Bonefish (*Albula vulpes*) home range to spawning site linkages support a marine protected area designation

Aaron J. Adams[1,2], Justin P. Lewis[1], Andrea M. Kroetz[3], R. Dean Grubbs[4]

[1]Bonefish & Tarpon Trust, Miami, FL aaron@bonefishtarpontrust.org

[2]Harbor Branch Oceanographic Institute Florida Atlantic University

[3]Riverside Technology, Inc. for NOAA, National Marine Fisheries Service, Southeast Fisheries Science Center

[4]Florida State University Coastal and Marine Laboratory

Abstract

1. A spatial approach to coastal management, such as marine protected areas, is being increasingly used to address biodiversity and fishery declines resulting from habitat loss, degradation, and overfishing. This approach is especially applicable in regions and fisheries that are data-poor, and often lack regulations and adequate capacity for enforcement. In data-poor situations, species that have economic, cultural, and charismatic value can provide leverage for ecosystem protection.

2. In this study, acoustic telemetry was used to confirm a pre-spawning aggregation site (PSA), acting as critical information for protection of essential habitat for bonefish. Additionally, data sharing with an acoustic telemetry study on smalltooth sawfish (*Pristis pectinata*), documented linkages between the PSA site and bonefish home ranges ≥70 km distant, thus providing an estimate of the catchment area.

3. These data provided post hoc support for a marine national park designated in 2002, and demonstrate that the park is of the appropriate spatial scale.

Journal Keywords: island, subtidal, mangrove, marine park, tracking, fish, fishing

Keywords: Bahamas, coastal habitat mosaic, fish spawning aggregation, marine spatial management, marine protected area, recreational fishery

1. Introduction

Among the top threats to coastal biodiversity and ecosystem integrity are overfishing, habitat loss, and habitat degradation (Brown, 2006; Lotze et al., 2006; Orth et al., 2006; Schmitter-Soto et al., 2018; Valiela, Bowen, & York, 2001). A spatial approach to coastal management, such as marine protected areas (MPAs), is being increasingly used to offset coastal ecosystem declines through habitat protection and user-group limitations (Gaines, White, Carr, & Palumbi, 2010; Green et al., 2015; Roberts, Halpin, Palumbi, & Warner, 2001). A spatial approach to management is especially important for fisheries and regions that are data-poor, which also tend to lack regulations and enforcement (Adams, Rehage, & Cooke, 2019; Johannes, 1998). For example, the creation of a protected area network in St. Lucia (West Indies), which lacks enforcement, resulted in an increase of fishery landings by 46% - 90%, depending on the fishery type (Roberts, Halpin, Palumbi, & Warner, 2001). However, obtaining sufficient data to support the designation and maintenance of protected areas remains a challenge (Cabral, Mamauag, & Alina, 2015).

Bonefish, *Albula vulpes*, support an economically important recreational catch-and-release fishery, as well as small-scale artisanal fisheries, in the Caribbean Sea and western North Atlantic Ocean (Adams et al., 2014; Danylchuk et al., 2007). For example, the estimated annual economic impact of the recreational fishery for bonefish in the Bahamas is US$169 million

(Fedler, 2019); bonefish is part of the recreational catch-and-release *flats fishery*, which also includes Atlantic tarpon (*Megalops atlanticus*) and permit (*Trachinotus falcatus*), with an estimated annual economic impact of US$465 million in the Florida Keys (Fedler, 2013) and US$50 million in Belize (Fedler, 2014). Bonefish are also important components of the coastal trophic system in that they rely heavily on benthic invertebrates as prey (Colton & Alevizon 1983; Crabtree, Stevens, Snodgrass, & Stengard, 1998; Griffin et al., 2019), and in turn are prey for sharks and barracudas (Cooke & Philipp, 2004; Danylchuk et al., 2007). An International Union for the Conservation of Nature (IUCN) assessment classified bonefish as Near Threatened due to habitat loss and fragmentation, coastal development and urbanization, declines in water quality, and harvest by commercial, artisanal and recreational fisheries (Adams et al., 2014).

