Impact case study (REF3)

REF2021

Institution: Edinburgh Napier University

Unit of Assessment: UoA7 – Earth Systems and Environmental Sciences

Title of case study: Improved Crab Fisheries Management Benefits Coastal Livelihoods in Brazil

Period when the underpinning research was undertaken: 2012 – 2020

Details of staff conducting the underpinning research from the submitting unit:

Name(s): Karen Diele	Role(s) (e.g. job title): Professor of Marine Ecology	Period(s) employed by submitting HEI: 01 February 2012-present

Period when the claimed impact occurred: January 2020 - ongoing

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact (indicative maximum 100 words)

Research led by Edinburgh Napier University (ENU) identified the temporal drivers of mass-mating of harvested Brazilian mangrove crabs and generated a mating forecast tool.

The ENU-made forecasts, informed by multiannual ENU-led fieldwork, were implemented by the Brazilian government into national crab fisheries legislation 2020 to 2024, for 96% (1,344,526 ha) of Brazil's mangrove area, affecting 11 federal states and 222 councils, including 76 sustainable use protected areas.

The new science-based crab mating forecasts replaced the former precautionary method (used by the government since 2003 for setting annual crab capture bans and which regularly had a 50% failure rate) with biologically meaningful and societally beneficial ones.

Avoidance of the unnecessary bans resulted in:
(a) increased environmental law compliance
(b) a 50% reduction in government spending on capture ban policing in 2020
(c) a 50% reduction in income losses in 2020, as compared to the former governmental policy

This impacted on (conservative estimates):
(i.) an estimated 51,635 crab fishers, sustaining approximately 283,990 household members
(ii.) over 600 crab traders *and*
(iii.) over 1,000 restaurant owners selling crab dishes (incl. beach huts)

2. Underpinning research (indicative maximum 500 words)

Mangrove ecosystems provide vital services at local, national and global scales, including habitat for exploitable species such as the crab *Ucides cordatus*. In Brazil, these mangrove crabs are of high cultural, socio-economic and ecological significance **[O1, O2].**

Tens of thousands of crab fishers, typically without alternative income options, depend on the *Ucides* crabs. The sustainability of this crab fishery is therefore of societal concern. There are no signs or projections of collapsing stocks, but the crabs are long-lived and grow very slowly which has led the government to implement a suite of fishing rules. However, government regulators have lost their credibility among crab fishers, due to a mismatch between precautionary capture bans implemented annually since 2003 - to protect the crabs during their conspicuous mass-mating events - and the actual occurrence of such mating events.

Fishers adhering to the bans miss out on crucial income; consequently 'wrong' bans have sparked conflict and environmental law incompliance.
To solve this conflict, Professor Karen Diele, at ENU since February 2012, with Brazilian colleague Dr Anders Schmidt (former PhD student and postdoctoral research assistant, now Lecturer at the Universidade Federal do Sul da Bahia) designed and conducted novel research

between 2006 and 2020 **[O3,O4]**, which was instrumental for the successful development of a new fisheries management tool used to inform the Brazilian government.

The multi-annual research designed and conducted by Diele and Schmidt evidenced that the occurrence of mass-mating is linked with geophysical cycles **[O3,O4].** The crabs' mating can therefore be predicted in time, and over a large spatial scale.

Diele and Schmidt first observed this link for a crab population in the north-eastern state of Bahia, and in 2012 identified what they named the Syzygy Tide Inequality Cycle (STIC) as the driver of the temporal pattern of the mass-mating **[O3]**. STIC is a superposition of the neap-spring cycle with the anomalistic cycle. The latter describes the differing distances of the moon relative to earth while it moves along its elliptical orbit. The point of the orbit closest to earth is called perigee. Whether mass-mating (and subsequent larval release a month later) occurs at full or at new moon largely depends on which of the two moons is closer to earth in a given reproductive season, likely to the stronger gravitational pull and consequential larger tidal amplitudes **[O3,O4]**. In *Ucides*, peak larval release typically takes place at the onset of strong perigee ebb tides when the offspring are quickly exported from the inner estuary to coastal waters.

To scale-up from the Bahia study site, in 2013 Diele and Schmidt founded the informal researcher network REMAR during Schmidt's six-month PDRA stay at ENU, funded by the Brazilian 'Science Without Borders Program'. REMAR unites researchers from ENU (Diele), nine Brazilian Universities and research institutions. Between 2014 and 2020 REMAR researchers have recorded mass-mating events at up to nine sites along the 7,500 km of the Brazilian coast, from north to south, including macro-, meso- and microtidal regimes.

