Assessing the Efficacy of Fishery Management Changes Implemented for the Biscayne National Park Fishery Management Plan

A Science Plan Prepared by the
National Park Service
and the
Florida Fish and Wildlife Conservation Commission

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EXECUTIVE SUMMARY

The Biscayne National Park Fishery Management Plan (FMP) Final Environmental Impact Statement (FEIS) was issued in 2009 and called for a 20% increase in the sizes and abundances of targeted species within the park. This science plan, a collaborative effort between the National Park Service (NPS) and the Florida Fish and Wildlife Conservation Commission (FWC), presents recommendations for monitoring targeted fisheries resources within Biscayne National Park to assess the efficacy of park-specific regulations implemented in support of that FMP.

This plan provides the basic definitions, limitations, and assumptions under which monitoring, data analyses, and reporting should occur. Targeted species have been divided into two tiers. Tier 1 species are considered a priority because they are routinely fished in the park, can be monitored using existing or easily developable sampling methods, and are deemed amendable to responding to proposed management actions. Tier 2 species currently lack adequate monitoring and could be added to monitoring efforts as appropriate methods are developed and as staffing and funding allow.

Monitoring and research efforts have been divided into six major categories: a) Quantifying changes in the abundance and size-structure of targeted species, b) Monitoring changes in recreational fishing patterns, c) Monitoring changes in commercial fishing activity, d) Monitoring fishing-related benthic habitat impacts, e) Research to inform interpretation of responses of targeted species to management regulations, and f) Development of new monitoring programs for under-studied species. Specific projects for each category are described, including summaries of previous and ongoing work and action items needed to bring the proposed monitoring to fruition.

Progress reports, completed once every four years starting from the implementation of regulations in support of the FMP, will be produced. Findings should include the consideration that many of the Tier 1 species have been under considerable fishing pressure for some time, so for the slow-growing, long-lived fish that have long generation times, it may take fifteen years (or longer) for results to be achieved. Each report will provide a detailed summary of monitoring activity described in this science plan. At a minimum, the summary for each monitoring activity should include the management activity status, a comparison of baseline and current values for the metrics associated with each activity, and, as applicable, a determination of whether the goal of reaching the 20% increases in size and abundance benchmarks was met. Finally, recommendations for adaptive management (for example, additional regulatory changes) to address any instances where the 20% goal was not met will be provided, as will recommendations regarding the need for continued monitoring activities.

LIST OF ABBREVIATIONS

BNP	Biscayne National Park
BTT	Bonefish and Tarpon Trust
CPUE	Catch Per Unit Effort
CUA	Commercial Use Authorization
FEIS	Final Environmental Impact Statement
FMP	Fishery Management Plan
FWC	Florida Fish and Wildlife Conservation Commission
HPUE	Harvest Per Unit Effort
MOU	Memorandum of Understanding
MRIP	Marine Recreational Information Program
NMFS	National Marine Fishery Service
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
OMB	Office of Management and Budget
RVC	Reef-fish Visual Census
SFCN	South Florida and Caribbean Network Inventory & Monitoring
SPL	Saltwater Products License
SRS	Stratified Random Sampling

PARK BACKGROUND AND HISTORY OF THE FISHERY MANAGEMENT PLAN

Located in southeastern Florida, Biscayne National Park (BNP) is 95% underwater and includes 173,900 acres spanning from just south of Key Biscayne to just north of Key Largo. The coral reefs of Biscayne National Park lie due east of the park's keys and are part of the Florida Reef Tract that stretches through the park and extends approximately 200 miles southwest to the Dry Tortugas. The shallow, protected waters of Biscayne Bay contain the estuarine environment of the park, which supports seagrasses and hardbottom communities.

BNP was initially established by Congress in 1968 as Biscayne National Monument, with the intent "to preserve and protect for the education, inspiration, recreation and enjoyment of present and future generations a rare combination of terrestrial, marine, and amphibious life in a tropical setting of great natural beauty" (PL 90-606). In 1980, BNP was re-designated as a national park. In the legislative history for the 1980 enabling legislation, Congress recognized "the unique and special values" of the resources within BNP, as well as the "vulnerability of these resources to destruction or damage due to easy human access by water" (House Report 96-693, 1979). Congress therefore directed the NPS to "manage this area in a positive and scientific way in order to protect the area's natural resource integrity".

BNP's enabling legislation establishes that fishing will continue to occur in BNP waters in accordance with State of Florida regulations. Both commercial and recreational fishing occur within BNP. With minor exceptions, fishing in BNP follows State of Florida fishing regulations, as determined by the Fish and Wildlife Conservation Commission (FWC). Recreational fishing, which occurs in multiple habitats in both bay and ocean waters, targets species such as bonefish, snook, tarpon, permit, blue crabs, stone crabs, various snappers and groupers, grunts, barracuda, spadefish, spiny lobster, and triggerfish. Commercial fishing also occurs in both bay and ocean waters, and targets numerous species including invertebrates (lobster, blue crabs, stone crabs, and bait shrimp), food fish (typically members of the snapper/grouper complex, concentrated on yellowtail snapper), and baitfish (ballyhoo, Spanish sardines, thread herring and pilchards).

The BNP Fishery Management Plan Final Environmental Impact Statement (FMP/FEIS) is the result of a cooperative decade-long effort between BNP and the FWC. The FEIS was released in May of 2014. A Record of Decision identified the alternative entitled "Rebuild and Conserve Park Fisheries Resources," as the selected alternative. This alternative calls for adjusting current management strategies in order to achieve substantial improvements in park fisheries resources and further reductions in fishing-related habitat impacts. The selected alternative seeks to implement management actions to "increase in abundance and average size of targeted fish and invertebrate species within the park by at least 20% over current conditions and over conditions in similar habitat outside the park". Although the FMP did not explicitly state how the desired outcomes should be achieved, it did present a range of possible management activities for consideration, including: changes to bag limits, size limits, and/or slot limits; seasonal and/or temporal closures; elimination of the two-day lobster sport season; restricting certain kinds of spearfishing gear; creation of a limited entry, non-transferable, use-or-lose commercial permit that requires annual renewal; and establishment of trap-free zones in bay and coral reef habitats.

FMP SELECTED ALTERNATIVE GOAL: CLARIFICATIONS AND DEFINITIONS

Rationale for Restricting Geographic Scope of Assessment of Plan Efficacy

The Selected Alternative in the FMP refers to improving park fisheries resources relative to current conditions in the park as well as to concurrent conditions in similar habitats outside the park. Due to the high number of uncontrollable factors occurring outside the park (including but not limited to differing regulatory actions, variable fishing pressure, variable enforcement efforts, localized habitat effects such as coral bleaching or disease outbreaks, and broader-scale inter-annual variability), it would be difficult to find truly comparable areas outside the park. Furthermore, comparing park data to areas outside the park will require an unfeasible doubling (or greater) of sampling effort in order to detect spatial differences in a statistically robust way. Thus, this plan recommends only the temporal comparison between baseline estimates and periodic post-implementation estimates *within the park*.

Definitions and explanations of terms

The definitions of terms, listed here alphabetically, provide details about the terminology used in the text of the stated goals of the FMP and how they are to be applied to monitoring work described in this science plan.