Bonefish make extensive use of the coastal habitat mosaic (Haak, Power, Cowles, & Danylchuk, 2019; Murchie et al., 2019). Adults show high site fidelity to areas of shallow flats habitats of sand, seagrass, mangroves, and hardbottom during the non-spawning season (Boucek et al., 2019; Brownscombe et al., 2019; Brownscombe, Danylchuk, & Cooke, 2017; Murchie et al., 2013). Spawning season occurs October through April near full and new moons and adults undergo migrations to pre-spawning sites that are composed of shallow protected bays near deep water (Danylchuk et al., 2011). Bonefish form pre-spawning aggregations (PSAs) at these sites before moving offshore at dusk to spawn at night, with spawning occurring at depths >50m near deep-water drop-offs with overall water depth >1000 m, before fish return to their shallow water flats habitats (AJA, unpub. data; Boucek et al., 2019; Danylchuk et al., 2011). Planktonic larval duration is 41 to 71 d (Mojica, Shenker, Harnden, & Wagner, 1995). Settlement and early juvenile habitats are sand or sandy-mud bottoms in shallow, protected bays with low wind-induced wave energy (Haak, Power, Cowles, & Danylchuk, 2019). The combination of the species' broad use of the coastal habitat mosaic and offshore waters and the previously described high economic value of the recreational fishery provide leverage for conservation (Adams & Murchie, 2015).

This study used acoustic telemetry as part of a programme to identify bonefish PSA sites, with the intent of using these data to contribute to a spatial marine management approach in The Bahamas. This study further benefitted from a long-term acoustic telemetry study of smalltooth sawfish (*Pristis pectinata*), which provided data detections of tagged bonefish that demonstrate the links between the bonefish pre-spawning site and adult home ranges. The findings are presented in the context of their value relative to a marine park focused on habitat protections.

2. Methods

<u>Site description</u>

Andros is the largest island in the archipelago of The Bahamas, though it is itself an archipelago within The Bahamas, with a total land area of 5,957 km^2 (Figure 1). The island is low-lying, and contains extensive shallow flats and wetlands. This mosaic of shallow coastal habitats supports an economically important recreational bonefish fishery, with annual angler expenditures of US$34.6 million on Andros (Fedler, 2019). The high biodiversity supported by this extensive shallow habitat mosaic was the main factor driving the establishment of the West Side National Park. The West Side National Park was declared in 2002 after an extensive public comment period, as well as a Rapid Ecological Assessment that provided data supporting park designation. The park is 1.5 million acres of coastal mangrove habitat and flats on the west side of Andros Island (Figure 1), and is managed by Bahamas National Trust (https://bnt.bs/west-side-national-park/). Although the park features bonefish as a focal species for habitat protection, data on spatial connectivity by bonefish on Andros have not been available.

Acoustic Telemetry

Bonefish captured from a likely PSA on the east side of Andros (Figure 1) were fitted with acoustic transmitters as part of the protocol to verify this as a PSA site (Adams et al., 2019). The goals were to: 1) verify the temporal pattern of presence/absence typical of PSA sites – diurnal presence, with absence from dusk to dawn (spawning is nocturnal in offshore waters: Adams et al., 2019; Danylchuk et al., 2011; Adams unpub. data); and 2) determine return rate to the PSA site within a spawning season (Adams et al., 2019).

Bonefish were captured from the PSA with hook and line. For implantation of transmitters, bonefish were held ventral-side up in a 33 l plastic cooler. A 2 cm incision was made on the ventral surface of the fish, and the transmitter (Vemco, V9, 9 mm diameter, 21 mm long, 3.3 g in air, min and max delay times 45–135 s) was inserted into the peritoneal cavity. The incision was closed with two interrupted sutures (Ethicon 3–0 PDS II, Johnson and Johnson, New Jersey). Bonefish recovered in an aerated cooler or floating mesh pen for approximately 30 min before being released into the PSA. To confirm that bonefish in the PSA were following the temporal patterns of synchronous movement offshore at dusk (Danylchuk et al., 2011), an acoustic receiver (VR2W, Vemco, Nova Scotia) was anchored at the centre of the site. The receiver was in place from 29 November 2017 to 4 September 2018.

Separately, the PSA-verification project benefitted greatly from collaboration among acoustic telemetry projects. These collaborations are enhanced by networks (e.g. Florida Atlantic Coast Telemetry (FACT), Integrated Tracking of Aquatic Animals in the Gulf of Mexico (iTAG), Ocean Tracking Network (OTN), Atlantic Cooperative Telemetry Network (ACT)) that were created to facilitate sharing of acoustic receiver detection data. In this case, acoustic receivers were deployed on the west side of Andros as part of a research project of the National Oceanographic and Atmospheric Administration (NOAA) Southeast Fisheries Science Center (SEFSC) Panama City Lab and Florida State University Coastal and Marine Laboratory (FSUCML) to track movements of smalltooth sawfish, an endangered species that inhabits shallow coastal waters in the western Atlantic Ocean (Brame et al., 2019).

3. Results

Six bonefish were acoustically tagged and released at the PSA site on 2 December 2017 with the full moon on 3 December 2017 (Table 1). All of the bonefish were detected for at least a day at the site, and showed presence only during the day, confirming the expected temporal patterns for a PSA (Adams et al., 2019; Danylchuk et al., 2011) (Figure 2). One tagged bonefish was also detected on one day (30 December 2017) just prior to the next full moon on 1 January 2017. There were no additional detections at the PSA site for the remainder of the spawning season.

