Report on Monitoring of Lobster Fishery Impacts on Marine Habitats and Ecosystems in The Bahamas

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Contents

Cover Image: Lobster emerging from an artificial shelter in a seagrass meadow. Image © Nicholas Higgs.

Management Summary

The Bahama Banks are dominated by soft-sediment habitats, including vast expanses of seagrass ecotypes, with lower cover of hard-bottom and reef habitats. Lobsters can be found at all of these habitats and move between them through their lifecycle. Fishing occurs throughout all of these habitats and fishing gear is estimated to directly impact 11 km^2 (0.008%) of the Bahamas seabed each year.

Reefal hardbottom habitats are some of the most well studied and monitored in The Bahamas. Monitoring programs over the last two decades have provided high-quality data, adequate for detecting changes in reef habitats and associated ecosystem functioning. However, there is a lack of understanding of the functional role that lobsters play in reef ecosystems. Consequently the impact (if any) of reduced lobster populations on reefs as a result of fishing is unknown.

Although there is a somewhat better understanding of lobster fishery impacts in soft sediment habitats, more work is needed to understand how artificial lobster shelters impact the soft sediment ecosystem, particularly seagrass. Remote sensing methods offer the greatest potential for monitoring soft sediment habitats that are relevant to the spiny lobster fishery. However, current habitat maps produced using these technologies are not accurate enough to monitor the small impacts expected from the fishery. More fine-scale monitoring is required to detect impacts in seagrass ecosystems.

Both non-reefal hardbottom habitats and deep (>20 m) reef habitats will be expected to have reduced lobster populations as a result of the lobster fishery, but are unlikely to be directly impacted by fishing gear. Non-reef hardbottom habitats have received limited monitoring and research attention, but monitoring to date has shown these habitats are in better condition than reef habitats. Deep reef habitats are not monitored and their condition is unknown.

None of the monitoring reviewed in this report was carried out for the specific purpose of evaluating lobster fisheries impacts. Nearly all monitoring occurs near to land (<5 miles) and is consequently heavily biased towards reef habitats that are impacted by small-scale fishers and fin-fisheries. This geographical bias means that monitoring is not adequate for assessing impacts of the industrial-scale fishery that takes place across the full breadth of the Bahama banks (much of which is >20 miles from land), both on soft sediment habitats and especially patch reefs.

Most of the monitoring is carried out with the permission of, or in collaboration with, The Bahamas Government's Department of Marine Resources, but much of the scientific research and monitoring programs are dependant on external funding sources. This means that the future of monitoring programmes is precarious and there is no guarantee of their continuity. Management plans should contain a financial strategy with adequate funding set aside for continued monitoring of habitats and their associated ecosystems (MSC principle 3).

Introduction

Rationale

The Bahamas is known for its productive spiny lobster (*Panulirus argus*) fishery and is one of the leading exporters of lobster tails worldwide. To improve management and sustainability of the lobster fishery, The Bahamas Department of Marine Resources, The Bahamas Marine Exporters Association (BMEA), The Nature Conservancy, Friends of the Environment in Abaco and other conservation partners are working with the World Wildlife Fund (WWF) to implement a fishery improvement project (FIP) for the Bahamian spiny lobster fishery. The goal of the FIP is to move the lobster fishery toward meeting the Marine Stewardship Council (MSC) standard for sustainable fisheries.

Principle 2 of the Marine Stewardship Council (MSC) principles for sustainable fisheries states that fishing operations should allow for the maintenance of the structure, productivity, function and diversity of the ecosystem on which the fishery depends. In order for The Bahamas spiny lobster fishery to achieve the goal of MSC certification it must be demonstrated that the fishery is conducted in a manner that maintains natural functional relationships among species and should not lead to trophic cascades or ecosystem state changes. This is to encourage the management of fisheries from an ecosystem perspective under a system designed to assess and restrain the impacts of the fishery on the ecosystem.

In addition to these FIP goals The Bahamas has an obligation under international law to protect its natural heritage from overexploitation. Sustainable management of marine resources is mandated by the United Nations Convention on the Law of the Seas (UNCLOS) and the Convention on Biological Diversity (CBD), both of which The Bahamas is a signatory to.

The Spiny Lobster Fishery in the Bahamas

The Bahamas spiny lobster fishery is mostly undertaken through large-scale industrial operations that account for 71% of all commercial fishery landings, with a small scale artisanal, subsistence & recreational fisheries (collectively termed ‘small-scale fisheries’ in this report) contributing the rest[1]. Large-scale fisheries operations are undertaken on mother-ships that will stay out at sea for ~3-5 weeks, with numerous smaller tender vessels that go out to fish each day from the mother-ship. In contrast, the small-scale fisheries mainly utilise small skiffs that go out from port on day trips, returning to land their catch each day. The industrialised operations tend to focus their efforts across the entirety of the Bahama Banks, whereas artisanal and recreational fisheries are more localised, tending to utilise inshore habitats.