A best-practice fieldwork protocol was used, developed by Diele, for standardized counting of crabs outside their burrows, despite disturbance (a reliable indicator for mass-mating events) along five transects per site, at each new and full moon, during the crabs' peak reproductive season.

The data collected at the REMAR sites were compiled and analysed by Diele for the Brazilian government **[O4]**. Informed by the multiannual field data **[O3,O4]**, Diele and Schmidt developed an algorithm including a component to account for the crabs' anticipatory behaviour **[O3]** to robustly predict the moon phase of future mass-mating events for macro- and mesotidal North and North-Eastern Brazil.

The data generated through fieldwork conducted by REMAR are being complemented through citizen-scientists entering observations of mass-mating crabs into the purpose-built smartphone application REMAR_CIDADÃO **[O4]**. The app, developed by Diele in collaboration with Schmidt and colleagues and students from ENU's School of Computing, was launched in Brazil in November 2017.

3. References to the research (indicative maximum of six references)

[O1] Nascimento, DM, Alves RRN, Barboza RR., Schmidt AJ, Diele K, & Mourão JS (2017) Commercial relationships between intermediaries and harvesters of the mangrove crab *Ucides cordatus* (Linnaeus, 1763) in the Mamanguape River estuary, Brazil, and their socio-ecological implications. Ecological Economics, 131, 44-51. Contribution to data analysis and manuscript writing https://doi.org/10.1016/j.ecolecon.2016.08.017. [Rigorous peer review process]

[O2] Nascimento DM, Alves ÂGC, Alves RRN, Barboza RRD, Diele K & Mourão JS (2016) An examination of the techniques used to capture mangrove crabs, *Ucides cordatus*, in the Mamanguape River estuary, north-eastern Brazil, with implications for management. Ocean and Coastal Management, 130, 50-57. Contribution to data analysis and manuscript writing https://doi.org/10.1016/j.ocecoaman.2016.05.010 [Rigorous peer review process]

[O3] Schmidt AJ, Bemvenuti CE & Diele K (2012) Effects of geophysical cycles on the rhythm of mass mate searching of a harvested mangrove crab. Animal Behaviour, 84(2), 333-340. Contribution to concept, study design, analyses, manuscript writing; senior author and scientific lead as PhD supervisor of Schmidt https://doi.org/10.1016/j.anbehav.2012.04.023 [Rigorous peer review process]

[O4] Diele K, Schmidt AJ (2019) Monitoramento e previsões de andadas de caranguejo-uçá, *Ucides cordatus*, no Brasil. Rede de Monitoramento de andadas reprodutivos de caranguejos – REMAR. 24pp.
[Translated title: Monitoring and forecasts of mass-mating of the crab *Ucides cordatus* in Brazil. Network for Monitoring Mass-Mating in Crabs - REMAR. 24 pp.].
Contribution: Initiated and led the mass mating monitoring through researcher network REMAR. Wrote report, led data analysis, produced figures and tables.
https://drive.google.com/file/d/1KaySNbsxcwRBd9DW8pHbr4z39Semn19k/view?pli=1
[or available on request]

4. Details of the impact (indicative maximum 750 words)

Complementary REMAR research and outreach activities led by Diele and Schmidt have informed and significantly transformed awareness, behaviour and decision-making of the main actors involved in the management of the Brazilian mangrove crab fishery.

Strategic engagement with a variety of stakeholders and the public increased confidence in REMAR's newly developed method for predicting mass-mating and ultimately facilitated the first major change in the government's precautionary approach to fisheries management since 2003.

Forecasts of the likely lunar phase of future crab mass-mating events (which Diele provided to the government twice upon request) have set the timing for capture bans during the main reproductive season of this important mangrove fisheries resource for 5 years, for 2020 and for 2021 to 2024, for 96% of Brazil's mangroves and 4,870 km coastline. The legislation for 2020 halved public spending for policing bans and reduced income losses of approximately 337,225 dependants of the fishery, including socially and economically marginalized artisanal fishers and their families, traders and restaurant owners (see beneficiaries section). Similar benefits are expected to result from the 2021-2024 legislation.

The path to policy change in mangrove crab fisheries management was spearheaded by the Chico Mendes Institute for Biodiversity Conservation (ICMBio[1]), the administrative branch of the Brazilian Ministry of the Environment (MMA[2]). Between 2016 and 2019, Diele and Schmidt implemented strategic "demonstration years" in a sustainable use protected area at the Bahia-state study site to inform the manager (and fishers) before each breeding season at what moon phase the crabs would mate. These forecast were 100% correct, much to the manager's and local fishers' surprise, as shown by this quote of an anonymous email: *"I want to know how you do to have such a favourable result in relation to the prediction (of the mating) of the species"* (received by REMAR on 03/01/2018, translated from Portuguese).