20% increase is defined as the targeted amount of change between the pre-FMP implementation baseline estimate and subsequent estimates for each size and abundance metric assessed.

Abundance: Abundance is typically defined as the total number of individuals representing a particular species, or size class thereof (such as the exploited-phase individuals of a particular species), within the park. However, in this science plan, **abundance is represented as both frequency of occurrence AND density estimates obtained from fishery-independent sampling efforts**. To ensure proper interpretation of any potential changes in park fishery resources, any assessment of abundance should provide estimates for the entire species (all size classes) AND either a) exploited-stage individuals for those species with size regulations or b) adult individuals (based on known size-at-maturity estimates) for those species without a size regulation.

Although simple in concept, the actual calculation of true abundance (total number of individuals) is complicated. It is not feasible to directly measure the total number of fish occurring in the park; thus, a measurement of total abundance can only be estimated. For example, one could estimate the abundance of a species in the park by determining densities (number of individuals per unit of area) of that species in different habitat types and then extrapolating those habitat-specific estimated according to the total area of each different habitat class. The accuracy of calculations would be based upon the level of accuracy of habitat maps, and as the habitat classifications can vary widely with different versions of habitat maps and as habitat mapping technology changes, any final computed value carries with it a high margin of error. Thus, this plan will use density and frequency of occurrence as reasonable surrogates for total abundance.

Both density and frequency of occurrence can be directly measured and have lower margins of error than true abundance. Density is defined as the number of individuals per unit of sampled area. Frequency of occurrence is defined as the percentage of samples in which at least one representative of a species or size class has been observed. Frequency of occurrence could be particularly useful in assessing changes for currently uncommon species. Success of FMP regulatory changes for any given species will be based upon **BOTH** metrics showing a 20% improvement from baseline values.

Due to the high annual variability of fish populations, we recommend computing abundance (using density and frequency of occurrence as proxies) as a multi-year average. Combining multiple years will improve statistical rigor of analyses and prevent falsely attributing natural variability as evidence of success or failure of an implemented regulation. Baseline estimates of densities and frequencies of occurrence for the targeted species have been computed using all available Reef-Fish Visual Census (RVC) data collected within the park from 2008 through 2018. Post-implementation estimates will be computed using the last three sampling years' data.

Average Size: Average size refers to the arithmetic average of only a) exploited-stage individuals for those species with size-related regulation or b) adult individuals (based on known size-at-maturity estimates) for those species without a size-related regulation. Since the goal of the FMP is to increase the sizes and abundances of the targeted species, and the implied goal of the FMP is to increase the size of harvestable individuals, only those individuals that can be harvested should be included in computations of average size. Computing average size of exploited-stage/adult stage individuals only will help to prevent annual variability in recruitment of larval and juvenile stages, which are not targeted for harvest, from confounding interpretation of trends.

Due to the high natural variability occurring within populations of marine organisms, we recommend computing average size as a multi-year average based on the last three sampling years available. Combining multiple years will increase statistical rigor and prevent falsely attributing natural variability as evidence of success or failure of an implemented regulation. Baseline values of average size have been computed using all available RVC data collected within the park from 2008 through 2018. Post-implementation estimates of average size will be computed using the last three sampling years' data.

Baseline: The baseline values depict the current conditions of park fishery resources under existing regulations prior to development of FMP-specific regulatory changes. Each baseline value will serve as the basis for comparison when assessing if newly implemented regulations suggest that a fishery resource has recovered (or is trending towards recovery) to a desired future condition. The baseline values have been computed using available data collected within the park between 2008 and 2018. Using data from this expanded time period will improve accuracy that could be compromised due to the high natural variability that occurs within populations of marine organisms and, in some cases, is necessary to alleviate problems associated with low sample sizes for some less common species (*e.g.*, mutton snapper).

Exploited Stage: Those individuals of a species which can be legally harvested are defined as being in the exploited stage. For regulated species, exploited-stage individuals are those which meet or exceed a minimum size limit or which fall within the slot limit range. For analyses pertaining to species with a changing size regulation (for example, a 20-inch minimum legal size is changed to a 22-inch minimum size), the baseline exploited-stage value (in this example, 20 inches) will be used as the cut-off point to separate exploited-stage individuals from non-exploited stage individuals.

Generation Time: This term follows the NOAA Fisheries Glossary (Blackhart et al. 2006) definition as it pertains to setting maximum allowable rebuilding time periods. Generation time is defined as the time required for a female to produce a reproductively-active female offspring. The generation times for targeted species are, when available in the literature, provided in Table 1.

The estimated generation times differs widely among the different target species, due to differences in their life histories (see Table 1). Generation time should be taken into account when determining if the desired 20% increase in size and/or abundance has been met, as it may take at least one full generation time span for success to be achieved. For example, because the long-lived, slow-to-mature, and hermaphroditic black grouper (*Mycteroperca bonaci*) has an estimated generation time of at least ten years, it would be unreasonable to expect that a 20% increase in abundance might be achieved by the end of the first reporting period (seven years). Thus, a failure to reach a 20% increase after a few years should not automatically be interpreted to mean that the regulatory changes have failed. Rather, data should continue to be collected and analyzed for increasing periods of time which cover at least one full generation time. Analyses completed for time intervals that are less than the species' generation time could be used to monitor trends and direction of change, but not necessarily to determine success or failure of the newly implemented regulations.

Targeted Species: We recommend a two-tier classification of targeted species, as shown in Table 1. Species classified as Tier 1 should be considered priorities and should be included from the very beginning of monitoring efforts. Species in Tier 1 are those that are routinely fished in the park, can be monitored using existing or easily developable sampling methods, and are deemed amenable to responding to proposed fishery management actions (within appropriate time periods as determined by their species-specific life history characteristics; see discussion in Generation Time above). Species classified as Tier 2 currently lack adequate sample sizes, understanding, and/or monitoring and could be added into ongoing monitoring efforts as appropriate sampling methods are tested and developed, and as staffing and/or funding allow. *Note:* Two different species of porgy are lumped together as "Porgy spp" due to their similar appearance (and thus uncertainty in being able to distinguish between these species during visual surveys) and low individual sample sizes.

Success: An FMP-associated fishing regulation designed to increase the abundance and/or average size of a species will be declared successful when: i) a status report (see Deliverables) confirms that the 20% benchmark (see Tables 2-4 below) has been met or exceeded, based on

multi-year metric calculations as defined above, and ii) ongoing monitoring and future status reports confirm that a 20% (or better) improvement has been maintained.

TABLE 1: List of species recommended for monitoring, with tier designation and life history information. Life history information presented here was, to the extent possible, selected from studies conducted in South Florida or the most geographically close location from available data sources.