Spiny lobster are primarily harvested using two distinct methods in the large-scale commercial fishery. The first utilises traditional wooden slat lobster traps deployed and recovered by rope line. This activity is directly monitored, since their use requires a government permit. The second method utilises artificial shelters (also known as condos or casitas) that act as aggregation devices, which are then harvested by divers using hooks or spears. This method is not directly monitored and consequently estimates of their prevalence are somewhat uncertain. In 2001 it was estimated that 105,000 lobster

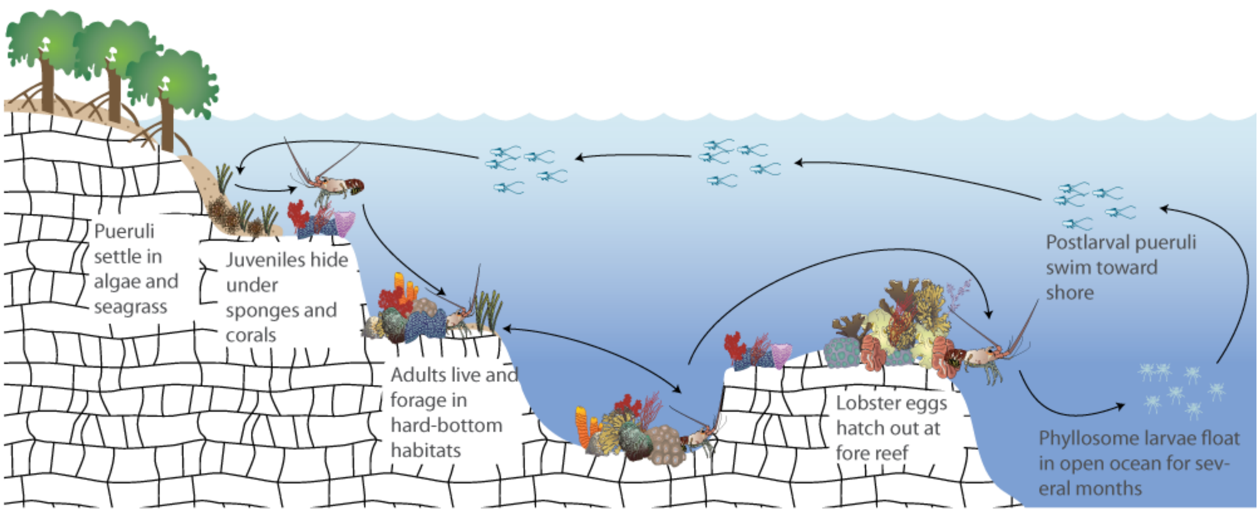
[1] Smith, NS & Zeller, D (2016) Unreported catch and tourist demand on local fisheries of small island states: the case of The Bahamas, 1950-2010. Fishery Bulletin 114:117–131.

traps were in use in The Bahamas, whilst ~650,000 artificial shelters were deployed[2]; i.e. the latter method is approximately six times more popular with fishermen than the former. By 2009 this ratio had shifted further in favour of casitas, with fewer and fewer of new fishers employing traps[3]. Thus the primary mode of interaction with ecosystems will be centred around artificial-shelter based fishing and these potential interactions will be the primary consideration of this report, whilst some consideration will also be given to trap-based fishing interactions.

Key Habitats and Ecosystem Processes in the Bahamas

Spiny lobster fisheries are targeted at adult members of *Panulirus argus* populations, which typically inhabit rocky or coral outcrops, large undercuts, or sponge and soft coral aggregations associated with reefs, ranging from 1-100 m depth (Kanciruk 1980)[4]. Adult lobsters are highly nomadic, undertaking various types of migratory behaviour associated with reproduction or foraging[5]. In The Bahamas, migration between onshore and offshore reefs (Figure 1) necessitates traversing the wide Bahama Banks; therefore, lobsters may be found in any number of habitats across the Banks.

Figure 1: Spiny lobster life cycle diagram. Courtesy of Jane Thomas, Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/imagelibrary/).



Conceptual diagram illustrating the life cycle of lobsters, showing that just one species needs many connected habitats to survive and reproduce successfully.
Diagram courtest of the Integration and Application Network (ian.umces.edu), University of Maryland Center for Environmental Science. Source: Kaufman L and Tschirky J 2010. *Living with the Sea.* Science and Knowledge Division, Conservation International, Arlington, VA, USA.

The Great and Little Bahama Banks, where most fishing occurs, are dominated by seagrass and hard/sandy bottom habitats (Figure 2), with less than 2% coral reef cover[6].

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[2] Deleveaux, V.K.W. & Bethel, G. 2001. National report on the spiny lobster fishery in the Bahamas. *FAO Fishery Report* No. 619: 161-167.

