5 Ecology and Management of Bonefish (*Albula* spp.) in the Bahamian Archipelago

Andy J. Danylchuk, Sascha E. Danylchuk, Steven J. Cooke, Tony L. Goldberg, Jeff Koppelman, and David P. Philipp

CONTENTS

INTRODUCTION

Bonefish (*Albula* spp.) are an important group of fishes inhabiting shallow, nearshore marine environments worldwide. Historically, bonefish have played a strong role in supporting local and regional economies of the Bahamian Archipelago (i.e., The Bahamas and the Turks and Caicos Islands) (Alexander, 1961; BEST, 2002, 2005), an extensive expanse of shallow bank environments that comprise nearly 90% of the 300,000 km^2 archipelago (Sealey, 1994, Buchan, 2000). The ample nearshore habitats of the Bahamian Archipelago make bonefish readily accessible to local residents and visitors of this unique island chain (Kaufmann, 2000).

Despite their regional, economic, and ecological importance, relatively little scientific information exists to assist assessment or conservation management of bonefish in the Bahamian Archipelago. The purpose of this chapter is to review the history of the Bahamian bonefish fishery, and to highlight ecological and fishery research that has been conducted on bonefish in the Bahamian Archipelago, either as a target species or incidentally as part of other studies. This synthesis and analysis will help identify information gaps in the Bahamian Archipelago that need to be filled before bonefish stocks can effectively be managed and conserved.

HISTORY OF THE BONEFISH FISHERY

Subsistence Fishery

For generations, bonefish have been the focus of subsistence and artisanal fisheries in The Bahamas and the Turks and Caicos Islands (Olsen, 1986; BEST, 2002; BEST, 2005). Catches of bonefish tend to be sold to individuals or small restaurants in rural communities, where bonefish were a favored species of finfish for consumption (Olsen, 1986). Subsistence and small-scale commercial harvesting was traditionally conducted in relatively shallow waters using handlines or by "hauling" seine nets (Olsen, 1986). Recently, monofilament gill nets have been employed for the harvest of bonefish in some areas. Unfortunately, these gears are nonselective, resulting not only in excessive harvests of bonefish, but also in substantial bycatch of other important species (e.g., turtles, barracudas, dolphins, sharks) (Clark and Danylchuk, 2003).

Use of bonefish as a subsistence food item has declined in recent decades (Rudd, 2003). Attrition of old-time "haulers" and the increased availability of commercially produced food items to local communities have contributed to the decreased reliance on bonefish as a staple food. In addition, the social stigma of bonefish as a "poor man's" food to some extent has reduced its popularity among islanders (Rudd, 2003).

Recreational Fishery

As subsistence and small-scale commercial fisheries for bonefish in the Bahamian Archipelago have subsided, bonefish have gained importance as a target species for specialized recreational anglers. Angling for bonefish has become extremely popular because their wary nature and powerful swimming abilities when hooked make them a challenge to catch using lightweight fly-fishing and conventional hook-and-line gears (Kaufmann, 2000; Davidson, 2004; Fernandez, 2004). In addition, the remoteness and tranquil beauty of subtropical and tropical locales and serene qualities of the "flats" environment has turned bonefishing into a highly sought-after "holistic" angling experience. The clear, unpolluted waters of the Bahamian Archipelago with abundant bonefish and proximity to the United States are all draws for well-healed recreational anglers (BEST, 2002).

Interest in sportfishing has influenced the development of tourism-based industries specifically focused on recreational angling for bonefish (Figure 5.1).

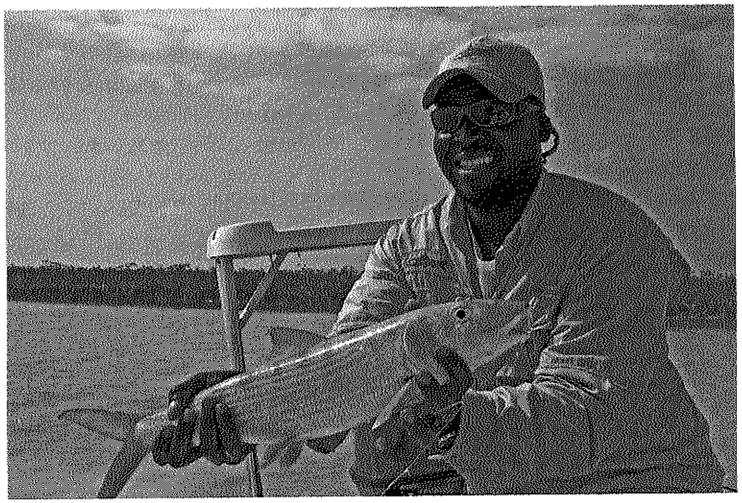

FIGURE 5.1 A beautiful Bahamas bonefish, a real focus of the region's high-value tourism industry. (Photo courtesy of Bob Stearns.)

From fishing tackle and guiding fees to travel and accommodations, the amount of direct and indirect revenues from the bonefishing industry can be high (Humston, 2001). For example, in the Florida Keys, regional economic contributions of the recreational industry centered on bonefishing generate a billion dollars in revenue per annum (Humston, 2001; Ault et al., Chapter 26, this volume). In developing countries, such as The Bahamas and Turks and Caicos Islands, local communities can be solely reliant on revenues generated by recreational bonefishing, especially when there is a paucity of alternative sources of revenue.