Tier	Grouping	Species Common Name	Species Scientific Name	Age at maturity (years)	Maximum Age (years)	Generation Time (years)
ONE	Snapper	Gray (mangrove) snapper	*Lutjanus griseus*	2 (Allen 1985)	24 years overall, 15 years in South Florida (Burton 2001)	7 (Gold et al., 2009
		Lane snapper	*Lutjanus synagris*	1 (Luckhurst et al., 2000)	19 (Luckhurst et al., 2000)	5-6 (Lindeman, Anderson, Carpenter, Claro, Cowan, Padovani-Ferreira et al., 2016c)
		Mutton snapper	*Lutjanus analis*	3.7 (O'Hop et al., 2015)	40 (O'Hop et al., 2015), 29 years (Burton, 2002)	8-22 (Lindeman, Anderson, Carpenter, Claro, Cowan, Padovani-Ferreira et al., 2016a)u
		Yellowtail snapper	*Ocyurus chrysurus*	2 (Claro et al., 2001)	19 overall (Araújo et al., 2002), 14 in South Florida (Manooch et al, 1987),	11-12 (Lindeman, Anderson, Carpenter, Claro, Cowan, Padovani-Ferreira et al., 2016b)
		Schoolmaster snapper	*Lutjanus apodus*	1 to 2 (Claro & Lindeman 2008, Lindeman, Anderson, Carpenter, Claro, Cowan, Espinosa-Perez et al., 2016)	10 (Murray & Bester, 2018)	Unavailable

Tier	Grouping	Species Common Name	Species Scientific Name	Age at maturity (years)	Maximum Age (years)	Generation Time (years)
	Grouper	Red grouper	*Epinephelus morio*	4-5 (transition from female to male at 3-13 years) (Garcia-Moliner et al., 2004)	25 (Garcia-Moliner et al., 2004)	8-11 (Garcia-Moliner et al., 2004)
	Hogfish	Hogfish	*Lachnolaimus maximus*	2, transition from female to male at 3-5 (McBride & Richardson, 2007)	23 (McBride & Richardson, 2007)	12
	Grunt	Bluestriped grunt	*Haemulon sciurus*	3-4 (Pitt et al., 2009)	23 (Pitt et al., 2009)	Unavailable
		White grunt	*Haemulon plumierii*	1.5 (Ault, Bohnsack,et al., 1998)	8 (Ault, Bohnsack,et al., 1998)	4-9 (Lindeman, Anderson, Claro et al., 2016)
	Triggerfish	Gray triggerfish	*Balistes capriscus*	1 (males) and 2 (females) (Wilson et al., 1995, Ingram, 2001).	16 (SEDAR 9, 2005)	4-8 (Liu et al., 2015)
TWO	Grouper	Black grouper	*Mycteroperca bonaci*	5.2 (transition from female to male at 15.5 years) (Ferreira et al., 2008)	33 (Crabtree & Bullock, 1998)	10+ (Ferreira et al., 2008)
	Barracuda	Great barracuda	*Sphyraena barracuda*	1-2 (males) and 3-4 (females) (Aiken et al., 2015, Kadison et al., 2010)	14 (Aiken et al., 2015)	8.8 (Pauly, 1978)
	Porgy spp.	Saucereye, Littlehead,	*Calamus calamus*, *Calamus proridens*	Unavailable	Unavailable	Unavailable
	Mackerel	Cero mackerel	*Scomberomorus regalis*	< 1 year (Blue Ocean	Unavailable, but congener	Unavailable

Tier	Grouping	Species Common Name	Species Scientific Name	Age at maturity (years)	Maximum Age (years)	Generation Time (years)
				Institute, 2018)	Spanish Mackerel has been noted to be 8 (Powell, 1975)	
	Lobster	Caribbean spiny lobster	*Panulirus argus*	2 (Chávez, 2001)	20 (Ehrhardt, 2005)	10 (Butler et al., 2011)
	Crab	Blue crab	*Callinectes sapidus*	0.5 to 1 (Hines et al., 2010)	2-3 (Van Engel, 1958	0.8 to 1.3 (Hines et al., 2010)
		Stone crab	*Menippe mercenaria*	2 for females, 3 for males (Gerhart & Bert, 2008)	7-9 (Fluech, 2013)	Unavailable

Baselines and Benchmarks

The Fishery Management Plan's goal to increase the size and abundance of targeted species within the park by 20% over baseline values. In order to accurately assess the efficacy of regulations implemented in support of, this plan it is necessary to define the baseline and targeted 20% increase values.

Tables 2-4 provide information on the baseline metrics and benchmark (20% improvement) targets for the densities, frequencies of occurrences, and average sizes of the Tier 1 Target Species. For these tables, it is important to recall that, as described previously:

- Densities and frequencies of occurrences are computed for both the entire species (all size classes), AND EITHER
    - exploited-stage individuals for those species with size regulations

      OR

    - adult individuals (based on known size-at-maturity estimates) for those species without a size regulation
- Average exploited length estimates are computed only for the exploited-stage individuals for those species with size regulations or adult individuals (based on known size-at-maturity estimates) for those species without a size regulation
- Baseline values were computed using all available reef-fish visual census (RVC) survey data collected in the park from 2008 through 2018. Benchmark (20% increase) values were determined by computing the 20% increase from the baseline value.

Table 2: Baseline and Benchmark Values of Density Estimates for Tier 1 Targeted Species. Benchmarks are in bold.

Grouping	**Species Common Name**	**Species Scientific Name**	**Baseline Density for Entire Species (fish per visual census cylinder)**	**Benchmark (20% Increase) Density for Entire Species (fish per visual census cylinder**	**Baseline Density for Exploited-Stage (or Adult) Individuals (fish per visual census cylinder**	**Benchmark (20% Increase) Density for Exploited-Stage (or Adult) Individuals (fish per visual census cylinder**
Snapper	Gray (mangrove) snapper	*Lutjanus griseus*	2.15	**2.58**	0.57	**0.68**
	Lane snapper	*Lutjanus synagris*	0.40	**0.48**	0.12	**0.14**
	Mutton snapper*	*Lutjanus analis*	0.09	**0.11**	0.02	**0.024**
	Schoolmaster snapper**	*Lutjanus apodus*	0.57	**0.68**	0.15	**0.18**
	Yellowtail snapper	*Ocyurus chrysurus*	3.48	**4.18**	0.19	**0.23**
Grouper	Red grouper	*Epinephelus morio*	0.09	**0.11**	0.02	**0.024**
Hogfish	Hogfish*	*Lachnolaimus maximus*	1.30	**1.56**	0.18	**0.22**
Grunt	Bluestriped grunt†	*Haemulon sciurus*	2.56	**3.07**	0.81	**0.97**
	White grunt†	*Haemulon plumierii*	17.11	**20.53**	4.47	**5.36**
Triggerfish	Gray triggerfish	*Balistes capriscus*	0.06	**0.07**	0.01	**0.012**

Table 3: Baseline and Benchmark Values of Frequency of Occurrence Estimates for Tier 1 Targeted Species. Benchmarks are in bold.