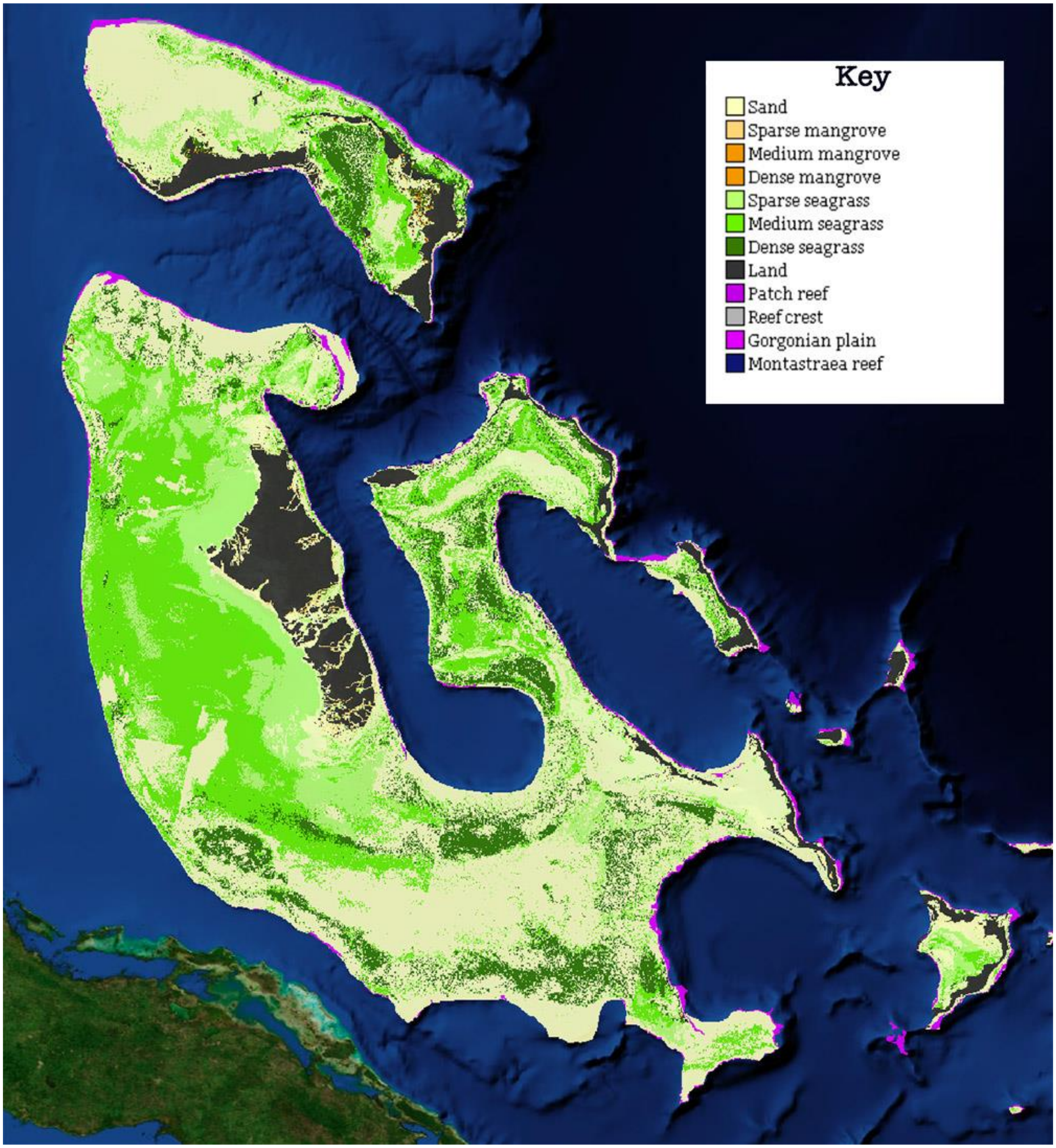
[3] MRAG Americas (2009) Pre-Assessment of the Bahamian Lobster Fishery. *Bahamas Lobster Fishery Improvement Project*. 29pp.

[4] Kanciruk, P (1980) Ecology of Juvenile and Adult Palinuridae (Spiny Lobsters). In: *The Biology and Management of Lobsters: Volume II* (Cob & Phillips eds.) Academic Press, London. pp 59-96.

[5] Herrnkind, WF (1980) Spiny Lobsters: Patterns of Movement. In: *The Biology and Management of Lobsters: Volume I* (Cob & Phillips eds.) Academic Press, London. pp 349-408.

[6] Buchan, KC (2000) The Bahamas. *Marine Pollution Bulletin*. 41:94-111.

Figure 2: Habitat map of the Great & Little Bahama Banks. Used with permission of the Khaled bin Sultan Living Oceans Foundation, Bahamas Webmap.



An Ecoregional Plan for the Bahamian Archipelago has categorised local marine habitats into four broad geomorphic types, with further subdivision into specific ecotypes in accordance with a hierarchical classification system developed by The Ecological Society of America and the NOAA's Office of Habitat Conservation[7], as follows:

Table 1: Habitat classification for the Bahamas marine habitats according to geomorphic- and eco-types.

Reefal Hard-Bottom	**Soft Sediment**	**Non-Reefal Hard Bottom**	**Deep Reef Resources**
Patch reef on Banks	Sand Bores, Oolite Banks	Channel, Algal dominated	Reefs at >20 m depth
Patch reef near shore	Mud, Bare Bottom	Channel, Octocoral/ Sponge dominated	
Channel reef	Mud, with Seagrass	Platform Margin, Algae dominated	
Platform margin reef	Sand, Bare Bottom	Nearshore	
Platform margin barrier	Sand, with Patch Seagrass		
	Sand, with Sparse Seagrass		
	Sand, with Dense Seagrass		

This report will assess potential impacts of The Bahamas spiny lobster fishery on these four categories of habitat and also assess effects on associated faunal communities that comprise the full ecosystem and its functionality. Monitoring of these habitats and associated ecosystems will then be reviewed and evaluated.

Fishery Interactions with Bahamian Ecosystems

In order to determine the potential vulnerability of habitats and ecosystem processes to pressures from the spiny lobster fishery, it is first necessary to determine the impacts that the spiny lobster fishery will have in each habitat.

Reefal Hard-Bottom

Reefal hard bottom habitats encompass classic fringing and barrier coral reef systems, as well as smaller patch reefs that occur across the Bahama Banks. Direct fishery impacts on these habitats occur through lobster fishing by individual divers with spear or hook. Lobster fishing in reef habitats is largely (though not exclusively) carried out by the small-scale lobster fishers because of the proximity of reef habitats to centres of population (Figure 2). In this instance impacts occur through direct removal of lobsters from the reefs and sublethal effects on small/reproductive (i.e. illegal) individuals that are harmed but not taken[8]. Additionally, damage to the reef structure may occur in the act of capturing the lobsters.

In 1977 Davis noted that "the consequences of removing a substantial proportion of the population of such a large sized and abundant carnivore [*P. argus*] from the

[7] Sullivan Sealy, K. et al. (2002) *An Ecoregional Plan for the Bahamian Archipelago*. Taras Oceanographic Foundation, Jupiter, Florida. 227 pp.