In The Bahamas, tourism represents more than 50% of the annual gross domestic product, making tourism the largest single contributor to the country's economy (Buchan, 2000; BEST, 2002). Recreational angling is a popular activity for tourists visiting The Bahamas and the Turks and Caicos Islands, many of whom dedicate their entire trip to fishing for bonefish. Of the 1.5 million tourists in 2004 who filled out immigration departure forms in The Bahamas, 5000 (0.3%) of these individuals stated that the purpose of their trip was for "bone/fly-fishing" (Government of The Bahamas, unpublished data). Most of these tourists who visited primarily for angling responded that their "bone/fly-fishing" trip targeted the "family islands" such as Abaco, Andros, and Eleuthera (Figure 5.2). Almost all respondents (92%) were from the United States, and most of these individuals were from the southern (41.1%) or northeastern areas of the country (28.8%) (Government of The Bahamas, unpublished data).

ECOLOGY OF BONEFISH IN THE BAHAMAS

General Applicability

Research conducted on the ecology of bonefish in the waters of the Bahamian Archipelago has been relatively limited. Fewer than 10 peer-reviewed scientific publications

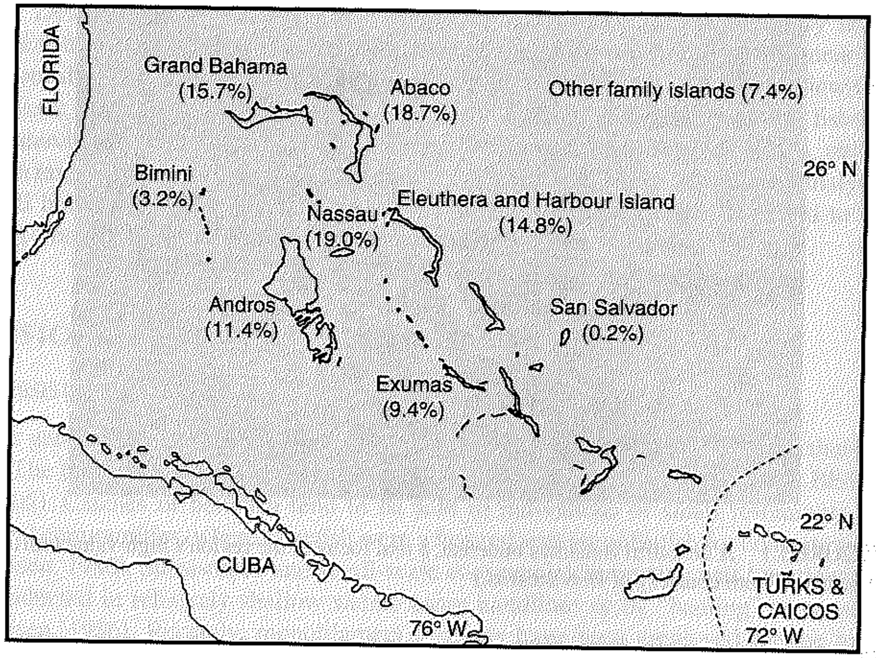

FIGURE 5.2 Proportion of immigration departure cards collected throughout The Bahamas in 2004, whose respondents indicated that the purpose of their visit was "bone/fly-fishing" (n = 5000). (From Government of The Bahamas, unpublished data.)

have been produced that specifically focus on bonefish (e.g., Colton and Alevizon 1983a, 1983b; Clark and Danylchuk, 2003; Cooke and Philipp, 2004; A.J. Danylchuk et al., 2007; S.E. Danylchuk et al., 2007) or that sampled bonefish as part of broader research questions (e.g., Layman and Silliman, 2002; Layman et al., 2004; Nero and Sullivan-Sealey, 2005). Although research conducted on bonefish in other parts of the world can provide some insights into the ecology and management of bonefish inhabiting the Bahamian Archipelago, studies by Pfeiler et al. (2000) and Colborn et al. (2001) have revealed the potential existence of multiple species of bonefish across several spatial scales. This brings into question the legitimacy of extrapolating results across geographic regions because different species may have vastly different life histories and behavioral patterns. Most accounts in the scientific literature refer to bonefish inhabiting the Bahamian Archipelago as *Albula vulpes*; however, rarely has the species identity of these populations been confirmed through genetic and morphometric analyses. An exception is a study by Bowen et al. (2003), which identified both *A. vulpes* and a second species (nova or species b) in a sample of bonefish collected from Bimini, although their overall sample size was relatively small. Regardless, comparative studies of genetics and morphometrics for bonefish may help to clarify whether distinct stocks occur across the Bahamian Archipelago and help lay the framework for ecological studies and management plans.

Understanding the ecology of bonefish in the Bahamian Archipelago could be complicated by the sheer size and unique oceanographic features characteristic of the region (Buchan, 2000). The Bahamian Archipelago is made up of a series of banks distributed on a southeast to northwest axis to the north of Cuba and Hispaniola that are separated by deep expansive oceanic toughs (Sealey, 1994; Buchan, 2000). The strong northward-flowing oceanic currents of the Gulf Stream to the west and the Antilles current to the east interact with these banks and troughs to generate complex patterns of water circulation that can influence the recruitment, distribution, abundance, and genetic differentiation of marine organisms on a regional scale (Gunn and Watt, 1982; Colin, 1995; Almada et al., 2001; Floeter et al., 2001). Similarly, variation in bathymetry and tidal currents generated by the close proximity of landmasses and the influence of wind on water movement across the shallow banks (Smith, 2004a, 2004b) could influence the ecology of bonefish populations. As such, extrapolating the results of other studies to bonefish in the Bahamian Archipelago (or vice versa) should be done with caution until the extent of the variation in systematics and ecology of bonefish populations in the region are more thoroughly examined.