Grouping	**Species Common Name**	**Species Scientific Name**	**Baseline Frequency of Occurrence for Entire Species (Percent of surveys in which species was observed)**	**Benchmark (20% Increase) Frequency of Occurrence for Entire Species (Percent of surveys in which species was observed)**	**Baseline Frequency of Occurrence for Exploited-Stage (or Adult) Individuals (Percent of surveys in which species was observed)**	**Benchmark (20% Increase) Frequency of Occurrence for Exploited-Stage (or Adult) Individuals (Percent of surveys in which species was observed)**
Snapper	Gray (mangrove) snapper	*Lutjanus griseus*	28.84%	**34.61%**	17.29%	**20.75%**
	Lane snapper	*Lutjanus synagris*	4.17%	**5.00%**	2.00%	**2.40%**
	Mutton snapper*	*Lutjanus analis*	10.17%	**12.20%**	2.09%	**2.51%**
	Schoolmaster snapper**	*Lutjanus apodus*	21.11%	**25.33%**	9.21%	**11.05%**
	Yellowtail snapper	*Ocyurus chrysurus*	63.16%	**75.79%**	11.29%	**13.55%**
Grouper	Red grouper	*Epinephelus morio*	11.82%	**14.18%**	2.26%	**2.71%**
Hogfish	Hogfish*	*Lachnolaimus maximus*	61.08%	**73.30%**	17.11%	**20.53%**
Grunt	Bluestriped grunt†	*Haemulon sciurus*	41.88%	**50.26%**	25.11%	**30.13%**
	White grunt†	*Haemulon plumierii*	81.58%	**97.90%**	68.90%	**82.68%**
Triggerfish	Gray triggerfish	*Balistes capriscus*	5.82%	**6.98%**	1.13%	**1.36%**

Table 4: Baseline and Benchmark Values of Average Size Estimates for Tier 1 Targeted Species. Benchmarks are in bold.

Grouping	**Species Common Name**	**Species Scientific Name**	**Current Minimum Legal Size (or Size at Maturity for unregulated species indicated with an †, cm)**	**Baseline Estimate of Average Length of Exploited/adult Stage Individuals, in cm (inches)**	**Benchmark (20% Increase) Average Length of Exploited/adult Stage Individuals, in cm (inches)**	**Estimated Time in months for an individual to grow from the current minimum legal size to a 20% larger size‡.**
Snapper	Gray (mangrove) snapper	*Lutjanus griseus*	25	27.60 (10.87")	**33.12 (13.04")**	13.6
	Lane snapper	*Lutjanus synagris*	20	21.54 (8.48")	**25.85 (10.18")**	11.0
	Mutton snapper*	*Lutjanus analis*	41	47.80 (18.82")	**57.36 (22.58")**	14.3
	Schoolmaster snapper**	*Lutjanus apodus*	25	28.61 (11.26")	**34.33 (13.52")**	25.2
	Yellowtail snapper	*Ocyurus chrysurus*	31	35.00 (13.78")	**42.00 (16.54")**	19.5
Grouper	Red grouper	*Epinephelus morio*	50	57.88 (22.79")	**69.46 (27.34")**	20.0
Hogfish	Hogfish*	*Lachnolaimus maximus*	31	35.87 (14.12")	**43.04 (16.95")**	23.4
Grunt	Bluestriped grunt†	*Haemulon sciurus*	20.5†	23.87 (9.40")	**28.64 (11.28")**	2.3
	White grunt†	*Haemulon plumierii*	18†	21.12 (8.31")	**25.34 (9.98")**	0.5
Triggerfish	Gray triggerfish	*Balistes capriscus*	30	31.72 (12.49")	**38.06 (14.99")**	18.7

**Hogfish and mutton snapper minimum size limits were recently increased from 12" to 16" and from 16" to 18" respectively. These populations have not had time to experience the effects of these regulations in Biscayne National Park. Therefore baseline values for these species were calculated at the pervious minimum size limits.

** Estimates for schoolmaster snapper were calculated using fish counted in all three time periods, while the estimates for the rest of the species were calculated using fish counted during only the first two time periods, per NOAA's recommendation.

† See Ault et al. 2005.

‡ Estimates were based upon an inverted Von Bertalanffy growth equation (see Slipke & Maceina 2001). Since these times are estimates, these should be considered the minimum time frames that we would expect fish to need to grow to from the minimum size limit to a 20% larger size. Fish that are not at the current size limit will take longer to reach these sizes.

Recommended Monitoring and Research Activities

This Science Plan calls for evaluation of six performance measures related to FMP implementation. Under each performance measure is a summary and justification, identification of essential and supplemental activities, descriptions of previous and ongoing studies, and information on proposed studies. Table 5 contains a summary of the proposed essential and supplemental activities to be conducted under each performance measure.

In addition to the activities described here, we recommend that, when evaluating the success of implemented regulations on park fishery resources, scientists and managers should also review findings from relevant permitted research activity that has occurred or is currently occurring within the park. Although this additional information, on its own, is not sufficient to evaluate changes in park fishery resources for the purposes of evaluating the efficacy of management actions implemented under the FMP, it could provide additional details to help inform the interpretation of results of the recommended monitoring and research activities described in this document. Summary reports of all permitted research, in the form of Investigator Annual Reports, can be downloaded from the NPS Research Permit and Reporting System (https://irma.nps.gov/rprs/).

Performance Topic 1: Quantify changes in the abundance and size-structure of targeted species within BNP

Summary: A stated goal of the BNP FMP/FEIS is to increase the abundance and average size of targeted fish and invertebrate species within the park by at least 20% over current conditions. Recommendations for park-specific state and federal regulations will be developed by a panel of FWC and NPS scientists and managers using modeling and analyses of the best available data.

FWC and NPS scientists compiled several sources of fishery independent (RVC) and fishery dependent data (Creel and MRIP) for BNP. Scientists examined the fishery dependent data to see whether it could be used in a decision support tool or a simulation approach to determine how regulation changes would affect tier one species. However, neither the Creel nor the MRIP datasets within BNP during 2014 through 2016 contained enough data to support such analyses. In the creel data set, only four of the tier one species had more than thirty measurements for legal-sized fish. In the MRIP data set, only one of the tier one species had more than thirty length measurements. In addition, there is no way to guarantee that fish were caught inside BNP, so the MRIP data may not accurately represent the catch rates and size structure of the tier 1 species inside BNP. The Creel and the MRIP datasets could not be combined due to the differences in survey methodology and sampling domain.

Due to the small sample size in the fishery dependent data, FWC and NPS scientists determined that the best way to monitor and quantify changes in the tier one fish populations was to use the RVC data. The RVC data contains length measurements for both the sub-legal and legal-sized fish and will therefore better reflect how regulations affect the entire population of tier one species within BNP.

Performance Measures:
For each Tier 1 targeted species, the following will be assessed:

- abundance (using density *and* frequency of occurrence as proxies) for all individuals within reef habitat
- abundance (using density *and* frequency of occurrence as proxies) for exploited stage/adult stage individuals within reef habitat
- average size of exploited-stage (or adult stage) individuals within reef habitat

REQUIRED ACTIVITY:

1. Reef-fish Visual Census Monitoring

Previous and Existing Studies
The RVC approach is an established method for monitoring reef fish in Florida and the Caribbean (Bohnsack & Bannerot 1986, Brandt et al. 2009, Bryan et al. 2013). Currently, this method has been adopted by numerous collaborating agencies and institutions to assess the status of reef fishes from Martin County to the Dry Tortugas. The RVC dataset has been used to track

short-term and long-term patterns in the presence, abundance, and sizes of reef fish. Sites are selected by stratified random sampling; sites within and around BNP have traditionally been assessed every other year. In 2018, (the most recent year in which the RVC surveys were completed in BNP), 88 reef sites within the Biscayne region (sites within and immediately adjacent to BNP) were surveyed.