Because the data are sensitive, exact locations of PSA sites are not shared outside of discussions with resource managers about protecting the sites and thus the exact location of the PSA is not shared here. A PSA site may be known by a local community or some fishing guides, but generally not outside the immediate community. This practice of not sharing site-specific information in published literature has become more common in scientific literature that incorporates sensitive information on species distributions and Traditional Ecological Knowledge (e.g., Sadovy De Mitcheson et al., 2008; Robinson et al., 2004).

All six bonefish tagged at the PSA site were detected by eight of the 20 acoustic receivers from the sawfish project between December 2017 and October 2018 (Table 1, Figure 3, see Figure 1 for generalized acoustic receiver locations). These receivers were in habitats and locations that are typical of non-spawning season home ranges of bonefish (Boucek et al., 2019). Home range is defined as the area an animal uses on a regular basis for its routine activities (Mace et al., 1983). Mark-recapture was used to document that bonefish exhibit high site fidelity, with the majority of recaptures within 5 km of the tagging location (Boucek et al., 2019). The distance from the PSA site to home range receivers in this study ranged from 71 km to 118 km (Table 2).

4. Discussion

This study continued the application of a protocol (Adams et al., 2019) to identify PSA locations for a fish species that is economically important throughout the Caribbean, by documenting the expected diurnal presence/absence of bonefish at the PSA site. This adds to previous findings on other islands in The Bahamas (Abaco, Grand Bahama, South Andros – Boucek et al., 2019; Grand Bahama – Murchie et al., 2013; Eleuthera – Danylchuk et al., 2011; Bimini and Long Island – Adams unpub. data), which contributed to the designation of marine national parks in The Bahamas (Adams et al., 2019). Similar findings have been reported for Belize (Perez et al.,

2019) and Cuba (Rennert, Shenker, Angulo, & Adams, 2019), where work to apply these findings to protected area designation is ongoing.

The most important finding of this study is the significant expansion of the linkages documented between the PSA site on the east side of Andros and home ranges on the west side of Andros. The first study to track bonefish on Andros (Haley, 2009) acoustically tagged 25 bonefish and placed 27 receivers to examine purported bonefish spawning migration patterns. In that study, bonefish were acoustically tagged on the west side of Andros, within the natural channel that connects the east and west sides of Andros, and on the east side of Andros, with receivers placed within this same area. Results documented the movement of seven bonefish between tagging locations on the west side of Andros and what at the time of the study was a purported spawning location on the east side of Andros (Haley, 2009). Since that work (Haley, 2009), the east Andros site addressed in this study has been confirmed as a PSA location following a protocol for establishing PSA sites (Adams et al., 2019). The greatest distance between the PSA site and the west side of Andros previously documented was 61 km (Haley, 2009). In this study, distances between the PSA site and bonefish home ranges were from 71 km to 118 km, which encompasses much of the west side of north Andros. That the bonefish tagged in this study were detected at only eight of the 20 receivers deployed as part of the sawfish project suggest that either the receivers detected a bonefish in transit (e.g. Transmitter 3949 was detected once by receiver 980; Table 1) to its home range, or the receiver was within the bonefish's home range (e.g. Transmitter 3955 was detected 283 times by a single receiver; Table 1).

Understanding the spatial extent of a catchment area (defined as the geographic extent of adults migrating to a PSA site and extent of larval dispersal from a PSA site – Sadovy De Mitcheson et al., 2008) for a population is crucial in determining the appropriate scale of spatial protection needed for a species (Sadovy De Mitcheson et al., 2008). This is because not doing so may inhibit fish maintaining a minimum abundance at a spawning aggregation site (Sadovy De Mitcheson et al., 2008; Sadovy & Domeier, 2005). As shown in this study, a single PSA site draws bonefish from an extensive home range area within a habitat mosaic of flats and mangroves on the west side of Andros. It is likely that this study defines the spatial extent of the catchment area for this PSA site. All of the bonefish tagged in this study were detected only by receivers in a finite geographic area on the west side of north Andros, despite receivers being deployed over a broader area. The acoustic receiver array deployed for the sawfish study extended from Receiver 911 on the north-west side of Andros to the Middle Bight, in the same area as the receiver placed by Haley (2009) that did not detect any tagged bonefish (Figure 1). Haley (2009) also only detected bonefish at receivers near the home range identified in this study, and also did not detect bonefish at receivers placed north and south of the PSA site on the east side of Andros, further suggesting that this PSA attracts bonefish only from the region identified in this study. A large catchment area for a PSA site on the eastern side of south Andros (70 km south of the PSA site in this study) was also documented using mark-recapture (Boucek et al., 2019), encompassing more than 71 km of the west side of south Andros, with no tagged fish captured outside of this area. Although it is possible that catchment areas for multiple PSA sites on Andros overlap, as was found for Nassau grouper (Dahlgren et al., 2016) and for bonefish on Grand Bahama (Murchie et al., 2015), overlap was not document this in this study.