[8] Parsons, D. & Eggleston D. (2005) Indirect effects of recreational fishing on behavior of the spiny lobster *Panulirus argus*. *Marine Ecology Progress Series*, 303:235-244.

ecosystem may be great" [9], yet there are remarkably few studies that examine the effect of reduced *P. argus* populations on the coral reef ecosystem. Changes in spiny lobster populations at temperate reefs have led to trophic cascades that have dramatically altered reef ecosystems[10], but is not clear that similar mechanisms operate in the Bahamas[11]. Spiny lobsters (*P.* argus) do seem to be more abundant in marine reserves compared to fished reefs, showing that there is a fishery effect[12], but there is no information on the impact of this effect on the wider reef ecosystem. The only available evidence for the functional role of *P. argus* in coral reef ecosystems is as a prey item for octopus and grouper, rather than as a predator of other invertebrates (which is certainly the case as well)[13]. Therefore it can only be estimated that fishing of *P. argus* reduces the prey availability for top predators in Bahamian reef ecosystems.

Impact on coral reefs will also occur if lobster traps are deployed directly onto reef habitats. Studies in the Florida Keys suggest that this is not likely to be a major impact since "the vast majority of traps are not set in coral or hardbottom. Fishers tend to drop traps in sand, rubble, and seagrass meadows when possible because there is potentially less damage to their traps[14] and it reduces bycatch of unwanted fish species. This study found that each trap that was actually deployed on coral reef resulted in an average of 1.66 injuries to the reef animals and impacted an area of ~50 cm^2, excluding any damage caused by those that were moved or lost[14]. Recent reef surveys in the Joulter Cays area did however find evidence of lost fishing gear impacting corals, although it is not clear if these were scale-fish traps or lobster traps[44].

Soft Sediment

The vast majority of lobster fishing gear is deployed in soft sediment habitats (both traps and artificial shelters) and fishers actively target seagrass where present[15], although they do deploy in other soft sediment ecotypes (N. Higgs & L. Gittens, personal observations). Assuming that there are ~650,000 artificial shelters on the Bahama Banks[2], they would cover a total area of ~2.72 km^2, or 0.002% of the total area of the banks. The artificial shelters are moved 3-4 times per year, so it can be estimated at that a maximum of ~11 km^2 is directly impacted by the large-scale fishing industry every year.

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[9] Davis, G. (1977) Effects of recreational harvest on a spiny lobster, *Panulirus argus,* population. *Bulletin of Marine Science*, 27(2):223-236.

[10] For example: Babcock RC, Kelly S, Shears NT, Walker JW, Willis TJ (1999) Changes in community structure in temperate marine reserves. *Marine Ecology Progress Series*, 189:125−134.

[11] Mumby, PJ *et al.* (2006) Fishing, trophic cascades, and the process of grazing on coral reefs. *Science*, 311:98-101.

[12] Lipcius, R.N. et al. (1997) Hydrodynamic decoupling of recruitment, habitat quality and adult abundance in the Caribbean spiny lobster: source-sink dynamics? *Marine and Freshwater Research*, 48:807-815; Cox, C. & Hunt, JA (2005) Change in size and abundance of Caribbean spiny lobsters *Panulirus argus* in a marine reserve in the Florida Keys National Marine Sanctuary, USA. *Marine Ecology Progress Series*, 294:227-239.

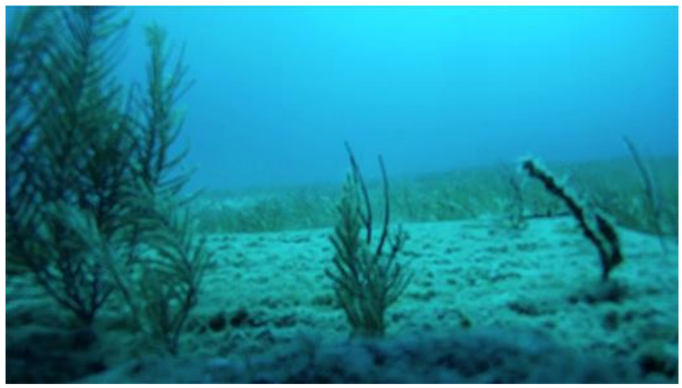
[13] Reviewed by: Boudreau, S. & Worm, B. (2012) Ecological role of large benthic decapods in marine ecosystems: a review. *Marine Ecology Progress Series, 469:195-213.*

[14] Lewis et al. (2009) Lobster trap impact on coral reefs: effects of wind-driven trap movement. *New Zealand Journal of Marine and Freshwater Research 43:* 271-282.

[15] Briones, P. *et al.* (1994) The use of artificial shelters (casitas) in research and harvesting of Caribbean spiny lobsters in Mexico. In: *Spiny Lobster Management* (Cobb & Phillips, eds.), Fishing News Books, Oxford. pp. 340-362.

In non-seagrass soft sediment habitats, fishing gear may smother sessile fauna such as sponges, hydroids and soft corals. Any reduction in these benthic epiphytes and epifauna is likely to also result in a decrease in the abundance and diversity of animals living on and around them[16], because of a reduction in habitat complexity in the area directly underneath the artificial shelters cause by loss of habitat. However, aged shelters provide beneficial hard substrate that supports the growth of sessile erect epifauna (Figure 3).

Figure 3: Artificial shelter in seagrass habitat, colonised by gorgonians and algal turf.



In terms of impacts beyond the area directly underneath the fishing gear, no effect was found on the seagrass community composition around artificial shelters, despite the concentration of mobile predators that fed on benthic fauna[17]. It therefore seems that the ecosystem impacts of artificial shelters are likely to be localised in the immediate area underneath the shelters, but more research is needed on the ecological role of lobsters in seagrass ecosystems (as with reefs discussed above)[13].