Data have been collected with this approach in BNP since 2000 (with more limited sampling occurring even earlier), providing a high-quality baseline dataset. A full description of the methods is available within Brandt et al. (2009). Briefly, a team of four divers conducts the visual census at each site by each diver recording presence, abundance, and sizes of all fish species occurring within his/her unique 7.5m radius cylinder.

The multi-agency RVC study will continue to be used to assess the abundance and size structures of targeted species within BNP, using the same field methodology and site selection protocol as in past years. With implementation of park-specific state regulations in support of the BISC Fishery Management Plan, NPS and FWC staff will increase sampling frequency from the current every-other-year effort to an annual sampling effort.

ACTION ITEMS

a) Analyze existing reef fish visual census (RVC) data to design an adequate sampling program to detect a 20% change in density, frequency of occurrence, and average size of Tier 1 fish species. The sampling design should include details on the sample size (setting a goal for the number of surveys for each sampling period), frequency of sampling (for example, annual vs. biennial), and how to compute the multi-year moving average, taking into account that for species with lengthy generation times, responses to changes in regulations may be slow to be observed.

b) Implement a reef fish visual census (RVC) using a stratified random sampling design (SRS) inside BNP.

ESSENTIAL ACTIVITY:

1. Caribbean Spiny Lobster Assessment

Previous and Existing Studies

From 2004 through 2008, park biologists conducted surveys of lobster abundances at various sites just before and after the annual two-day mini-season, with the goal being to assess localized impacts of lobster populations on reefs. The (unpublished) findings were not easy to interpret, as it was not possible to determine if observed differences in local lobster abundances were the result of natural lobster movement or lobster harvest.

Proposed research should follow peer-reviewed in-water survey methodologies (see Cox & Hunt 2005 as one example) and will aim to determine the presence, abundance, and size-structure of the Caribbean spiny lobsters (*Panulirus argus*). Randomly selected sites should be stratified by habitat type. The NPS South Florida and Caribbean Network (SFCN) has a protocol in review

for monitoring the Caribbean Spiny Lobster in several south Florida and Caribbean parks including BNP. Once the protocol is reviewed and finalized, sampling will be implemented.

ACTION ITEMS

a) Analyze BNP pilot data (from surveys conducted within BNP used to evaluate the newly developed SFCN protocol) to generate baseline values of above-described performance measures for spiny lobster.

b) Analyze BNP pilot data (generated to evaluate the above-described SFCN protocol) to design an adequate sampling program to detect a 20% change in spiny lobster density, frequency of occurrence, and average size. The sampling design should include details on the sample size (setting a goal for the number of surveys for each sampling period), frequency of sampling (for example, annual vs. biennial), and how to compute the multi-year moving average.

c) Adopt and implement a lobster visual census using a stratified random sampling design inside BNP.

Performance Topic 2: Monitor changes in recreational fishing patterns within BNP

Summary and Justifications: Recreational fishing activity within BNP must be monitored to track changes in fishing effort, fishing success, and catch and harvest patterns and trends. These fishery-dependent surveys are an important complement to the fishery-independent methods described under Performance Topic 1. An anticipated outcome of FMP implementation is an improved fishing experience (for example, the ability to catch more fish or bigger fish). Monitoring recreational fishing activity will assess the fishing experience.

In addition to monitoring catch and harvest patterns of individual recreational fishers, it is also useful to have a good understanding of the amount of fishing occurring in the park, and if and how fishing intensity varies with day of the week or time of the year. However, several factors make it difficult to determine the level of fishing activity in Biscayne National Park. Park users can access the park from just about anywhere; there is not a single entrance point, and there is no entrance fee system which could be used to monitor park visitation. Those wishing to fish in the park can do so from land (along the mainland shoreline at areas such as Black Point Park and Convoy Point) or by boat. Boaters can launch their boats from private property, from one of the Miami-Dade County marinas (Black Point, Homestead Bayfront, Mattheson Hammock, etc.) that serve the area, as well as from access points in Monroe County. Thus, getting an accurate estimation of fishing intensity in the park is not a simple task.

Performance Measures: recreational catch and harvest species compositions; recreational catch-per-unit-effort (CPUE) and harvest-per-unit-effort (HPUE) rates for targeted species; average size of landed fish; satisfaction of recreational fishers; daily, seasonal, and annual estimates of fishing intensity (number of people fishing, number of fishing trips).

ESSENTIAL ACTIVITIES:

1. Recreational creel survey of visitors fishing within BNP.

Surveys will cover various entry points and include collection of data that will allow for assessment of numbers of targeted fish and lobsters harvested and released by species, catch per unit effort, sizes of landed fish and lobsters, and visitor satisfaction.

Previous and Existing Studies

Since 1976, BNP scientists have conducted creel surveys of visitors recreationally fishing in park and adjacent waters. This survey instrument allows the interviewer to collect information on fisher demographics, areas and species targeted, species caught and released, level of fisher satisfaction, and the numbers and sizes of landed fish. From the information provided, park biologists can estimate catch per unit effort for different species and locations in the park as well as examine trends in catch per unit effort for different species across space and time and trends in visitor satisfaction (see Ault et al. 2001, Harper et al. 2000, McDonough 2009). These surveys also provide an estimate of the level of poaching (such as the harvest of undersized fish or fish in excess of the bag limit). Due to present staffing limitations, surveys are currently conducted on Sunday afternoons and almost exclusively to boaters returning to Homestead Bayfront Park.

Additionally, since 1987, park staff has conducted creel surveys during the two-day lobster sport season, which falls on the last consecutive Wednesday and Thursday in July. From these surveys, park managers have been able to examine trends in lobster harvest over time. The latest report produced from this effort is a ten-year assessment covering the years 2002 through 2011 (see McDonough 2012); this report is available at http://www.nps.gov/bisc/planyourvisit/upload/Biscayne-Lobster-Mini-Season-10-year-Report_FINAL.pdf. A tri-fold brochure presenting data collected from 2002 through 2015 was also prepared and disseminated to those participating in the 2016 lobster mini season.

The National Marine Fisheries Service (NMFS) Marine Recreational Information Program (MRIP) is a national survey tool used to estimate recreational saltwater catch and fishing effort. Visitors who recreationally fish within and adjacent to BNP provide data for this survey effort when they are interviewed by FWC staff who periodically complete MRIP surveys at the various marinas adjacent to the park. The entire MRIP database is available online at http://www.st.nmfs.noaa.gov/recreational-fisheries/data-and-documentation/run-a-data-query. Due to the nature of the survey, it is not possible to obtain information specific to BNP.