Distribution and Abundance

Anecdotal observations by subsistence fishers, recreational anglers, and guides indicate that bonefish are widely distributed throughout the Bahamian Archipelago. Popular media articles and books on bonefish often provide extensive detail as to the regional and local distribution and relative abundance of bonefish the Bahamian Archipelago (e.g., Kaufmann, 2000). For instance, Kaufmann (2000) highlights the Abacos, Andros Island, Berry Islands, Bimini, Crooked and Acklins Islands, Eleuthera including Spanish Wells and Harbour Island, the Exumas, Grand Bahama Island, Great Inagua, Long Island, and the Turks and Caicos as prime destinations for recreational angling for bonefish. Undoubtedly, bonefish reside in the waters adjacent to other islands in the Bahamian Archipelago; however, their presence, distribution, and relative abundance are not generally known.

Although it is recognized that bonefish are distributed throughout the Bahamian Archipelago, no formal studies have been conducted to determine their distribution and relative abundance across a range of spatial and temporal scales. Recreational anglers and guides often comment on relative differences in the abundance and size structure of bonefish inhabiting different islands in the Bahamian Archipelago and during different seasons (Kauffmann, 2000); however, there has been no formal study or population census quantitatively assessing the abundance of bonefish in the region or whether spatial and temporal patterns in abundance do indeed exist. Spatial and temporal variation in the abundance of bonefish both within and among distinct regions of the Bahamian Archipelago could be related to intrinsic (e.g., reproductive ecology, species distribution) or extrinsic factors (e.g., oceanography, predation); and identifying the relative influence of such factors on bonefish abundance is crucial to developing reliable conservation management plans.

Habitat Use and Movements

Bonefish in the Bahamian Archipelago generally inhabit shallow, nearshore waters (Kaufmann, 2000). Studies on the localized movements of bonefish in The Bahamas have suggested that bonefish utilize a range of nearshore habitats, including seagrass beds, mangrove creeks, and even coral reefs (Colton and Alevizon, 1983a, 1983b; Cooke and Philipp, 2004; A.J. Danylchuk et al., 2007; S.E. Danylchuk et al., 2007). Articles in popular angling publications and ancillary information garnished from recreational anglers and guides indicate that bonefish in the Bahamian Archipelago are also often observed and caught from other habitat types within the nearshore flats environment (Kaufmann, 2000), including sandy flats devoid of benthic vegetation (Layman and Silliman, 2002; Layman et al., 2004; Nero and Sullivan-Sealey, 2005).

Nearshore movements of bonefish within the Bahamian Archipelago have received some attention. Colton and Alevizon (1983a) used ultrasonic telemetry to examine the activity and daily movements of bonefish in waters near Deep Water Cay off Grand Bahama Island. Of the 13 fish surgically implanted with transmitters, only 3 were relocated more than 24 h post-release. The inability to detect 10 of the transmitter-implanted bonefish could have been attributed to predation following release or their movement out of reception range. The three remaining bonefish were tracked for between 5 and 100 days post-release, and their movements tended to be synchronous with the ebbing and flooding tides (moving into deeper water with ebbing tides and moving into shallow flats on flooding tides). On Andros Island, Nero and Sullivan-Sealey (2005) attributed variability in fish abundance among sites, including bonefish, to tides as well as to season; however, their data were not sufficient to determine if specific coastal or benthic factors were driving observed differences. Bohlke and Chaplin (1993) also reported that bonefish move into deeper water at slack low tides, with large schools being observed at depths of over 15 m below the edge of the drop-off in the Tongue of the ocean near Green Cay. Such movements are similar to the reoccurring localized pattern observed by Humston et al. (2005) for bonefish studied with acoustic telemetry in the Florida Keys, and by Colton and Alevison (1983a) for bonefish at Deep Water Cay in The Bahamas. Both studies inferred that the bonefish movement into deeper channels was attributed to avoidance of high water temperatures associated with shallow flats. In the case of Deep Water Cay, Colton and Alevison (1983a) noted that the proportion of large fish (>555 mm fork length, FL) was inversely correlated with inshore water temperatures, and that these observations were supported by anecdotal information provided by guides, anglers, and lodge owners.

Bonefish movement and migration patterns in the Bahamian Archipelago may also reflect the distribution and abundance of predators (Cooke and Philipp, 2004; Humston et al., 2005; A.J. Danylchuk et al., 2007). Although Humston et al. (2005) suggested that Florida Keys bonefish may avoid deep channels frequented by sharks; several recent studies in The Bahamas demonstrated that even bonefish in shallow waters (i.e., <0.5 m depth) are susceptible to predation, particularly following catch-and-release angling (Cooke and Philipp, 2004; A.J. Danylchuk et al., 2007; S.E. Danylchuk et al., 2007). Predation may have also affected the observations made by Colton and Alevizon (1983a) about the long-term movement patterns of bonefish at Deep Water Cay, since their lack of detection of transmitter-implanted fish or the recapture of externally tagged fish may have been caused by bonefish migrating out of the study area, or by predation by sharks or barracudas following release.