Regardless of the extent to which PSA catchment areas might overlap on Andros, the dependence of bonefish that reside on the west side on PSAs on the east side (Boucek et al., 2019; Haley, 2009) suggests that PSAs on the east side of Andros should also be considered for protection. Indeed, although the documentation of the PSA to home range linkages provides important post hoc support for the West Side National Park, the fact that the PSA site is not currently protected is a gap in the Bahamas-wide effort to use spatial protections for conservation benefit. This is because many species of fish that aggregate to spawn, such as groupers, are listed as threatened by IUCN (iucnredlist.org) due to the harvesting of fish from aggregations (Sadovy De Mitcheson et al., 2008). Although harvesting of bonefish at the PSA site in this study is not currently an issue on Andros, this does occur on other islands in The Bahamas (J. Lewis, pers. obs.), in Cuba (Rennert, Shenker, Angulo, & Adams, 2019), and in Mexico (A. Perez, ECOSUR, pers. com.). This spawning-associated harvest appeared to reduce the size (age) at maturity and maximum size in Cuba (Rennert, Shenker, Angulo, & Adams, 2019), and resulted in lower abundance, smaller size, and earlier sexual maturation of a related species (*A. glossodonta*) at multiple locations in the Pacific (Beets, 2001; Filous et al., 2019; Filous et al., 2020a; Johannes & Yeeting, 2001). Unlike groupers and many other aggregate-spawning fish, bonefish PSA sites are also threatened by habitat loss and degradation. The sites are typically along a shoreline protected from rough seas that are also adjacent to deep water, which is appealing for the construction of deep-water ports or marinas. Deep water areas near ocean currents are also targeted for sewage outfalls and other effluent discharges.

The economic and cultural importance of the fishery provides leverage for conservation (Adams & Murchie, 2015). The recreational bonefish fishery in The Bahamas has an annual economic value of US$169 million, supports more than 7,800 jobs (Fedler, 2019), and the per capita economic impact of the fishery exceeds that of standard tourism (Fedler, 2010). The fishery is especially important to the economy and culture of what are termed the Family Islands – islands that lack the urban centres of Nassau, on New Providence, and Freeport, Grand Bahama. The fishery is also relatively low environmental impact in that it is catch-and-release with generally high post-release survival (Danylchuk et al., 2007), there is very little bycatch and gear loss, and can support sustainable economies associated with ecotourism (Zwirn, Pinsky & Rahr, 2005). Recreational anglers and guides engaged in catch-and-release fisheries tend to be advanced anglers who understand the connection between the health of the environment and quality of the fishery (Oh & Ditton, 2006), and will advocate for habitat conservation that helps to protect their fishery (Cowx et al., 2010). The dependence of bonefish upon a healthy and intact habitat mosaic that encompasses both shallow coastal home range habitats and offshore spawning locations means that protection of habitats important to the bonefish fishery also benefits the many other species that use these habitats. This is reflected by previous application of bonefish movement data to national park designation in The Bahamas, whereby five new national parks were delineated and one existing park was expanded based on tracking information on bonefish (Adams et al., 2019; Boucek et al., 2019). Similarly, acoustic tracking and mark-recapture were used to inform spatial and temporal protection for *A. glossodonta* in the Pacific (Filous et al., 2020a,b). Since *A. glossodonta* and other species of *Albula* are economically important in the tropical Pacific Ocean (e.g., Filous, Lennox, Clua, & Danylchuk, 2019), these methods might be similarly incorporated in regional conservation efforts.

Though the sample size (n=6) in this study was relatively small, when viewed as part of the larger research effort on bonefish movements, the findings are supported by previous research of bonefish that showed similar PSA-home range linkages. For example, the results of this study build upon Haley (2009), who tracked seven bonefish moving between the east and west sides of Andros. In addition, mark-recapture was used to document the links between PSA sites and home ranges at four additional PSA sites in The Bahamas, including a PSA site in south Andros (Boucek et al., 2019). Such linkages for bonefish were also documented in Belize (Perez, Schmitter-Soto, Adams, & Heyman, 2019), and around Grand Bahama Island (Murchie et al., 2015). More generally, data poor situations are common for tropical species, including commercially important species like groupers (Serranidae) that also aggregate to spawn (Sadovy de Mitcheson et al., 2008). For bonefish and many of these other species, it is unlikely that the data poor status is going to improve substantially. It is therefore essential to develop a spatial approach to conservation of bonefish and other data poor fisheries that are managed with high levels of data uncertainty (Johannes, 1998). In this context, the documentation of bonefish home range to PSA site connectivity at this and other locations, albeit with relatively low sample size in each independent study, combined demonstrate this connectivity and support broad spatial conservation.