Consequently, future efforts should seek to expand the BNP creel survey spatially and temporally. Efforts should be made to conduct the recreational creel surveys a minimum of three days per week, particularly on Friday, Saturday and Sunday, when park use peaks and fishing activity is, presumably, at its highest. Interviews should be conducted throughout the entire day to include those who fished overnight or in the early morning hours and who are returning to a marina early in the day. Surveys should also be conducted at the three Miami-Dade County marinas (Homestead Bayfront Park, Black Point Marina, and Matheson Hammock Park) that provide access to BNP, as well as from park vessels patrolling park waters. Increased collaboration between park resource managers and park law enforcement rangers can result in increased data collection since law enforcement rangers have the authority to inspect a park visitor's catch (thereby elevating the public's cooperation from voluntary to required). In order to assess trends over time, the survey questions should, to the best extent possible, be consistent. Any changes to the survey questions asked by a government official must first undergo review by the Office of Management and Budget (OMB), and this approval process is expected to take a minimum of one year. Surveys conducted independently by non-governmental entities (such as universities, external researchers etc.) do *not* require OMB approval.

ACTION ITEMS

a) Analyze BNP creel survey database and lobster mini-season database to generate baseline values of CPUE, HPUE, and average sizes of Tier 1 species; percent of interviewed fishers satisfied with fishing experience; and daily, seasonal, and annual estimates of fishing intensity (number of people fishing, number of fishing trips).

b) Analyze BNP creel and MRIP survey databases and BNP lobster mini-season database to design an adequate sampling program needed to detect changes in CPUE, HPUE, average size of Tier 1 species, and percent satisfaction. The sampling design should include details on the

sample size (number of surveys per year), frequency of sampling (for example, annual vs. biennial), locations of sampling, and how to compute multi-year moving averages, taking into account that for species with lengthy generation times, responses to changes in regulations may be slow to be observed.

c) Implement a spatially and temporally expanded recreational fishing survey.

2. Collect, via a logbook system, effort, catch, and landings data from charter boat and guide operations authorized to conduct business within BNP.

Previous and Existing Studies
Charter boats and guide operations within BNP do not currently report their fishing activity and there has been no attempt to monitor or document the fishing activity of these operations.

Proposed Studies
Under the FMP, all professional charter and guide boats operating in BNP will be required to obtain a Commercial Use Authorization (CUA) to conduct their activities in the park. It is anticipated that the CUA requirement will go into effect in 2019. As a condition of the CUA, the permittee will be required to provide monthly reports detailing how many trips were made to each zone within the park. As part of their annual reporting requirements, the permittee will have to report total number of trips made in the park, irrespective of location visited. Information provided in the monthly logs and annual reports can be used to calculate guide and charter fishing intensity in terms of numbers of fishing trips made to the park.

ACTION ITEMS

a) Analyze existing CUA monthly logs and, if available, annual reports, to generate baseline values of the number of guide/charter trips taken in various zones and in the park overall.

b) Create a database system to record and store all future monthly logs and annual reports.

c) Utilize the above-described database to generate future estimates of the number of guide/charter trips taken in various zones and in the park overall.

SUPPLEMENTAL ACTIVITY:

1. Estimate overall fishing activity in BNP using aerial surveys.

Previous and Existing Studies
In 2003 and 2004, Dr. Jerald Ault and colleagues conducted aerial boater use surveys in Biscayne National Park, in tandem with trailer counts at the local marinas (see Ault, Smith, McClellan et al. 2008). The purpose of the study was to establish a cost-effective method for estimating boater use within Biscayne National Park. Their work examined all boating activity in the park, not just fishing activity, although surveyors did record the disposition of each

observed boat (including if the people on the boat were engaged in any type of fishing activity). The percentage of boats engaged in fishing activity ranged, by season, from approximately 30 to 45% for midweek activity, and from approximately 10- 30% for weekend activity. Their results led to the following recommendations: a) implementation of an automated system for obtaining daily trailer counts at Homestead/Bayfront Park, Black Point, Matheson Hammock, Dinner Key, and Crandon Park, and b) calibrating and verifying automated trailer counts with occasional on-site trailer counts by creel survey personnel, using their developed regression model to estimate the number of boats from the number of trailers counted.

A new series of aerial surveys, utilizing the same methods of the 2003/2004 approach, were completed in 2016 and 2017 (Ault, Smith, Manges et al. 2017). The study found that 89% of all vessel usage occurred on weekends and that small recreational vessels accounts for 60-80% of all observed vessels. Spatial patterns observed included: i) the presence of flats boats in hardbottom areas north of Elliott Key and grass/sand flats south of Soldier Key, and ii) fishing and diving vessels occurring in dense concentrations in the offshore reef areas along the park's eastern border. Estimates of annual boater use (88,585 boats) decreased somewhat from the 2003-2004 study (92,484 boats). Recommendations produced from 2016-2017 followed those from the 2003-2004 study, but included an updated formula for computing boat numbers from trailer counts.

Aerial surveys should be repeated at a reasonable frequency (such as every five years, funding-contingent). Extra care should be given to discern the proportion of boats engaged in fishing activity, and to that extent, effort should be made to differentiate the different types of fishing activities (such as recreational hook and line, recreational spearfishing, commercial trawling, commercial wing-netting, commercial trapping, commercial lampara netting etc.). As the NPS develops and revises policies on the use of drones for park management issues, the use of drones, which is much more cost-effective than aerial surveys via small planes, should be considered.

ACTION ITEMS

a) Use the most recent 2016/2017 survey results to generate baseline values of the number of boats engaged in fishing on a daily, seasonal, and annual basis.

b) Analyze existing aerial survey data to design an adequate sampling program to monitor recreational fishing effort over time. The sampling design should include details on the sample size (number of aerial surveys per year), periodicity of sampling (for example annual vs. biennial), and timing of surveys (weekend vs. weekday, summer vs. winter etc.).

c) Implement a periodic aerial survey as designed in Action Item b, considering the use of drones as a more cost-effective mode of survey (if state and NPS polices allow for drone use).

Performance Topic 3: Monitor changes in commercial fishing activity within BNP

Summary and Justifications: Commercial fishing has occurred in BNP waters since its establishment as Biscayne National Monument in 1968. Commercial fishing occurs in both bay and ocean waters, and targets numerous species including invertebrates (spiny lobster, blue crab, stone crab, and pink shrimp), food fish (typically members of the snapper/grouper complex; in particular yellowtail snapper), and baitfish (ballyhoo, Spanish sardines, thread herring and pilchards). Modes of commercial fishing occurring with BNP include trapping, trawling, wing-netting, lampara netting, cast netting, diving, and hook and line. Commercial fishing continues to be an important source of income and culturally-significant maritime activity for area residents (See Figure 1). The bait shrimp fishery and the spiny lobster fishery are the most economically important commercial fisheries for the bay and ocean components of the park, respectively. Changes in commercial fishing activity within the park have the potential to effect achievement of the FMP goal to increase the sizes and abundances of targeted species by 20% over baseline values.

In addition, the BNP FMP/FEIS proposes a gradual phasing out of commercial fishing within Biscayne National Park through the implementation of a lifetime, non-transferable, use-or-lose permit system that requires annual renewal. If implemented, park managers would be able to track the number of permitted individuals commercially fishing in the park.