Movements of bonefish in the Bahamian Archipelago may be related to body size, reproductive maturity, spawning migrations, or ontogenetic shifts in feeding habits (Colton and Alevizon, 1983a; Bohlke and Chaplin, 1993). According to anecdotal accounts by Bahamian fishermen, large bonefish appear to return to tidal creeks in the fall where they aggregate in large numbers prior to spawning (Colton and Alevizon, 1983a). It is also commonly observed that schools of bonefish are generally composed of small- to medium-sized fish, while larger individuals tend to be more solitary, at least outside the spawning season (Bohlke and Chaplin, 1993). In the Turks and Caicos Islands, Clark and Danylchuk (2003) collected a total of 120 bonefish ranging in size from 28 to 72 cm total length (TL) as part of a tag-and-release study to determine movements on the Caicos Bank. During the course of the study, only one tagged bonefish was recaptured, with the fish being caught by a local hauler using a seine net (Clark and Danylchuk, 2003). They noted that the mean size of bonefish increased from west to east across Caicos Bank, potentially indicating ontogenetic shifts in habitat use. Local fishermen from South Caicos have also reported schools of large bonefish over offshore patch and coral reefs close to the wall of the Columbus Passage during winter months, and they believe that these aggregations might be related to spawning activity.

Feeding Ecology

Several diet studies, which examined stomach contents, have been conducted on bonefish in the western Atlantic (e.g., Warmke and Erdman, 1963; Crabtree et al., 1998b), with two of these in The Bahamas (Colton and Alevison, 1983b; Layman and Silliman, 2002). In all studies, bonefish were found to feed predominately on benthic invertebrates, but occasionally on small fishes. In Deep Water Cay, Colton and Alevizon (1983b) examined the stomach contents of 393 bonefish that ranged from 25 to 69 cm FL. Only 7% of stomachs were empty. Over 88% of the diet was comprised of invertebrates, with bivalves and crabs making up the majority of the biomass (dry weight) consumed (Colton and Alevizon, 1983b). Other prey items included small benthic fishes, such as gobies. Colton and Alevizon (1983b) also indicated that the dietary composition of bonefish differed among sand and seagrass habitats, likely related to the availability of prey items. Layman and Silliman (2002) examined the diet of considerably smaller bonefish (mean size of 13.8 ± 0.4 cm) in creek systems on Andros Island and found that 90% had eaten crustaceans, with 40% being decapod crabs. The majority of the diet by volume was composed of crustaceans (48%), mollusks (17%), and insects (18%) (Layman and Silliman, 2002). Although their sample size was relatively small (n = 10), Layman and Silliman (2002) did find that these small bonefish were most abundant over sand flats.

Population Dynamics

No formal studies on population dynamics of bonefish (e.g., age and growth, reproduction, survivorship) have been conducted in the Bahamian Archipelago. Only incidental accounts of body size for bonefish in the Bahamian Archipelago have been reported in the scientific literature (Table 5.1). Those collected by scientific studies, in general, tend to be smaller than those caught by anglers (Kaufmann, 2000). For instance, bonefish exceeding 5 kg have been reported by guides and anglers

TABLE 5.1

Body Size of Bonefish Reported in Studies Conducted for Populations across the Bahamian Archipelago

Location	Length	*N*	Capture Method	Purpose of Study	Source
Andros Island	13.8 ± 0.4 mm SD	10	Cast net	Diet	Layman and Silliman, 2002
Deep Water Cay	50.5 – 61.0 cm FL	13	Angling (3), gill net (10)	Movement	Colton and Alevizon, 1983a
Deep Water Cay	25 – 69 cm FL	393	Not stated	Diet	Colton and Alevizon, 1983b
Deep Water Cay	50.2 ± 1.4 cm TL SE	18	Angling	Post-release mortality	Cooke and Philipp, 2004
San Salvador	51.2 ± 1.4 cm TL SE	17	Angling	Post-release mortality	Cooke and Philipp, 2004
Eleuthera	48.2 ± 5.0 cm TL SE	87	Angling	Post-release mortality	S.E. Danylchuk et al., 2007
Eleuthera	50.0 ± 8.4 cm TL SE	14	Seine	Post-release mortality	S.E. Danylchuk et al., 2007
Eleuthera	47.1 ± 1.2 cm TL SE	12		Post-release mortality	A.J. Danylchuk et al., 2007
Turks and Caicos Island	28 – 72 cm TL	120	Angling, seine	Movement	Clark and Danylchuk, 2003

across the Bahamian Archipelago, but not in primary scientific research. Nevertheless, if age and growth patterns can be generalized across regions in the western Atlantic, bonefish in the 10–12 lb range inhabiting the Bahamian Archipelago could easily be over 12 years old (Bruger, 1974; Crabtree et al., 1996).

All information on the seasonal timing of bonefish reproduction in the Bahamian Archipelago is based on anecdotal observations made by local fishers, recreational anglers, and fishing guides. Anglers often comment on the release of milt or eggs when fish are handled, especially between January and May. Anecdotal observations made in the Bahamian Archipelago suggest that bonefish aggregate and spawn in the fall, winter, and early spring (November–April). Mojica et al. (1995) studied larval recruitment patterns of *Albula* spp. near Lee Stocking Island and found leptocephali during fall and early winter, in agreement with anecdotal observations and with maturation patterns for bonefish in the Florida Keys (Crabtree et al., 1997). However, Mojica et al. (1995) also noted a large pulse of recruitment during a single 72-day sampling period in the summer months, indicating that spawning may occur year-round in The Bahamas. Otolith analysis of larval duration for specimens collected near Lee Stocking Island ranged from 41 to 71 days. Almost all leptocephali were collected at night in the upper 1 m of the water column, and inshore movement was strongly associated with flooding tides and the new moon (Mojica et al., 1995).