Aggregating lobsters could also make *them* more susceptible to predation effects, but this is not the case for adult lobsters[18]. However, juveniles may suffer increased predation if shelters are placed in nursery habitat[18]. There is no indication that this occurs in the Bahamian fishery, especially with the establishment of the Andros West side national park protecting the largest of these nursery areas[19].

Artificial lobster shelters and lobster traps house lobsters at higher densities than they occur in the natural environment, raising some concern that they may alter the ecological role of lobsters in benthic ecosystems. Another issue arising from increased crowding is the possibility of increased disease prevalence and transmission, especially for the recently discovered PaV1 virus. This virus is confined to the Caribbean spiny lobster, *Panulirus argus*, and does not seem to be able to infect other species[20]. The use

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[16] Stoner, A (1980) The role of seagrass biomass in the organization of benthic macrofaunal assemblages. *Bulletin of Marine Science* 30(3):537-551.

[17] Nizinski, MS (2007) Predation in subtropical soft-bottom systems: spiny lobster and molluscs in Florida Bay. *Marine Ecology Progress Series*, 345:185-197.

[18] Gutzler, BC *et al.* (2015) Casitas: a location-dependent ecological trap for juvenile Caribbean spiny lobsters, *Panulirus argus*. *ICES Journal of Marine Science*, 72:177-184.

[19] http://www.bnt.bs/_m1731/The-National-Parks-of-The-Bahamas/West-Side-National-Park

[20] Shields, JD (2011) Diseases of spiny lobsters: A review. *Journal of Invertebrate Pathology*, 106:79–91.

of traps may increase the transmission rates of the virus between lobsters[21], but for the artificial shelters (where lobsters can freely move in and out) there is no evidence that the use of this gear causes increased infection rates[22]. Some researchers hypothesize that "casitas might actually reduce the potential for contact transmission, due to the large shelter area"[22]. Indeed, the Bahamas shows some of the lowest rates of infection in the Caribbean, despite the extensive use of artificial shelters[23].

In terms of direct impacts under artificial shelters, they will prevent light from reaching photosynthesising organisms such as seagrass, algae and bacterial mats, leading to the death of leaf or frond tissues underneath them. This impact is potentially important, given the large area of the Bahama Banks that are covered in seagrass and algae. The loss of leaf tissue will result in a decrease in overall rate of photosynthesis, and thus a reduction in productivity. The oxygen generated by photosynthesis is partially expelled through the root tissues of the plant, oxygenating the surrounding sediment, and so this vital ecosystem function will also be impacted[24]. Lower oxygenation rates in sediments would be expected to have negative impact on the biodiversity and functioning of the infaunal component of the ecosystem[25], however this has not been studied directly in the case of artificial lobster shelters on seagrass.

The smothering of seagrass by artificial shelters does not necessarily lead to the death of the whole plant. The root and rhizome tissues of the seagrass form vast interconnected networks that can redistribute resources among the network[26], which are usually larger than any one artificial shelter. This means that the root and rhizomes can survive, even though the leaves under the artificial shelters may die[27]. Because the artificial shelters are periodically moved by fishermen when they harvest the lobster, a light source is returned to the formally covered patch of rhizomes, which can grow new shoots. Patches of seagrass that were experimentally cut off from the rest of the root-rhizome network and shaded to 10% light levels, survived for 10 months before dying[28], suggesting that survival of connected rhizomes can persist for much longer. There are no published measurements of the rate at which seagrass recovery occurs after covering, nor for the recovery of associated benthic animal communities.

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[21] Behringer, D *et al.* (2012) PaV1 infection in the Florida spiny lobster (*Panulirus argus*) fishery and its effects on trap function and disease transmission. Canadian Journal of Fisheries and Aquatic Sciences, 69:136-144.

[22] Huchin-Mian, JP *et al.* (2013) *Panulirus argus* virus 1 (PaV1) infection prevalence and risk factors in a Mexican lobster fishery employing casitas**.** *Diseases of Aquatic Organisms*, 107:87-97.

[23] Moss, J *et al.* Distribution, prevalence, and genetic analysis of *Panulirus argus* virus 1 (PaV1) from the Caribbean Sea

[24] Enriquez, S. *et al.* (2001) Effects of seagrass *Thalassia testudinum* on sediment redox. *Marine Ecology Progress Series*, 219:149-158.

[25] Rosenberg, R. *et al.* (2001) Response of Benthic Fauna and Changing Sediment Redox Profiles over a Hypoxic Gradient. *Estuarine, Coastal and Shelf Science*, 53:343-350.

[26] van Tussenbroek, BI *et al.* (2006) The biology of *Thalassia*: paradigms and recent advances. In: Seagrasses: Biology, Ecology and Conservation (Larkem, Orth & Duarte, eds.) Springer, The Netherlands. pp. 409-439.

[27] For example, rapid regrowth is reported for heavily grazed seagrass: Peterson, BJ et al. (2002) Disturbance and recovery following catastrophic grazing: studies of a successional chronosequence in a seagrass bed. *Oikos*, 97:361-370/

[28] Czerny, AB (1995) The Effects of in Situ Light Reduction on the Growth of Two Subtropical Seagrasses, *Thalassia testudinum* and *Halodule wrightii*. *Estuaries*, 18(2):416-427.

Most of these impacts remain inferential, since there is no published information on the impact of artificial lobster shelters on benthic ecosystems[29]. This lack of information prevents a full analysis of the impact of the lobster fishery on soft sediment habitats, however it is possible to constrain the scale of any possible impacts to 0.008% of the seabed ecosystem per year.