Commercial landings are currently reported to the FWC through the use of the "Marine Fisheries TripTicket" system, allowing for the NPS and FWC to monitor patterns of commercial fishing activity within the park. Regardless of whether the proposed measure to gradually phase out commercial fishing within the park is implemented, changes in commercial harvest can be tracked without additional reporting requirements for those commercially fishing in the park (commercial landing data will continue to be collected through the Marine Fisheries TripTicket system). Landings are reported with respect to zones established by the FWC (see Levesque 2009). In 2003, the FWC altered the reporting zones to include two zones located entirely within the park: one for harvest from the bay portion of the park (zone 744.4); and one for harvest from the ocean portion of the park (zone 744.5). A small portion of reporting zone 744.8 also falls within the ocean portion of the park.

Performance Measures: Pounds landed annually by species or species group, number of commercially-licensed fishers operating within BNP, size structure of commercial landings.

ESSENTIAL ACTIVITIES:

1. Utilize existing commercial fishery-dependent monitoring programs to obtain and utilize data on commercially important species

Previous and Existing Studies

The TripTicket program is, exclusively, the means by which resource managers at BNP track commercial fishing activity within the park. Commercial fishing data, including the number of trips made, the location (from one of three possible demarcated zones located within BNP) of fishing activity, pounds of each species or species grouping harvested, and dollar value of each species or species grouping harvested, are reported to the FWC by the commercial dealers. As requested, these data are then made available to BNP, with minor redactions and/or omissions to protect the privacy of the commercial fishers involved. Using these data, resource managers are able to assess annual and long-term patterns of commercial harvest for various species.

ACTION ITEMS

a) Using the TripTicket program data, determine baseline values of park commercial landings (as total poundage harvested per year) for each species (or species group) for which there is a significant fishery. Each baseline value should be computed by averaging annual values from the three most recent years' data.

b) Continue to use the TripTicket program data to assess and monitor commercial landings of different species. Managers should pay special attention to precipitous changes in landings and should conduct necessary follow-up investigations to determine if these changes are the result of altered fishing patterns (such as a change in the number of commercial fishing trips in the park) or if these changes are suggestive of a changing condition of park fishery resources.

2. Track number of commercial fishers utilizing BNP.

Previous and Existing Studies

The TripTicket program is, exclusively, the means by which resource managers at BNP currently track commercial fishing activity within the park, including information on the number of fishers with FWC-issued Saltwater Products Licenses (SPLs) operating within the park. As shown in Figure 1 below, FWC data suggest that the number of commercial fishers operating within the park peaked in 2005 then declined substantially, but began rising again in recent years before trending down again.

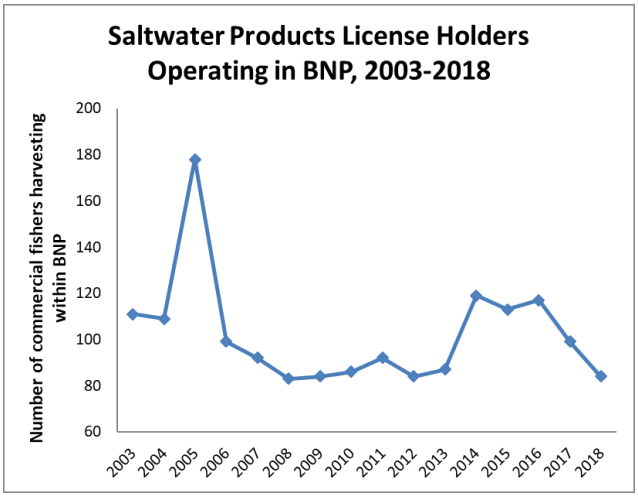

Figure 1: FWC data on the number of Saltwater Products License holders reporting catch from within BNP.

ACTION ITEMS

a) Using the TripTicket program data, determine the baseline value of numbers of commercial fishers operating in the park immediately prior to the implementation of the proposed federal rule to gradually phase out commercial fishing in the park.

b) Continue to use the TripTicket program data to monitor the number of commercial fishers active in the park.

c) If implemented, utilize the park's commercial fishing permit system to monitor the number of commercial fishers granted permits to commercially fish in the park. Due to the conditions of the proposed permit, the number of permitted commercial fishers over time should remain stable or decrease, but should never increase. Any indication that the number of permits issued has increased will require investigation.

d) Compare annual values obtained from Action Items b and c above. If the TripTicket program reports a higher number of commercial fishers operating in the park compared to the park's commercial fishing permit system data, it will be necessary to coordinate with NPS and/or FWC law enforcement to identify unpermitted individuals operating within the park. If the TripTicket program reports a lower number of commercial fishers operating in the park compared to the park's commercial fishing permit system data, this suggests that some of the park-permitted fishers did not operate in the park that year and thus, due to the use-or-lose nature of the permit, would not be able to renew a permit for the following year.

SUPPLEMENTAL ACTIVITY:

1. Assess the size structure of commercial landings.

Previous and Existing Studies

Currently, data collected from commercial SPL holders include number of trips, pounds of each species or species grouping landed, the area (zone) from where the fish was landed, the gear

used, and the market value of landings (by species or species group). Currently, there are no data available on the size structure of commercially harvested fish species, although commercial fishers do have to follow FWC commercial fishing regulations, which include minimum size limits for many targeted species.

ACTION ITEMS

a) Develop a list of the potential methods (such as onboard observer, a data recorder present at commercial dealers (fish houses), photo documentation of landings processed by commercial dealers, etc.) listing the advantages and disadvantages of each method. From this list, select the most appropriate and feasible method(s) to be able to measure size structure of commercially landed target species.

b) Using the method selected from Action Item a (above), design a sampling program to assess the size structure of commercially landed target species. The sampling design should include details about sample size, timing and frequency of sampling, and randomization of sampling locations (different commercial dealers). Estimates of the resources (such as staffing, field supplies, etc.) and budget needed to implement the plan should also be included.

c) Implement a program to measure the size structure of commercial landings.

Performance Topic 4: Monitor fishing-related benthic habitat impacts

Summary and Justifications: The FMP recommends the creation of Coral Reef Protection Areas (CRPAs) and a no-trawl zone. The use of traps would be prohibited in CRPAs, thereby protecting sensitive coral species and coral reef habitat from the known harmful effects that traps and trap line can cause to stationary benthic organisms. Among other expected benefits, the no-trawl zone would protect sensitive softbottom and hardbottom habitats, that are utilized by a variety of animals, from trawl-related damage.

Monitoring will be necessary to determine if the anticipated beneficial impacts to the benthic habitats are being realized, using comparisons both across time (*i.e.*, before and after implementation of each restricted-activity zone) and across space (*e.g..*, within a CRPA vs comparable habitat outside a CRPA).

The below-described activities will require additional resources (budget, personnel, expertise etc.). Given the dire state of coral reefs in the park (resulting from several years of intense bleaching and a severe disease outbreak), the monitoring of trap-related impacts to corals within these CRPAs should be considered an essential activity and a high priority. A lack of response from the benthic habitat to the restricted activity zones (CRPAs and/or no-trawl zones) could trigger the need for increased enforcement and education or could suggest that additional factors are affecting habitat health.

Performance Measures: Density of debris (pieces per m2), weight of debris (g per m2), number of debris-related injuries, coral diversity (number of coral species observed), and percent coral cover in implemented CRPAs compared to: a) those same areas before implementation and b) similar habitat outside the CRPAs; total area of trawl-related habitat damage, number of trawl-related habitat injuries, presence and abundance of seagrass community (seagrass, macroalgae, sponge species etc.) in implemented no-trawl zones compared to a) those same areas before implementation and b) similar habitat outside of the no-trawl zones.