BONEFISH CONSERVATION AND MANAGEMENT STRATEGIES

Despite their ecological and economic importance, fishery regulations for bonefish across the Bahamian Archipelago are limited. In The Bahamas, the capture of bonefish using nets and the commercial trade of bonefish are prohibited (Bahamas Department of Fisheries, 1986). In the Turks and Caicos Islands, there are no specific regulations for bonefish (Turks and Caicos Islands Government, 1998a). At the same time, fishing guides in the Turks and Caicos Islands state that monofilament gill nets are being deployed across tidal creeks, resulting in the mortality of large numbers of juvenile and adult bonefish, as well as the bycatch of other important species such as marine turtles (Clark and Danylchuk, 2003).

In an effort to conserve fish stocks and their habitats, both countries are using marine protected areas in conjunction with existing fisheries regulations to build sustainable fisheries and protect marine biodiversity (Turks and Caicos Islands Government, 1998b). Although a marine reserve was established in the Turks and Caicos Islands in 1992 with bonefish conservation specifically in mind, no formal scientific information was used in its design and implementation. Only recently has there been any effort to assess the efficacy of this particular marine reserve, or whether marine protected areas in general are useful for conserving bonefish stocks (Clark and Danylchuk, 2003; Cooke et al., 2006).

One potential way in which bonefish in the Bahamian Archipelago are partially protected is through voluntary catch-and-release efforts (Cooke et al., 2006). Catch-and-release is commonly practiced by recreational anglers with a strong conservation ethic who travel to The Bahamas and the Turks and Caicos Islands. Catch-and-release angling can be an effective way to help maintain bonefish stocks only if the postrelease mortality is minimized (Cooke and Suski, 2005). When a fish is hooked by an angler, many factors affect the outcome of the event for the fish (Cooke et al., 2002; Cooke and Philipp, Chapter 25, this volume). At best, the fish will survive the event. At worst, the fish will not survive. Although anglers strive for the former outcome, an intermediate outcome in which the fish suffers transient physiological and behavioral impacts is probably more likely (Cooke and Philipp, 2004; Cooke and Suski, 2005; Bartholomew and Bohnsack, 2005), can increase the susceptibility of released fish to predation (Cooke and Philipp, 2004), and may ultimately lead to population-level effects.

Recently, Bartholomew and Bohnsack (2005) highlighted a number of factors related to recreational angling that influenced the mortality of released fish. They concluded that catch-and-release angling was not compatible with the conservation objectives of no-take marine protected areas. In a response, Cooke et al. (2006) indicated that the effects of the factors identified by Bartholomew and Bohnsack (2005), such as hooking in vital organs and angling duration and handling, could be reduced to the point where the fishing mortality rate approached zero, increasing the likelihood of integrating catch-and-release angling with no-take reserves. Determining whether catch-and-release is a useful tool for bonefish conservation requires more attention, especially as there is an increase in the demands of recreational anglers seeking bonefish along with the associated tourist operations supporting this activity (Crabtree et al., 1998a; Cooke and Philipp, 2004; Bartholomew and Bohnsack, 2005; Cooke et al., 2006).

Some studies have examined the short-term (24–48 h) mortality of bonefish following catch-and-release angling. In The Bahamas, these studies have found that predation of bonefish by lemon sharks (*Negaprion brevirostris*) and barracuda (*Sphyraena barracuda*) can range from 0 to 39%, with predation rates being correlated with the relative abundance of predators (Cooke and Philipp, 2004; A.J. Danylchuk et al., 2007) and the handling practices of anglers (S.E. Danylchuk et al., 2007). Post-release predation rates on bonefish could be regulated by the actions of anglers, potentially reducing the impacts of catch-and-release angling and making this activity more compatible with the conservation goals of no-take reserves (Cooke et al., 2006).

RESEARCH AND CONSERVATION NEEDS

A systematic, integrative, and cooperative approach is clearly needed to better understand and manage bonefish populations in the Bahamian Archipelago. Developing effective ecosystem management plans depends greatly on a comprehensive understanding of the systematics, biology, ecology, and population dynamics of bonefish throughout the region. Identifying if unique bonefish stocks occur (by compatible genetic and morphometric methods) in the Bahamian Archipelago is of primary importance, since stock mixing could significantly complicate management of the species. To determine whether traits in bonefish populations vary significantly across the large spatial scale of the Bahamian Archipelago, basic information on the genetic identity, age, growth, and reproductive potential (e.g., size and age at maturity, fecundity) needs to be collected at multiple locations across the region as part of a coordinated Bahamian Archipelago–wide sampling (monitoring) and assessment effort. Such an archipelago-wide program would help encompass potential variation in bonefish populations associated with different properties of individual shallow water banks (e.g., degree of physical isolation, interactions with major oceanographic currents, and latitude). Such sampling should occur at regular intervals throughout the year to determine whether the population structure of bonefish varies temporally and is potentially related to spawning migrations, recruitment, or climatic patterns. Sampling the age, growth, and reproduction of bonefish populations at multiple locations throughout the year will allow for the examination of age- and size-specific trends in the allocation of energy to gonad development that, in turn, would help quantify the spatial and temporal patterns in the phenology of reproduction for bonefish across the Bahamian Archipelago. At selected focal research sites, the input of bonefish leptocephali could be monitored using channel nets or light traps as a way to cross-validate the seasonal timing of reproduction inferred through the direct examination of gonad development. In addition, movement studies of bonefish using remote acoustic telemetry could be conducted in concert with the examination of gonad development and larval input to help determine where spawning activity actually occurs.