The study also highlights the importance of collaboration among researchers conducting acoustic telemetry studies (Griffin et al., 2018). Passive acoustic telemetry is increasingly being used as a tool to understand movements and habitat use of marine organisms (Heupel &

Webber, 2012). Acoustic transmitters are available in a variety of sizes with lifetimes of up to ten years, which allow examination of movements at long-term and broad spatial scales. However, a weakness of this approach is that if a tagged individual is not detected by a researcher's acoustic receivers, the researcher can only conclude that the tagged individual was outside of the receiver array's detection range. This weakness is being addressed by data sharing collaborations that are enabled because acoustic receivers detect transmitters from other studies. The collaborative networks applicable to this study include OTN, FACT, iTAG, and ACT. In addition, the producer of acoustic telemetry equipment (Vemco.com) connects individual researchers when transmitters are detected on external receiver arrays. The success of these collaborative arrays is dependent on good-faith data sharing and data use policies among participating researchers. This level of collaboration was not only essential for the findings in this study but has been for many additional studies (e.g. Brownscombe et al., 2019; Griffin et al., 2018; Whoriskey & Hindell, 2016).

Acknowledgements

AJA and JPL were funded by Bonefish & Tarpon Trust. AMK was funded by Riverside Technology Inc. for NOAA-SEFSC. We thank C. Luck, A. Smith, S. Smith, and Bahamas National Trust for field assistance with bonefish tagging. We thank J. Carlson for field assistance with the smalltooth sawfish project. We thank A.J. Danylchuk for helpful comments on an earlier manuscript draft. We thank the Save Our Seas Foundation, NOAA-SEFSC, and the Rackley Family Foundation for funding to support the Andros west side acoustic array and the Flamingo Cay Rod and Gun Club for logistical support. The research in West Side National Park was approved by permits from the Bahamas Department of Marine Resources (Permit MAMR/FIS/17) and the Bahamas

National Trust. The tagging of bonefish at the PSA was conducted under a permit from the Bahamas Department of Marine Resources to BTT. The views and opinions expressed or implied in this article are those of the authors and do not necessarily reflect the position of the National Marine Fisheries Service, NOAA. The authors have no conflicts of interest to declare.

References

Adams, A. J., Horodysky, A. Z., McBride, R. S., Guindon, K., Shenker, J., MacDonald, T. C., Harwell, H. D., Ward, R., & Carpenter, K. (2014). Global conservation status and research needs for tarpons (Megalopidae), ladyfishes (Elopidae) and bonefishes (Albulidae). *Fish and Fisheries, 15 (2),* 280–311.

Adams, A. J., & Murchie, K. J. (2015). Recreational fisheries as conservation tools for mangrove habitats. *American Fisheries Society Symposium, 83*, 43-56.

Adams, A. J., Rehage, J. S., & Cooke, S. J. (2019). A multi-methods approach is essential for effective conservation and management of recreational flats fisheries. *Environmental Biology of Fishes, 102(2),* 105-115.

Adams, A. J., Shenker, J., Jud, Z., Lewis, J., Carey, E., & Danylchuk, A.J. (2019). Identifying pre-spawning aggregation sites for bonefish (*Albula vulpes*) in the Bahamas to inform habitat protection and species conservation. *Environmental Biology of Fishes, 102(2),* 159-173.

Beets, J. (2001). Declines in finfish resources in Tarawa Lagoon, Kiribati, emphasize the need for increased conservation effort. *Atoll Research Bulletin, 490,* 1–14.

Boucek, R. E., Lewis, J. P., Stewart, B. D., Jud, Z. R., Carey, E., & Adams, A. J. (2019). Measuring site fidelity and homesite-to-pre-spawning site connectivity of bonefish (*Albula vulpes*): using mark-recapture to inform habitat conservation. *Environmental Biology of Fishes, 102(2),* 185-195.

Brame, A. B., Wiley, T. R., Carlson, J. K., Fordham, S. V., Grubbs, R. D., Osborne, J., Scharer, R. M., Bethea, D. M., & Poulakis, G. R. (2019). Biology, ecology, and status of the smalltooth sawfish *Pristis pectinata* in the USA. *Endangered Species Research, 39,* 9-23.