Non-Reefal Hard Bottom

The non-reefal hard bottom ecotypes most relevant to this review are those on the platform margins. These typically consist of exposed lithified sand-rock with pockets of sand, locally called 'hard-bar', that occur at the edges of the Banks. The bottom is dominated by algae and "species richness of sessile invertebrate taxa is among the lowest of all reefal and non-reefal hard-bottom types in the archipelago"[7]. Early work in The Bahamas showed that these areas provide shelter for larger reproductively active lobsters, compared to shallower bank areas[30].

Little fishing effort is directed to these habitats, partly because they make up only a small proportion of the marine seascape and the rough nature of the bottom is not amenable to fishing gear[14]. Additionally, the high incidence of natural crevice habitat[30], means that artificial shelters are not as attractive to lobsters as in other habitats.

Deep Reef

Deep reefs occur on the margins of the Banks at depths below 20 m, and represent a transition zone between shallow bank and open ocean; however, "deep reef resources are largely undescribed in The Bahamas"[7]. There is a general migration of lobsters to these deeper areas with the onset of autumnal storms[5] and *Panulirus argus* have been found down to 45-180 m depth in the US Virgin Islands[31]. Deep reefs play an important part in the spiny lobster life cycle (Figure 1), when large reproductive females mate and release eggs. The steep gradients and rapid drop-offs into very deep water largely prohibits fishing and so these reefs act as a refuge for lobster populations against fishing mortality[32].

The effects of the fishery on these habitats will be indirect, resulting from a reduction in the overall size of the spiny lobster populations. This may result in a negative feedback cycle where reduced deep-reef populations produce fewer larvae, which in turn leads to a reduction in the future population. As with shallower reefs discussed above, the ecological impacts of this population reduction are not well understood. This is even more so with the deeper habitats which are far less studied.

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[29] Bellchambers, LM *et al.* (2014) Addressing environmental considerations for Marine Stewardship Council certification: A case study using lobsters. *Marine Policy*, 50:249-260.

[30] Kanciruk, P & Herrnkind, WF (1976) Autumnal Reproduction in *Panulirus argus* at Bimini, Bahamas. *Bulletin of Marine Science*, 26(4):417-432.

[31] Armstrong, R. *et al.* (2006) Characterizing the deep insular shelf coral reef habitat of the Hind Bank marine conservation district (US Virgin Islands) using the Seabed autonomous underwater vehicle. *Continental Shelf Research*, 26(2):194-205.

[32] Lozana-Alvarez, E. *et al.* (1993) Occurrence and seasonal variations of spiny lobsters, *Panulirus argus* (Latreille), on the shelf outside Bahia de la Ascension, Mexico. *Fishery Bulletin*, 91(4):809-815.

Monitoring of Bahamian Ecosystems

The Bahamas aims to effectively conserve and manage 20% of its coastal & marine environment by the year 2020[33]. To help achieve this goal, The Bahamas designated sixteen new national marine protected areas and expanded two existing protected areas in 2015. This designation has been based on a series of rapid ecological assessments (REAs) and community consultations to determine the state of the protected areas. A key component of management of the marine protected areas is monitoring of the habitats within them[34].

The REAs cover a range of habitats, some relevant for this report. In addition, coral reef habitats have been surveyed around New Providence and Andros as part of the Atlantis Blue Project's Coral Report Card program, with a view for producing report cards for the entire country in the future[35]. Most of these projects use the Atlantic and Gulf Rapid Reef Assessment (AGRRA) program field methodology, providing standardised high-quality datasets for monitoring of reef populations. The AGRRA program produced reports of coral health in the late 1990's[36]. The Reef-Check program also has trained divers in The Bahamas to carry out reef surveys, with the number of surveys ranging from 1-16 in each year since 1999[37]. Greenforce runs a marine conservation program for volunteers, monitoring the reefs on the east side of Andros[38].

Reefal Hard-Bottom

At the turn of the century Bahamian reefs appeared to be in a poor state. Reef health on the east side of Andros was ranked the worst of seventeen Atlantic sites surveyed in the AGGRA program, with Abaco reefs the third worst[39]. However, certain features were good: Andros reefs showed healthily populations of *Acropora palmata* (important for habitat complexity and ecosystem functioning) and were highest ranked for densities of Nassau grouper. More recently, extensive reef monitoring around New Providence between 2008-2011 has shown that "overall, about half of the reefs surveyed in the New Providence area were in fair to good condition and about half were in poor condition", although patch reefs were in particularly poor condition[40]. Similarly, REAs for inshore reefs in less populated areas around Grand Bahama[41] and Abaco[42] have shown relatively low coral cover that is typical for the area, while reefs in the Lucayan National Park on Grand Bahama appeared to be "fairly diverse in coral cover, with mean live coral surpassing that of the Caribbean"[43]. Reefs at the northern tip of Andros were "quite varied, with some reefs possessing high coral cover for the region, populations of

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33 The Caribbean Challenge Initiative (CCI)

34 Brumbaugh, D *et al.* (2014) Monitoring Programme for the Bahamas National Protected Area System

35 Dahlgren, C. (2015) A Five Year Study of Coral Reefs off New Providence and Rose Islands. Accessed March 2016: http://blueprojectatlantis.org/coral-reef-report-card/

36 Available on the AGRRA website: http://www.agrra.org/reports/field-reports.html

37 http://www.reefcheck.org/country-details/BS Accessed March 2016

38 http://www.greenforce.org/bahamas Accessed March 2016

39 Kramer, PA (2003) Synthesis Of Coral Reef Health Indicators For The Western Atlantic: Results Of The AGRRA Program (1997-2000) In: *Status of Coral Reefs in the western Atlantic: Results of initial Surveys, Atlantic and Gulf Rapid Reef Assessment (AGRRA) Program*. (J.C. Lang ed.), pp.1-55.