Given that the nearshore environment of the Bahamian Archipelago is relatively diverse at both the local and regional scales and that the region is prone to environmental extremes (e.g., high summer water temperatures, freshwater input, hurricanes), understanding how natural variation and natural disturbance regimes shape bonefish populations will allow for a more thorough evaluation of how anthropogenic disturbances may affect bonefish stocks (Cooke and Philipp, 2004; Sealey, 2004). Such comparisons could be facilitated through before-after-control-impact studies (Underwood, 1994), empirical studies on bonefish populations subjected to a range of natural and anthropogenic disturbances, and experimental or manipulative studies that target particular disturbances. For instance, the tourist industry is steadily increasing throughout the Bahamian Archipelago, often resulting in anthropogenic disturbances such as dredging and coastal eutrophication (Rudd, 2003; Sealey, 2004). The potential effects of such disturbances on bonefish populations could be examined by monitoring bonefish populations before and after dredging or shoreline development has occurred in a particular area, specifically to test if modifying or eliminating foraging habitat has cascading impacts on bonefish distribution, life history traits, and ultimately abundance (Syms and Jones, 2000; Gust et al., 2001; Hixon et al., 2001; Sadovy, 2005). Similarly, comparative and manipulative studies may help differentiate the effects of recreational activities or if angling-related activities such as wading have detrimental effects on the integrity of nearshore habitats (Cooke and Suski, 2005).

The interdependence of coastal environments of the small islands and the dependence of local communities on bonefish for income in the Bahamian Archipelago calls for a holistic and comprehensive management strategy to conserve and protect bonefish stocks. Although marine protected areas are often advocated and used throughout the Bahamian Archipelago as a low-cost tool for protecting habitats and species (BEST, 2005; Dahlgren, 2002; Danylchuk, 2003; Lubechenco et al., 2003), they will only be effective if they balance the needs of society with the needs of the local marine resources (Murray et al., 1999; Hanna, 2001; Roberts et al., 2001; Sealey, 2003). With this in mind, determining whether or not catch-and-release angling is compatible with the conservation goals of marine-protected areas is important (Bartholomew and Bohnsack, 2005; Cooke et al., 2006). If recreational angling for bonefish is deemed compatible with marine-protected areas, then the development of locally based tourism focused on this activity could be promoted as part of a larger integrative management plan without disrupting the overall level of protection offered to the ecosystem (Cooke et al., 2006).

An effective archipelago-wide sampling and management program for bonefish will depend greatly on collaborative partnerships between scientific institutions, pertinent local and regional governments, conservation organizations, and stakeholders. Integrating cooperative research with education and outreach programs throughout the Bahamian Archipelago will also instill the importance for marine conservation, including the protection of bonefish stocks. Only through such partnerships and education programs will realistic conservation management plans be developed that adequately encompass the needs of bonefish stocks, as well as the sustainable development of local communities in the Bahamian Archipelago.

ACKNOWLEDGMENTS

We gratefully acknowledge Chris Maxey and the Cape Eleuthera Foundation for financial and logistical support during the preparation of this chapter. We thank Earlston McPhee and Garry Young from The Bahamas Ministry of Tourism for providing statistics on bonefishing-based tourism in The Bahamas. Thanks also to J. Ault and two anonymous reviewers for their comments and suggestions on an earlier version of this chapter. We would also like to thank the many anglers, guides, and local fisherman who have provided invaluable anecdotes on bonefish, including S. Gardiner (Silver Creek Adventures), B. Jayne and G. Lockhart (Beyond the Blue Charters), B. Gardiner (Bonefish Unlimited), A. Dean (Silver Deep), F. Lockhart, T. Morris, S. Jennings, C. Leathen, R. Reckley, H. Rolle, A. McKinney, and D. Rankin. A special thanks also goes out to T. Davidson and R. Fisher (Bonefish & Tarpon Unlimited) for their guidance and support.

REFERENCES

Alexander, E.C., A contribution to the life history, biology and geographical distribution of bonefish, *Albula vulpes* (Linnaeus), Dana-Report, *Carlsberg Found.*, 53, 1, 1961.

Almada, V.C., Oliveria, R.F., Gonçalves, E.J., Almeida, A.J., Santos, R.S. and Wirtz P., Patterns of diversity of the north-eastern Altantic blenniid fish fauna (Pisces: Blenniidae), *Global Ecol. Biogeo.*, 10, 411, 2001.

Bahamas Department of Fisheries, *Bahamian Fisheries Regulations and Reports*, 1986.

Bahamas Environment, Science and Technology Commission (BEST), *Bahamas Environment Handbook*, Government of The Bahamas, 2002.

Bahamas Environment, Science and Technology Commission (BEST), *State of the Environment*, Government of The Bahamas, 2005.

Bartholomew, A. and Bohnsack, J.A., A review of catch-and-release angling mortality with implications for no-take reserves. *Rev. Fish Biol. Fish.*, 15, 129, 2005.

Bohlke, J.E. and Chaplin, C.C.G., *Fishes of The Bahamas and Adjacent Tropical Waters*, 2nd edition, University of Texas Press, Austin, TX, 1993.

Bowen, B.W., Colborn, J., Karl, S.A. and Curtis, C., Systematics and ecology of bonefish (*Albula* spp.) in Florida waters, in *Investigations into Nearshore and Estuarine Gamefish Behavior, Ecology, and Life History in Florida*, Five year Performance Report to the US Fish and Wildlife Service, Sport Fish Restoration Project F-59, Florida Marine Research Institute, St. Petersburg, FL, 14, 2003.

Bruger, G.E., Age, growth, food habits and reproduction of bonefish (*Albula vulpes*) in South Florida waters. *Mar. Res. Pub.*, 3, Florida Department of Natural Resources, St. Petersburg, FL, 1974.

Buchan, K.C., The Bahamas. *Mar. Pollut. Bull.*, 41, 94, 2000.