Brown, C. (2006). *Marine and coastal ecosystems and human wellbeing: a synthesis report based on the findings of the millennium ecosystem assessment.* United Nations Publications.

Brownscombe, J. W., Danylchuk, A. J., & Cooke, S. J. (2017). Spatiotemporal drivers of energy expenditure in a coastal marine fish. *Oecologia, 183,* 689-699.

Brownscombe, J. W., Griffin, L., Gagne, T., Haak, C. R., Cooke, S. J., Finn, J., & Danylchuk, A. J. (2019). Environmental drivers of habitat use by a marine fish on a heterogeneous and dynamic reef flat. *Marine Biology, 166,* 18, DOI: 10.1007/s00227-018-3464-2

Brownscombe, J. W., Adams, A. J., Young, N., Griffin, L. P., Holder, P., Hunt, J., Acosta, A., Morley, D., Boucek, R., Cooke, S. J., & Danylchuk, A. J. (2019). Bridging the knowledge-action gap: A case of research rapidly impacting recreational fisheries policy. *Marine Policy, 104,* 210-215.

Cabral, R. B., Mamauag, S. S., & Alina, P. M. (2015). Designing a marine protected areas network in a data-limited situation. *Marine Policy, 59,* 64-76.

Colton, D. E., & Alevizon, W. S. (1983). Feeding ecology of bonefish in Bahamian waters. *Transactions of the American Fisheries Society, 112,* 178–184

Cooke, S. J., & Philipp, D. P. (2004). Behavior and mortality of caught and released bonefish (*Albula* spp.) in Bahamian waters with implications for a sustainable recreational fishery. *Biological Conservation, 118,* 599–607.

Crabtree, R. E., Stevens, C., Snodgrass, D., & Stengard, F. J. (1998). Feeding habits of bonefish, *Albula vulpes*, from the waters of the Florida Keys. *Fishery Bulletin, 96,* 754–766

Danylchuk, A. J., Danylchuk, S. E., Cooke, S. J., Goldberg, T. L., Koppelman, J. B., & Philipp, D. P. (2007). Biology and Management of bonefish (Albula spp) in the Bahamian Archipelago. In J. Ault (ed.), *Biology and Management of the World's Tarpon and Bonefish Fisheries.* Boca Raton, Florida, CRC Press.

Danylchuk, A. J., Danylchuk, S. E., Cooke, S. J., Goldberg, T. L., Koppelman, J. B., & Philipp, D. P. (2007). Post-release mortality of bonefish (*Albula vulpes*) exposed to different handling practices during catch-and release angling in South Eleuthera, Bahamas. *Fisheries Management and Ecology 14,* 149–154.

Danylchuk, A. J., Cooke, S. J., Goldberg, T. L., Suski, C. D., Murchie, K. J., Danylchuk, S. E., Shultz, A. D., Haak, C. R., Brooks, E. J., Oronti, A., Koppelman, J. B., & Philipp, D. P. (2011). Aggregations and offshore movements as indicators of spawning activity of bonefish (*Albula vulpes*) in the Bahamas. *Marine Biology, 158,* 1981–1999

Fedler, A. (2013). Economic impact of the Florida Keys flats fishery. Report to bonefish & Tarpon Trust, FL 30p. https://www.bonefishtarpontrust.org/downloads/researchreports/stories/BTT%20-%20Keys%20Economic%20Report.pdf Accessed 11 September 2020.

Fedler, A. (2014). Economic impact of flats fishing in Belize. 19p.

https://www.bonefishtarpontrust.org/downloads/researchreports/stories/2013-belize-economic-study.pdf Accessed 11 September 2020.

Fedler, A. (2019). The 2018 economic impact of flats fishing in The Bahamas. Report to bonefish & Tarpon Trust, 24p. https://www.bonefishtarpontrust.org/downloads/research-reports/stories/bahamas-flats-economic-impact-report.pdf Accessed 11 September 2020.

Filous, A., Lennox, R. J., Clua, E. E. G., & Danylchuk, A. J. (2019). Fisheries selectivity and annual exploitation of the principal species harvested in a data-limited artisanal fishery at a remote atoll in French Polynesia. *Ocean and Coastal Management*, 178, 104818 https://doi.org/10.1016/j.ocecoaman.2019.104818

Filous, A., Lennox, R. J., Coleman, R., Friedlander, A. M., Clua, E. E. G., & Danylchuk, A. J. (2019). Life-history characteristics of an exploited bonefish *Albula glossodonta* population in a remote South Pacific atoll. *Journal of Fish Biology, 95,* 562-574.