Due to the accuracy of the forecasts, the responsible Bahia ICMBio-CEPENE[3] office (National Centre for Research, Conservation and Marine Biodiversity in North-East Brazil) requested a stakeholder report from Diele and Schmidt, i.e. a summary of their research to that date with a stakeholder recommendation in laymen terms. The report **[O4]** supplemented a 'Technical Note' (Nota técnica) **[C1]** sent by the local ICMBio office to other national ICMBio offices in August 2019. As a result, in November 2019, Diele and Schmidt were invited to present at a conference run and attended by key national ICMBio employees. For example, Mr Leonardo Pacheco (ICMBio-DIBIO) later discussed REMAR's research and Diele and Schmidt's stakeholder recommendation **[O3,O4]** in the capital with representatives of the Brazilian Ministry of Agriculture, Food Stock and Supply (MAPA[4]) and its affiliated Secretariat of Aquaculture and Fishery (SAP[5]).

In December 2019, SAP/MAPA, the branch responsible for fisheries legislation in Brazil, requested Diele's advice on the definition of *Ucides cordatus* crab capture bans for the 2020 reproductive season, for North and Northeast Brazil **[C2-A]**. Diele submitted forecasts of likely

dates/moon phases of forthcoming mass-mating events **[C2-B]**, i.e. the times when capture of male crabs should be banned each month within the three months of peak reproductive activity (as per law, females are protected throughout the entire three months).

The Brazilian Navy and the National Observatory provided Diele with future tidal and moon phase data needed for the forecast calculations.

Diele's policy advice for 2020 was formally implemented by SAP/MAPA through a legislative normative act **[C2-C&D]**, marking the end of the 17 years of precautionary approach for crab fisheries management. The new normative act applied to 11 federal states and 222 councils, containing 96% of the country's mangrove area, the obligate habitat of the harvested crabs. The capture bans specified in the act regulate: the capture, the meat processing industry, transportation, and commercialization of the crabs during their reproduction.

The success of the 2020 policy change was demonstrated by a questionnaire sent by ICMBio to 27 protected area managers, revealing a 95% match between Diele's predicted moon phases of mass-mating and the actual mating **[C3**, page 10**]**. Due to the convincing results, in October 2020 SAP/MAPA requested new mass-mating forecasts from Diele for the forthcoming next 4 years (2021-2024) **[C4-A,B]**, showing their trust in the forecasting method.

The 2021-2024 normative act was published in December 2020, for the same states as that of 2020 **[C4-C,D]**. A normative act for consecutive years is a novelty and significantly facilitates the planning of the executionary branches and productive chain of the crabs' fishery (see below).

To help evaluate and improve the accuracy of the mass mating forecasts in future years, SAP/MAPA are advocating on their webpage the use of the REMAR_CIDADÃO citizen science app to report mass-mating events **[C5-A]**; likewise, the app has been advertised on ICMBio webpages each year starting in 2018 **[C5-B,C]**. Since its 2017 launch, the app has been downloaded over 1,000 times from Google Playstore/Brazil, from all 16 Brazilian coastal states with mangroves, and received a 4.9* out of 5* rating to date (n = 28) **[C6]**. It has encouraged university students to engage with fisheries management: *"Dear Dr. Karen Diele, it is with great satisfaction that I join the REMAR Cidadão program, via the mobile app, my name is …., I am graduate in Sciences and I am interested in working in the research area. …"* (email received by REMAR 20/12/2017) and the app was featured multiple times in Brazilian TV, radio, print and social media **[C7]**.

BENEFICIARIES:
(i.) Decision-Makers: Engagement with the government (i.e. SAP/MAPA and ICMBio), through 6 presentations given by Diele (in person or virtual) was key for achieving knowledge transfer, behavioural change and, ultimately, policy change. For example, 100% (n = 41) of the attendees giving feed-back after Diele's presentation to SAP/MAPA employees on 24th September 2020 responded that they had gained new knowledge relevant to their work, and 85% said it would positively influence their actions in fisheries management **[C8]**. SAP/MAPA benefitted significantly through the implementation of Diele's policy advice, as protected area managers and the fishing community gained confidence in their decision-making. The accuracy of government measures is key to law compliance and sustainable fisheries, which has been cited as one of several positive effects of the amended legislation for 2020: "*…..,when a ban coincides with the mass mating events, everything makes more sense for the society and the protection measure becomes more effective'* **[C3**, page 19**]**.