40 Dahlgren, C. (2014) New Providence and Rose Island, Bahamas 2014 Coral Reef Report Card.

41 Dahlgren, C. (2014) REA of the Fish and Benthic communities for East Grand Bahama.

42 Dahlgren, C. (2014) REA Report for Fish and Benthic communities - Cross Harbour.

43 Sherman, K. *et al.* (2014) REA for the Expansion of Lucayan National Park.

endangered species and an abundance of fish resources, while other sites have greatly reduced coral cover and less diverse and abundant fish assemblages"[44]. In contrast, reefs around several islands in the southeastern Bahamas "had high diversity, a wide variety of reef types and were in very good condition"[45].

Reef assessments for the Joulter Cays REA noted that "spiny lobster were rarely observed, with the Caribbean spiny lobster (*Panulirus argus*)… only being observed at a few sites", suggesting that these reefs had decreased lobster populations. Similarly low abundances of lobsters were found at reefs around New Providence[46], Abaco[42] and the southeastern Bahamas reefs[45]. No lobsters were observed at the Grand Bahama site[43]. This low abundance of lobster is lower than would be expected for undisturbed reef populations in The Bahamas[46] and may be suggestive of fishing impacts from small-scale fishers. Lobster abundance in these assessments does not seem to correlate with overall reef health, which was quite variable across the sites, despite a universal paucity of lobsters.

Long-term comparisons of reef cover at a site in the Exumas show a decline in reef cover from 13% in 1991 to just 3% in 2004[47]. Similarly, comparisons of reef fish assemblages around New Providence with surveys conducted over 50 years ago reveal that current reef status should not be taken as a baseline, since there appears to have been a long-term decline over this time period[48]. However, these studies also demonstrate the ability of current monitoring to detect changes in reef ecosystem health when combined with historical baseline data. Therefore, it seems that current reef monitoring efforts are capable of detecting change in reef habitats should this progress further, but it would not be possible to attribute any changes in reef health to lobster fishery impacts, partly because there is no proven link between lobster abundance on reefs and the functioning of reef ecosystems. Indeed, lobster fishing is not listed as a priority threat to coral reefs in The Bahamas, whereas intense teleost fisheries, invasive lionfish, disease, coastal development and climate change are perceived to be more important threats to Bahamian reefs[49].

Furthermore, there is a geographical bias in reef monitoring to near-shore environments and centers of population. It is accepted that these areas are most at risk to human impacts but, in the particular case of lobster fisheries impact monitoring, there will be a bias towards areas impacted by small-scale lobster fishers. There is no monitoring of patch reefs across the wider Great Bahama Banks where the majority of industrial lobster fishing takes place.

Soft Sediment

Soft sediment habitats were also assessed by divers in many of the REAs, but none of these sites were in areas targeted by the lobster fishery. As noted previously, impacts

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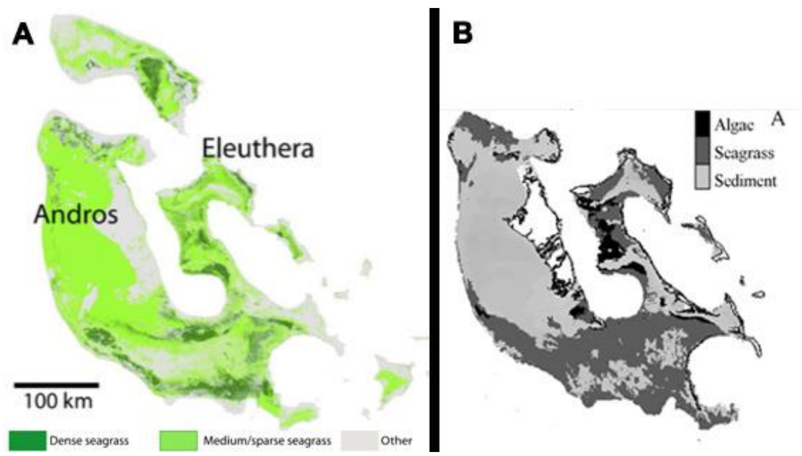
[44] Dahlgren, C. (2014) REA of the Fish and Benthic communities for the Joulter Cays, Bahamas.
[45] Deleveaux, VKW *et al.* (2013) Southeastern Bahamas Coral Reef & Island Survey REA Report.
[46] Dahlgren, C. (2009) REA of the Proposed Southwest New Providence National Park.
[47] Pante, E *et al.* (2007) Short-term decline of a Bahamian patch reef coral community: Rainbow Gardens Reef 1991–2004. *Hydrobiologia*, 596:121-132.
[48] Ilves *et al.* (2013) Detection of shifts in coral reef fish assemblage structure over 50 years at reefs of New Providence Island, The Bahamas highlight the value of the Academy of Natural Sciences' collections in a changing world. *Proc. Acad. Nat. Sci. Phil.*, 162: 61-87.
[49] Gardner *et al.* (2003) Long-term region-wide declines in Caribbean corals. *Science*, 301:958-960.

of lobster fishing gear are largely confined to the area immediately underneath the gear. Monitoring the cumulative impacts of these many small localised impacts is difficult over the large Bahama Banks system.

Another approach for assessing the overall status of soft sediment habitats in The Bahamas (particularly seagrass) is to use remote sensing techniques (e.g. satellite or aerial photography images), which have proven useful for habitat mapping over large scales (Figure 2). However, there are significant discrepancies in the degree of predicted seagrass cover between the Landsat (Figure 4A) and the SeaWiFS (Figure 4B) techniques for large regions of the northern and central part of the Great Bahama Bank. This difference is in the order of 1000's of km^2 whereas the predicted impacted area is ~11 km^2 in total, fragmented over many small patches. Both methods have ~70% accuracy in predicting habitat correctly, but this level of reliability is currently too low to detect the small scale changes that might result from fisheries impacts.

