sendo dezembro e janeiro os meses de maior deposição de ninhos. Vamizi alberga uma população de nidificantes pequena, com um período de incubação de 60.9±10.6 dias e taxas de reprodução elevadas (HS = 86.5±18.9%; ES = 81.6±23.5%). A pressão dos pescadores sobre esta população é visível, dado os valores médios de SCL de tartarugas capturadas por pescadores (42.0±9.0cm). A possibilidade de as águas junto à costa serem utilizadas como habitats de desenvolvimento de hawksbill jovens, e a existência da pressão das artes de pesca, leva à necessidade de estabelecer medidas de proteção não só em Vamizi, mas também nestes habitats de desenvolvimento e nos corredores que conectam a área a outros locais do Índico oeste (Madagascar, Comoros, Tanzânia, Quénia, etc.). Também a análise genética revelou uma variedade de haplótipos que poderão contribuir para uma melhor compreensão da RMU desta região. Para tal, mais estudos que interliguem estas a outras áreas devem ser efectuados, que confirmem as suspeitas levantadas em Anastácio e Pereira, 2017.

O software “Turtles” surge precisamente para auxiliar projectos (existentes e novos) na colheita de informação da biologia reprodutiva das tartarugas marinhas. Dado que aumenta a eficácia na gravação dos dados de campo e garante uma análise estatística posterior mais robusta, poderá substituir a metodologia tradicional do papel, que se submete a vários erros: contagem, campos omissos, valores impossíveis, inconsistência dos valores introduzidos. Não tendo sido possível testar a metodologia e o software “Turtles” em Vamizi, foi-nos dada a oportunidade de o testar (estudo piloto) no México, nas praias de Akumal, com o consentimento do Centro Ecológico de Akumal (http://www.ceakumal.org/), e da Operation Wallacea (http://opwall.com/); para esta última instituição a autora trabalhou como “field supervisor” de quatro alunos de dissertação que fizeram os seus projetos com tartarugas marinhas nidificantes. Este projeto piloto deu origem a uma publicação na *Scientific Reports* e o software foi adotado pelo CEA para as próximas temporadas (de 2017 em frente).

A revisão sob os impactos das alterações climáticas nos ecossistemas aquáticos, principalmente no primeiro nível trófico, clarificou que devido à dependência da produtividade primária de vários factores abióticos, a mudança nestes pode reduzir o fluxo de energia para os consumidores de topo, aumentando a insegurança alimentar ao nível dos recursos pesqueiros, tanto a nível local, como regional e até global. Os factores abióticos em alteração são: a qualidade e quantidade da energia do espectro solar, a proporção de gases e poeiras, os padrões de variação da temperatura, o grau de acidificação de massas de água, a mobilização e introdução de nutrientes e substâncias tóxicas que interferem com os ciclos biogeoquímicos.

Por fim, como contributo para o SDG4 “Quality Education” propõe-se um novo currículo de Ciência, aberto à discussão, que tem em consideração as metas da educação 2020-2030 (da Incheon Declaration). Criar uma sólida “cultura da conservação” entre todos os cidadãos tocando na temática da proteção dos ecossistema e das espécies que contêm. Pensou-se especialmente nos sistemas de ensino (ainda) pouco robustos, ao nível de infraestruturas e pessoal docente. Porém, este currículo carece de teste. O artigo foi aceite para publicação da Creative Education (https://www.scirp.org/journal/ce/).

Das lições colhidas do processo de doutoramento, destacam-se as que se listam seguidamente. Aprendeu-se que os planos de gestão que nos inícios dos anos 70 (século XX) se concentravam em preservar espécies e habitats têm evoluído no sentido de aplicar metodologias de conservação/ restauro de paisagens inteiras. E que ao invés de se concentrarem somente no “expertise” científico, investem em metodologias das ciências sociais para incluir outro tipo de “stakeholders non-experts”, tais como, as populações locais que exploram diretamente os recursos e os serviços naturais, e os gestores políticos.

Aprendeu-se que os projetos de tartarugas marinhas nidificantes garantem uma taxa de satisfação considerável, dado que as técnicas de proteção dos ninhos e das nidificantes resultam no aumento de efetivos nas gerações seguintes, e também geram receita financeira. Porém, são projetos que implicam o envolvimento de entidades e pessoas ao longo de várias décadas, com regras relativamente rígidas, o que nem sempre é fácil de garantir. Implicam, também, uma recolha técnica de informação que nem sempre existe.

Constatou-se que é urgente recolher mais informação científica de espécies do Índico. No caso das tartarugas marinhas constata-se um “gap” ao nível da distribuição de haplótipos (e outra informação genética) que muito podia revelar sobre as espécies (distribuição geográfica, por exemplo). Assim, tem de haver um maior investimento na formação de biólogos nesta região.

Constatou-se que a resolução do HEC está longe de encontrar uma solução. Há locais onde é especialmente preocupante, não só pela perda de elefantes, mas pela perda de recursos agrícolas, ou mesmo pela perda de vidas humanas. As soluções existentes são intrusivas, ou implicam um grande investimento monetário (no caso das cercas elétricas), ou uma elevada manutenção (ver a metodologia desenvolvida por Lucy king, http://www.savetheelephants.org). Acreditamos que o futuro implicará a utilização de soluções tecnológicas que não careçam de elevado investimento monetário. Porém, a preservação das populações de elefantes está dependente da forma como, no futuro, o Homem decida o que fazer em relação ao marfim e ao território. O marfim detém um valor comercial que ameaça o futuro dos elefantes africanos, e a luta para inverter a procura por este bem material tem sido perigosa, mesmo para os conservacionistas.

Percebeu-se que a investigação mundial se encontra cooperante para encontrar uma solução que resolva os problemas apontados para o futuro do planeta – ao nível da agricultura (para o aumento da sua eficácia), do clima (para a redução das emissões de gases de estufa e mitigação de catástrofes de origem atmosférico/oceânica), da escassez de água potável, da dependência da energia fóssil – estando a criar plataformas e tecnologias que permitam diagnósticos e previsões mais rápidos. Que permitam, também, a tomada de decisões em parceria – algo que é fundamental para dar resposta a conflitos, necessidades, catástrofes, etc. Estas medidas visam criar um planeta mais justo, e, por conseguinte, mais preocupado com o meio ambiente e a biodiversidade.

E conclui-se que as metas globais (primeiro os MDG; hoje os SDG) têm de ser obrigatórias. A sobrevivência da espécie humana depende da sua capacidade em assumir as metas globais e dos compromissos que delas derivam. Só assim se pode evitar o resultado da soma das parcelas seguintes:

"Larger economy + population growth + 6^{th} mass extinction = Biosphere catastrophe"

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