Clark, S.A. and Danylchuk, A.J., Introduction to the Turks and Caicos Islands bonefish research project tagging program, *Proc. Gulf Carib. Fish. Inst.*, 54, 396, 2003.

Colborn, J., Crabtree, R.E., Shaklee, J.B., Pfeiler, E. and Bowen, B.W., The evolutionary enigma of bonefishes (*Albula* spp.): cryptic species and ancient separations in a globally distributed shorefish, *Evolution*, 55, 807, 2001.

Colin, P.L., Surface currents in Exuma Sound, Bahamas, and adjacent areas with reference to potential larval transport, *Bull. Mar. Sci.*, 56, 48, 1995.

Colton, D.E. and Alevizon, W.S., Movement patterns of the bonefish (*Albula vulpes*) in Bahamian waters, *Fish. Bull.*, 81, 148, 1983a.

Colton, D.E. and Alevizon, W.S., Feeding ecology of bonefish in Bahamian waters, *Trans. Am. Fish. Soc.*, 112, 178, 1983b.

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

Cooke, S.J. and Suski, C.D., Do we need species-specific guidelines for catch-and-release recreational angling to conserve diverse fishery resources? *Biodivers. Conserv.*, 14, 1195, 2005.

Cooke, S.J., Schreer, J.F., Dunmall, K.M. and Philipp, D.P., Strategies for quantifying sublethal effects of marine catch-and-release angling—insights from novel freshwater applications, *Am. Fish. Soc. Symp.*, 30, 121, 2002.

Cooke, S.J., Danylchuk, A.D., Danylchuk, S.A., Suski, C.D. and Goldberg, T.L., Is catch-and-release recreational fishing compatible with no-take marine protected areas? *Ocean Coastal Manage.*, 49, 342, 2006.

Crabtree, R.E., Harnden, C.W., Snodgrass, D. and Stevens, C., Age, growth, and mortality of bonefish, *Albula vulpes*, from the waters of the Florida Keys, *Fish. Bull.*, 94, 442, 1996.

Crabtree, R.E., Snodgrass, D. and Harnden, C.W., Maturation and reproductive seasonality in bonefishes, *Albula vulpes*, from the waters of the Florida Keys, *Fish. Bull.*, 95, 456, 1997.

Crabtree, R.E., Snodgrass, D. and Harnden, C., Survival rates of bonefish, *Albula vulpes*, caught on hook-and-line gear and released based on capture and release of captive bonefish in a pond in the Florida Keys, in *Investigation into Nearshore and Estuarine Gamefish Abundance, Ecology, and Life History in Florida*, Five year Technical Report to the US Fish and Wildlife Service, Sport Fish Restoration Project F-59, Florida Marine Research Institute, St. Petersburg, FL, 252, 1998a.

Crabtree, R.E., Stevens, C., Snodgrass, D. and Stengard, F.J., Feeding habits of bonefish, *Albula vulpes*, from the waters of the Florida Keys, *Fish. Bull.*, 96, 754, 1998b.

Dahlgren, C., Marine protected areas in The Bahamas, *Bahamas J. Sci.*, 9, 41, 2002.

Danylchuk, A.J., Fisheries management in South Eleuthera: can a marine reserve help save the "holy trinity," *Proc. Gulf Carib. Fish. Inst.*, 56, 169, 2003.

Danylchuk, A.J., Danylchuk, S.E., Cooke, S.J., Goldberg, T.L., Koppelman, J. and Philipp, D.P., Post-release mortality of bonefish (*Albula* spp.) exposed to different handling practices in South Eleuthera, Bahamas, *Fish. Manage. Ecol.*, 14, 149–154, 2007.

Danylchuk, S.E., Danylchuk, A.J., Cooke, S.J., Goldberg, T.L., Koppelman, J. and Philipp, D.P., Effects of recreational angling on the post-release behavior and predation of bonefish (*Albula vulpes*): the role of equilibrium status at the time of release. *J. Exper. Mar. Biol. Ecol.*, 346, 127–133, 2007.

Davidson, T., *Bonefish B. S. and Other Good Fish Stories*, Hudson Books, Toronto, 2004.

Fernandez, C., *Fly-Fishing for Bonefish*, Stackpole Books, Mechanicsburg, PA, 2004.

Floeter, S.R., Guimaraes, R.Z.P., Rocha, L.A., Ferreira, C.E.L., Rangel, C.A. and Gasparini, J.L., Geographic variation in reef fish assemblages along the Brazilian coast, *Global Ecol. Biogeogr.*, 10, 423, 2001.

Gunn, J.T. and Watt, D.R., On the currents and water masses north of the Antilles/Bahamas Arc, *J. Mar. Res.*, 40, 1, 1982.

Gust, N., Choat, J.H. and McCormick, M.I., Spatial variability in reef fish distribution, abundance, size and biomass: a multi-scale analysis, *Mar. Ecol. Prog. Ser.*, 214, 237, 2001.

Hanna, S., Managing the human-ecological interface: marine resources as example and laboratory, *Ecosystems*, 4, 736, 2001.

Hixon, M.A., Boersma, P.D., Hunter, M.L. Jr., Icheli, F., Norse, E.A., Possingham, H.P. and Snelgrove, P.V.R., Oceans at risk: research priorities in marine conservation biology, in *Conservation Biology, Research Priorities for the Next Decade*, Soulé M.E. and Orians G.H., Eds., Island Press, Washington, DC, 125, 2001.

Humston, R., *Development of movement models to assess the spatial dynamics of fish populations*, Ph.D. dissertation, Rosenstiel School of Marine and Atmospheric Science, University of Miami, FL, 2001.