(ii.) Managers of Sustainable Use Protected Areas: After 17 years of precautionary capture bans, 2020 was the first year that crab capture was only prohibited at <u>one</u> syzygy (at full moon, due to the generally slightly higher tidal amplitudes in that year) and not during new *and* full moon periods. In the feedback given to ICMBio by protected area managers on the changed policy, the following were identified as key positive effects of the new REMAR-advised approach: *saved costs* (see (iv) and **[C8]**)*, the reduction of conflicts, a higher income for crab fishers* and *more effective planning and conservation* **[C3**, page 18**]**. This shows that the step-change in Brazil's mangrove fishery management due to the policy change has been very well received by this important stakeholder group **[C2-D, C4-D].**

iii.) Crab fishers, traders and restaurant owners: As a consequence of the reduction of biologically unnecessary capture bans in North and Northeast Brazil 2020 onwards, loss of income for actors in the production chain is reduced by up to 50% when compared to the former policy. This benefitted an estimated 51,635 socioeconomically disadvantaged crab fishers in the region **[O1, O2] [C9-A, B],** and the approximately 283,990 household members they help sustain (extrapolated from **[O1]** and **[C9-A, B]**). Continued supply-chains instead of unjustified capture bans have also financially benefitted more than 600 crab traders **[C9-A, B]** and over 1,000 restaurant owners in North and North-eastern Brazil **[C9-C]**. These two groups further benefit from the new anticipated legislation, which now covers 4 years: For example, any person wanting to transport or trade pre-stocked crabs during capture ban periods must submit mandatory 'stock declarations' to SAP in advance. In the past, ban dates were only published very shortly ahead of the bans, complicating this process. For the first two bans in 2021 more than 800 declaration forms have been submitted to SAP **[C4-E]**.

(iv.) Brazilian public and species conservation: Policing for law compliance along the North and Northeast Brazilian coastline could be reduced by 50% in 2020 as a result of the new fisheries management approach. Extrapolating this to all protected areas with mangroves in the regions results in a cost reduction of up to BRL 2.23 million (March 2021) **[C10]**. The money saved through the new legislation 2020 to 2024 can be directed to other public needs, including investment into other measures to help conserve and sustainably use Brazil's ecologically and economically important mangrove crabs.

(v.) Holders of new research grants in Brazil: While presenting REMAR's research and achieved policy change for North/Northeast Brazil to ICMBio and University staff in southern Brasil in November 2020, I encouraged them to apply for grants to fill management-relevant data gaps on mass-mating of two species (incl. *Ucides*) in the microtidal South. As a result, one project, already approved by the Brazilian Biodiversity Fund (FUNBIO[6]), received BRL 1.19 million **[C11-A]**, and a second one, in the process of being approved, has been classified for a further BRL 1.20 million of funding **[C11-B].** ENU is a named partner in both projects.

[1] **ICMBio**:Instituto Chico Mende de Conservação da Biodiversidade; [2] **MMA**: Ministério de Meio Ambiente; [3] **ICMBio-CEPENE**: Centro Nacional de Pesquisa e Conservação da Biodiversidade Marinha do Nordeste; [4] **MAPA**: Ministério da Agricultura, Pecuária e Abastecimento; [5] **SAP/MAPA**: Secretaria de Aquicultura e Pesca; [6] **FUNBIO**: Fundo Brasileiro para a Biodiversidade

5. Sources to corroborate the impact (indicative maximum of 10 references)

[C1] Technical Note ICMBio-CEPENE
[C2] Request SAP/MAPA for advice for 2020 capture bans (A); Diele's advice for 2020 bans (B); Published Normative Act for 2020 bans (C); Declaration contribution policy change (D)
[C3] ICMBio analysis of stakeholder satisfaction questionnaire for 2020 policy change
[C4] Request SAP/MAPA for advice for 2021-24 capture bans (A); Diele's advice for 2021-2024 bans (B); Published Normative Act for 2021-24 bans (C); Declaration contribution policy change (D); Crab stock declarations of commercial agents (E)
[C5] REMAR_CIDADÃO smartphone app advertised on governmental webpages, SAP/MAPA (A) and ICMBio (B&C)
[C6] Google Playstore screen copy for the mobile phone app REMAR_CIDADÃO
[C7] Screenshots of media promoting REMAR and REMAR_CIDADÃO
[C8] Proof of invited talk given by Diele to SAP/MAPA and google questionnaire
[C9] Testimonial from ICMBio staff from Pará state (A); Estimate of the number of crab fishers, dependant household members and crab traders in North and Northeast Brazil [B]. Estimate of the number of crab dish selling restaurants and beach huts in north and northeast Brazil [C]
[C10] Testimonial of estimate of saved public expenditure for crab policing in North and Northeast Brazil, updated for current number of protected areas with mangroves
[C11] Testimonials from Brazilian Principal Investigators of new research grants