Filous, A., Lennox, R. J., Eveson, P., Clua, E. E. G., Cooke, S. J., & Danylchuk, A. J. (2020a). Population dynamics of bonefish *Albula glossodonta* at a remote coralline Atoll informs community-based management of an artisanal fishery. *Fisheries Management and Ecology, 27(2),* 200-214.

Filous, A., Lennox, R. J., Raveino, R., Friedlander, A. M., Clua, E. E. G., Cooke, S. J., & Danylchuk, A. J. (2020b). The spawning migrations of an exploited Albulid in the tropical Pacific: implications for conservation and community-based management. *Environmental Biology of Fishes, 103*, 1013-1031.

Gaines, S. D., White, C., Carr, M. H., & Palumbi, S. R. (2010). Designing marine reserve networks for both conservation and fisheries management. *Proceedings of the National Academy of Sciences USA, 107(43),* 18286–18293

Green, A. L., Maypa, A. P., Almany, G. R., Rhodes, K. L., Weeks, R., Abesamis, R. A., Gleason, M. G., Mumby, P. J., & White, A. T. (2015). Larval dispersal and movement patterns of coral reef fishes, and implications for marine reserve network design. *Biological Reviews, 90,* 1215-1247.

Griffin, L. P., Brownscombe, J. W., Adams, A. J., Boucek, R. E., Finne, J. T., Heithouse, M. R., Rehage, J. S., Cooke, S. J., & Danylchuk, A. J. (2018). Keeping up with the Silver King: using cooperative acoustic telemetry networks to quantify the movements of Atlantic tarpon (*Megalops atlanticus*) in the coastal waters of the southeastern United States. *Fisheries Research, 205,* 65-76.

Griffin, L. P., Haak, C. R., Brownscombe, J. W., Griffin, C. R., & Danylchuk, A. J. (2019). A comparison of juvenile bonefish diets in Eleuthera, The Bahamas, and Florida, U.S. *Environmental Biology of Fishes,* 102, 147-157.

Haak, C. R., Power, M., Cowles, G. W., & Danylchuk, A. J. (2019). Hydrodynamic and isotopic niche differentiation between juveniles of two sympatric cryptic bonefishes, *Albula vulpes* and *Albula goreensis*. *Environmental Biology of Fishes, 102(2)*, 129-145.

Haley, V. (2009). Acoustic Telemetry Studies of Bonefish (*Albula vulpes*) Movement Around Andros Island, Bahamas: Implications for Species Management. Florida International University Electronic Theses and Dissertations. http://digitalcommons.fiu.edu/etd/140

Heupel, M. R., & Webber, D. M. (2012). Trends in acoustic tracking: where are the fish going and how will we follow them? *American Fisheries Society Symposium, 76,* 219–231.

Johannes, R. E. (1998). The case for data-less marine resource management: examples from tropical nearshore finfisheries. *Trends in Ecology and Evolution, 13,* 243–246.

Johannes, R. E., & Yeeting, B. (2001) I-Kiribati knowledge and management of Tarawa's lagoon resources. *Atoll Research Bulletin, 489*, 1–24.

Lotze, H. K., Lenihan, H. S., Bourque, B. J., Bradbury, R. H., Cooke, R. G., Kay, M. C., Kidwell, S. M., Kirby, M. X., Peterson, C. H., & Jackson, J. B. C. (2006). Depletion, degradation, and recovery potential of estuaries and coastal seas. *Science, 312,* 1806–1809

Mojica, R. Jr., Shenker, J. M., Harnden, C. W., & Wagner, D. E. (1995). Recruitment of bonefish, *Albula vulpes*, around Lee Stocking Island, Bahamas. *Fishery Bulletin, 93,* 666–674

Murchie, K. J., Cooke, S. J., Danylchuk, A. J., Danylchuk, S. E., Goldberg, T. L., Suski, C. D., & Philipp, D. P. (2013). Movement patterns of bonefish (*Albula vulpes*) in tidal creeks and coastal waters of Eleuthera, the Bahamas. *Fisheries Research, 147,* 404–412.

Murchie, K. J., Shultz, A. D., Stein, J. A., Cooke, S. J., Lewis, J., Franklin, J., Vincent, G., Brooks, E. J., Claussen, J. E., & Philipp, D. P. (2015). Defining adult bonefish (*Albula vulpes*) movement corridors around Grand Bahama in the Bahamian archipelago. *Environmental Biology of Fishes, 98,* 2203–2212.

Murchie, K. J., Haak, C. R., Power, M., Shiply, O. N., Danylchuk, A. J., & Cooke, S. J. (2019). Ontogenetic patterns in resource use dynamics of bonefish (*Albula vulpes*) in the Bahamas. *Environmental Biology of Fishes, 102,* 117-127.