Figure 4: Seagrass habitat maps of the Bahama Banks produced using different remote sensing techniques. (A) Landsat[50]; (B) SeaWiFS ocean color sensor[51]



An alternative to monitoring the total seagrass cover might be to monitor a smaller region using high resolution satellite imagery[52]. High resolution (4 m^2 pixels) WorldView-2 satellite imagery was recently used to successfully map fine-scale habitat structure over relatively large areas of The Bahamas, such as the entire Cay Sal Bank[53]. This mapping was able to differentiate between ecotypes within the soft-sediment geomorphic habitat types. Thus, it may be more feasible and informative to focus on a small area that is known to be intensively fished and monitor and changes in seabed cover in detail to detect lobster fishery impacts. Targeting an area on the central Great

[50] Wabnitz, CC *et al.* (2008) Regional-scale seagrass habitat mapping in the Wider Caribbean region using Landsat sensors: Applications to conservation and ecology, 112:3455-3467.
[51] Dierssen, HM *et al.* (2010) Benthic ecology from space: optics and net primary production in seagrass and benthic algae across the Great Bahama Bank. *Marine Ecology Progress Series*, 411:1-15.
[52] e.g Mumby, PJ & Edwards, AJ (2002) Mapping marine environments with IKONOS imagery: enhanced spatial resolution can deliver greater thematic accuracy. *Remote Sensing of Environment*, 82:248-257.
[53] Bruckner, AJ *et al.* (2014) Khaled bin Sultan Living Oceans Foundation Atlas of Shallow Marine Habitats of Cay Sal Bank, Great Inagua, Little Inagua and Hogsty Reef, Bahamas. Panoramic Press, pp. 304.

Bahama Banks, away from other fishing impacts would allow a direct assessment of lobster fisheries impacts on soft sediment communities.

Non-Reefal Hard Bottom

Surveys of marginal hard bottom have been carried out in the Joulter Cays REA which found that “sites had moderate to high relief reef, but the structure of the reef was a spur and groove hardbottom with some corals present”[44]. Little other information was recorded except that sea cucumber abundances were lower than expected because they were targeted for fishing in the area. Additionally, spur and groove hard bottom habitats were surveyed in the southeastern Bahamas REA which seemed to host typical hard-bottom communities “covered with numerous corals, gorgonians and sponges”[45]. The authors note that the relatively lower diversity of coral compared to reef habitat probably relates to the high energy regime of the environment rather than anthropogenic reduction in coral cover. Similarly, hardbottom area around New Providence had a “naturally low coverage of hard corals and relatively high coverage of gorgonians”[46]. As discussed above, the frequency of recorded lobster sightings in these various areas were markedly different.

It seems that the few marginal hard bottoms surveyed to date show little sign of lobster fishing impacts, with the caveat of geographical bias mentioned above. Therefore current monitoring levels seem to be adequate for managing impacts in these habitats. Should any evidence of lobster fishing activity in these areas be detected or impact suspected, it would be necessary to carry out more extensive monitoring.

Deep Reef

Deep reefs (>20 m depth) are not routinely monitored in The Bahamas. Without any information on the lobster stocks in the deep reef environments it is not possible to evaluate lobster fishery impacts in these areas (potentially reduced population abundance). If these areas are acting as refugia for lobster stocks, any changes in their populations of lobster might provide an indicator of potential decline in the overall stock. Likewise, changes in lobster populations in these deep reefs might affect larval supply to shallower habitats. However, the costs of monitoring these sites are prohibitive, requiring specialist divers or remotely operated vehicles. Another option might be to undertake lobster trapping surveys to monitor these populations, guided by sonar to avoid loss of traps.

Summary Table

Habitat	Fishery Impacts			Monitoring			
	Type	Severity	Vulnerability	Quality	Trends	Impacts	Timeframe
Reefal Hardbottom	Direct	–	Medium	Adequate	Yes	Yes	2017?
Soft Sediment	Direct	– – –	Medium	Minimal	No	No	2016?
Non-reefal Hardbottom	Indirect	–	Low?	Indicative	Maybe	Maybe	?
Deep Reef	Indirect	–?	Unknown	None	No	No	N/A

Descriptors[54]

Vulnerability
This qualitative descriptor combines the sensitivity of the habitat to impacts and the severity of impacts that each habitat will experience from the lobster fishery:
High – High sensitivity habitat with medium or high severity
Medium – High sensitivity habitat with low severity impact
Low – Medium/low sensitivity habitat with low severity impact

Impact Severity & Direction
The number of signs (1-3) is proportional to severity:
– = negative interaction between species and lobster fishery
+ = positive interaction between species and lobster fishery
? = impact severity is uncertain

Monitoring Quality
Comprehensive = Multi-indicator data that is geographically relevant to the lobster fishery
Adequate = Multi-indicator data that is geographically limited in relevance to the lobster fishery
Indicative = Single indicator data that is geographically limited in relevance to the lobster fishery
Minimal = Single-indicator data of little relevance to the lobster fishery

Monitoring Trends
Is current or planned monitoring capable of detecting changes in habitat and ecosystem status? Yes/No. Maybe indicates that additional data may allow adequate monitoring.

Monitoring Impacts
Is current or planned monitoring capable of detecting lobster-fishery specific impacts on habitats and ecosystems? Yes/No. Maybe indicates that additional data may allow adequate monitoring.

[54] E.g. see: Mongruel, R. & Beaumont, N (2015) A Framework For The Operational Assessment Of Marine Ecosystem Services. Valmer Project; and Potts, T. *et al*. (2014) Do marine protected areas deliver flows of ecosystem services to support human welfare? *Marine Policy*, 44:139-148.