Humston, R., Ault, J.S., Larkin, M.F. and Luo, J., Movements and site fidelity of the bonefish *Albula vulpes* in the northern Florida Keys determined by acoustic telemetry, *Mar. Ecol. Prog. Ser.*, 291, 237, 2005.

Kaufmann, R., *Bonefishing*, Western Fisherman's Press, Moose, WY, 2000.

Layman, C.A. and Silliman, B.R., Preliminary survey and diet analysis of juvenile fishes of an estuarine creek on Andros Island, Bahamas, *Bull. Mar. Sci.*, 70, 199, 2002.
Layman, C.A., Arrington, D.A., Langerhans, R.B. and Silliman, B.R., Degree of fragmentation affects fish assemblage structure in Andros Island (Bahamas) estuaries. *Carib. J. Sci.*, 40, 232, 2004.
Lubechenco, J., Palumbi, S.R., Gaines, S.D. and Andleman, S., Plugging a hole in the ocean: the emerging science of marine reserves, *Ecol. Appl.*, 13, S3, 2003.
Mojica, R., Shenker, J.M., Harnden, C.W. and Wanger, D.E., Recruitment of bonefish, *Albula vulpes*, around Lee Stocking Island, Bahamas, *Fish. Bull.*, 93, 666, 1995.
Murray, S.N., Ambrose, R.F., Bohnsack, J.A., Botsford, L.W., Carr, M.H., Davis, G.E., Dayton, P.K, Gotshall, D., Gunderson, D.R., Hixon, M.A., Lubchenco, J., Mangel, M., MacCall, A., McArdle, D.A., Ogden, J.C., Roughgarden, J., Starr, R.M., Tegner, M.J. and Yoklavich, M.M., No-take reserve networks: sustaining fishery populations and marine ecosystems, *Fisheries*, 24, 11, 1999.
Nero, V.L. and Sullivan-Sealey, K., Characterization of tropical near-shore fish communities by coastal habitat status on spatially complex island systems, *Environ. Biol. Fishes*, 73, 437, 2005.
Olsen, D.A., *Fisheries assessment for the Turks and Caicos Islands*, Food and Agriculture Organization of the United Nations, Rome, 1986.
Pfeiler, E., Padron, D. and Crabtree, R.E., Growth rate, age and size of bonefish from the Gulf of California, *J. Fish Biol.*, 56, 448, 2000.
Roberts, C.M., Bohnsack, J.A., Gell, F., Hawkins, J.P. and Goodridge, R., Effects of marine reserves on adjacent fisheries, *Science*, 294, 1920, 2001.
Rudd, M.A., Fisheries landings and trade of the Turks and Caicos Islands, *Univ. Br. Columb. Fish. Cent. Res. Rep.*, 11, 149, 2003.
Sadovy, Y., Trouble on the reef: the imperative for managing vulnerable and valuable fisheries, *Fish Fish.*, 6, 167, 2005.
Sealey, K.S., Balancing development and the environment in the Bahamian Archipelago, *Bahamas J. Sci.*, 5, 2, 2003.
Sealey, K.S., Large-scale ecological impacts of development on tropical island systems: comparison of developed and undeveloped islands in the Central Bahamas, *Bull. Mar. Sci.*, 75, 295, 2004.
Sealey, N.E., *Bahamian Landscapes: An Introduction to the Geology of The Bahamas*, Media Enterprises Ltd., Nassau, Bahamas, 1994.
Smith, N.P., Transport over a narrow shelf: Exuma Cays, Bahamas, *Ocean Dyn.*, 54, 435, 2004a.
Smith, N.P., Transport processes linking shelf and back reef ecosystems in the Exuma Cays, Bahamas, *Bull. Mar. Sci.*, 75, 269, 2004b.
Syms, C. and Jones, G.P., Disturbance, habitat structure and the dynamics of a coral-reef fish community, *Ecology*, 81, 2714, 2000.
Turks and Caicos Islands Government, *Fisheries Protection Ordinance*, CAP 104, 1998.
Turks and Caicos Islands Government, *National Park Ordinance*, CAP 80, 1998.
Underwood, A.J., On beyond BACI: sampling designs that might reliably detect environmental disturbances, *Ecol. Appl.*, 4, 3, 1994.
Warmke, G.L. and Erdman, D.S., Records of marine mollusks eaten by bonefish in Puerto Rican waters, *Nautilus*, 76, 115, 1963.

6 Coastal Ecosystem Management to Support Bonefish and Tarpon Sportfishing in Peninsula de Zapata National Park, Cuba

Lázaro Viñola Valdez, Lázaro Cotayo Cedeño, and Natalia Zurcher

CONTENTS

INTRODUCTION

Located in the southern Matanzas province, the National Park of the Peninsula of Zapata is part of the protected area of Peninsula of Zapata wetland in Cuba (Figure 6.1). The wetland has been a protected area since 1995 (Cuban legislation, Executive Committee of the Council of Ministers, January 1995), and it was declared a biosphere reserve by the United Nations Educational, Scientific and Cultural Organization (UNESCO) in January 2000. It is both the largest and most ecologically important wetland in the Caribbean. Owing to its vast area and the importance of the ecosystem, the Peninsula of Zapata is one of the most remarkable geographic units of the Cuban territory. The natural resources of this large insular wetland are of vital importance for the livelihood of the locals, mainly the extraction of wood and production of charcoal. The forests are also used for tourism and as a source of food for local communities. A small fishing port in the area supplies the needs of southern Matanzas province.