Orth, R. J., Carruthers, T. J. B., Dennison, W. C., Duarte, C. M., Fourqurean, J. W., Heck, K. L., Hughes, A. R., Kendrick, G. A., Kenworthy, W. J., Olyarnik, S., Short, F. T., Waycott, M., & Williams, S. L. (2006). A global crisis for seagrass ecosystems. *Bioscience, 56*, 987–996.

Perez, A. U., Schmitter-Soto, J. J., Adams, A.J., & Heyman, W. D. (2019). Connectivity mediated by seasonal bonefish (*Albula vulpes*) migration between the Caribbean Sea and a tropical estuary of Belize and Mexico. *Environmental Biology of Fishes, 102(2),* 197-207.

Rennert, J., Shenker, J. M., Angulo, J., & Adams, A. J. (2019). Age and growth of bonefish, Albula species among Cuba habitats. *Environmental Biology of Fishes, 102(2),* 253-265.

Roberge, J. M. & Angelstam, P. E. R. (2004). Usefulness of the umbrella species concept as a conservation tool. *Conservation Biology, 18(1),* 76–85.

Roberts, C. M., Halpern, B., Palumbi, S. R., & Warner, R. R. (2001). Designing marine reserve Networks: why small, isolated protected areas are not enough. *Conservation, 2(3),* 10–17.

Robinson, J., Isidore, M., Marguertie, M. A., Ohman, M. C., & Payet, R. J. (2004). Spatial and temporal distribution of reef fish spawning aggregations in the Seychelles – An interview-based survey of artisanal fishers. *Western Indian Ocean Journal of Marine Science, 3(1),* 63–69.

Sadovy, Y., & Domeier, M. L. (2005). Are aggregation-fisheries sustainable? Reef fish fisheries as a case study. *Coral Reefs, 24,* 254–262.

Sadovy De Mitcheson, Y. S., Cornish, A., Domeier, M., Colin, P. L., Russell, M., & Lindeman, K. C. (2008). A global baseline for spawning aggregations of reef fishes. *Conservation Biology, 22(5)*, 1233-1244.

Schmitter-Soto, J. J., Aguilar-Perera, A., Cruz-Martinez, A., Herrera-Pavon, R. L., Morales-

Aranda, A. A., & Cobian-Rojas, D. (2018). Interdecadal trends in composition, density, size, and mean trophic levels of fish species and guilds before and after coastal development in the Mexican Caribbean. *Biodiversity and Conservation, 27,* 459-474.

Valiela, I., Bowen, J. L., & York, J. K. (2001). Mangrove forests: one of the world's threatened major tropical environments. *Bioscience, 51,* 807–815.

Whoriskey, F., & Hindell, M. (2016). Developments in tagging technology and their contributions to the protection of marine species at risk. *Ocean Development & International Law, 47 (3),* 221–232.

Zwirn, M., Pinsky, M., & Rahr, G. 2005. Angling ecotourism: issues, guidelines and experience from Kamchatka. *Journal of Ecotourism, 4*, 16-31.

Table 1. Summary of information of bonefish captured, tagged, and released at a pre-spawn aggregation (PSA) site. All bonefish were tagged on December 2, 2017. Dates of detections at the PSA site, and dates and number of detections at receivers in the west side home range area. See Figure 1 for general locations of the PSA and home range area.

				2018 Detections in Home Range Area		
Transmitter ID	Fish Fork Length (mm)	Fish Sex	2017 Detection Dates at PSA Site	Receiver Number	Dates	Total Detections
3949	486	F	December 2, 3, 4, 5	980	October 2	4
3950	474	F	December 2, 3	922	February 18	2
3951	442	F	December 2; December 30	931	June 30 - July 2; July 30 - August 1	57
				980	January 3	3
				990	June 24 - 25; June 27 - 28; August 1; August 20-21; September 2-3	72
3954	505	F	December 2	911	October 18	4
				918	October 18	3
				931	June 29 - 30	30
				990	December 18[a]; October 17	7
3955	483	F	December 2	922	February 23; February 25; Februrary 27; March 4 - 5	283
3956	517	F	December 3	908	January 7	5
				974	January 8	11
				980	January 4	1
				990	January 9	2

[a] This detection occurred on December 18, 2017. All other home range detections were in 2018.

Table 2. Estimated shortest distance (km) by water between the pre-spawning aggregation (PSA) site and the smalltooth sawfish program acoustic receivers within the west side home range area. See Figure 1 for the general locations of the PSA and home range area.

Receiver Number	Distance (km)
908	115
911	122
918	103
922	82
931	104
974	118
980	71
990	101