ESSENTIAL ACTIVITY:

1. Monitor habitat and debris status in Coral Reef Protected Areas (CRPAs) and comparable unprotected reefs

Previous and Existing Studies

Park divers have conducted a marine debris re-accumulation and impacts study on 14 offshore reefs of the park. In this work, they document the presence, abundance, and weight of debris among different categories of use (*e.g.*, hook and line debris, trap debris, boating debris etc), remove the debris while documenting the injuries and mortalities caused to different categories of sessile benthic fauna (*e.g.*, stony corals octocorals, sponges etc.), and then revisit the sites

annually to measure debris re-accumulation. However, no such work is conducted in any of the shallower sites where the CRPAs have been proposed.

Transects to estimate coral cover and coral diversity have been conducted (as staffing allows) at 12 long-term study sites, which includes 2 reefs (Alina's Reef and Ball Buoy Reef) considered for CRPA designation. Thus, pre-CRPA data on coral diversity and coral cover exist for these two locations.

ACTION ITEMS

a) Conduct periodic sampling of each CRPA to include: removal of all debris, documentation of the source of the debris (*e.g.*, trap-related, food and drink, boating etc.), density of debris, weight of debris, impacts to benthic habitat (*i.e.*, abrasions, deaths etc.), and transects to estimate coral diversity and coral cover. These surveys should be conducted annually, with the first sampling event occurring just prior to the implementation of the CRPAs.

b) Identify comparable (in terms of reef structure, depth, location etc.) control reefs outside the CRPA delineations. Conduct the same periodic sampling of these non-CRPA areas as described above.

SUPPLEMENTAL ACTIVITY:

1. Monitor habitat and trawl injury status in No-Trawl areas and comparable trawled locations.

Previous and Existing Studies

Ault et al. (1997) examined the impacts of roller-frame trawl activity on seagrass beds and sessile invertebrates. They detected impacts to sessile fauna from trawls in hardbottom habitat but not in softbottom (seagrass bed) habitat. The organisms most vulnerable to damage from trawls were the sponge *Ircinia felix* and soft corals in the genus *Pseudoplexaura*.

In unrelated studies, various permitted researchers have conducted (or continue to conduct) benthic transects to assess the seagrass community in various parts of Biscayne Bay.

The park's Habitat Restoration Program (HRP) responds to boat groundings in seagrass habitat and conducts seagrass habitat assessments, restoration, and long-term monitoring at these grounding sites. They currently do not respond to or restore seagrass habitat affected by trawling.

There are no current data related to the presence or size of trawl-related impacts to benthic habitat within BISC.

ACTION ITEMS

a) Conduct periodic sampling within the no-trawl zone(s). Each sampling should include documentation of number of trawl injuries and size (area) of each injury and seagrass community characterization (presence and abundance of different species of seagrass, macroalgae, sponges etc.). Sampling should be conducted annually, with the first sampling event occurring just prior to the implementation of the no-trawl zone(s). The seagrass community composition must be done through in-water techniques while the trawl injury assessment could be conducted either through in-water methods or through low-altitude aerial imagery.

b) Identify comparable (in terms of habitat structure, depth, location etc.) control habitat outside of the no-trawl zone(s) where trawling can occur. Conduct the same periodic sampling as described above within these trawled areas.

Performance Topic 5: Research to inform interpretation of responses of targeted species to regulatory changes

Summary and Justifications: The goal of the FMP is to increase the sizes and abundances of targeted species by 20% over baseline values. Changes to the existing fishing regulations will be the means to achieve this goal. Determining if this goal has been met is, however, not an easy feat, as the presence, abundances, and size structures of these targeted species are affected by much more than fishing pressure and changes in fishing regulations. The NPS and FWC must exercise caution in misinterpreting or over-interpreting results of the monitoring efforts and should, when possible, seek to obtain additional information on the distributional, reproductive and ecological patterns of these targeted species so that population trends can be assessed in light of this additional information. More research is needed to better understand the home-range, seasonal movements, and ontogenetic habitat shifts of many of the targeted species within and around BNP. There is a possibility that some species undergo habitat shifts to deeper waters as they grow, and since BNP's eastern boundary is the continuous 60-foot depth contour, it is possible that larger individuals from some species may not be expected to occur within the park, regardless of the level of protection from fishing. Moreover, the proliferation of the non-native Indo-Pacific lionfish could be negatively affecting natural occurrences, abundances, and sizes of native species through predation and competition. Lastly, reproduction and larval dispersal need to be better evaluated in order to improve our understanding of connectivity of BNP individuals to those from upstream and downstream areas.

Given that each of these below-described activities will require considerable levels of additional resources (budget, personnel, expertise etc.), each of these activities is considered supplemental and could be implemented as the required resources become available. Some of the below-proposed activities should be deemed a higher priority than others, as their findings could help managers better understand the response (or lack thereof) of targeted species to regulations implemented under the FMP. A lack of response to regulations by some species will trigger the need for additional research.

Performance Measures: Distributional patterns (by habitat, depth, etc.) of targeted species; movement patterns of targeted species; home range sizes of targeted species; spawning aggregation locations (if present) and spawning behaviors of targeted species; seasonal migration patterns of targeted species; impacts of lionfish on native species patterns; seasonal estimates of size, density, and frequency of occurrence of targeted reef fish; seasonal estimates of CPUE, HPUE, and average size of recreationally landed fish; size, density, and frequency of occurrence of targeted reef fish in seagrass habitats; egg production and reproductive potential of targeted species; larval dispersal and recruitment of target species.

SUPPLEMENTAL ACTIVITIES

1. Research the immigration and emigration of targeted species into and out of BNP utilizing telemetry and other approaches.

Understanding the movement patterns of targeted species can guide the interpretation of occurrence and abundance results for many of the studies described under Performance Topic 1. Whenever possible, information obtained should consider spawning behaviors (including locations of active and historic spawning locations in the area) and spawning frequency and timing.

Previous and Existing Studies

Previous and existing studies examining the movement patterns of targeted species within and outside of BNP have focused on gamefish, primarily bonefish and tarpon.

Larkin et al. (2008) utilized anchor tags across South Florida (including but not limited to BNP) and acoustic telemetry within BNP to examine movement patterns of bonefish. The anchor tagging studies resulted in 4% (331) of the 8,340 tagged bonefish being recaptured. Most observed bonefish movements were less than 20km in distance, and 45% of recaptured fish were recaptured at their original tagging location (suggesting little to no movement). The acoustic telemetry portion of the study elucidated that while bonefish move around quite a bit, they still show a high degree of site fidelity (Larkin 2011, Larkin et al. 2008).

Hammerschlag et al. (2012) compared movement patterns of bull sharks and tarpon from South Florida waters, including BNP waters. They found that tarpon preferred estuarine and riverine regions, and only occasional forayed into deeper marine waters, and furthermore, that that tarpon moved at relatively high speeds and in directed lines when moving through deep waters with high shark abundance, but moved at much slower speeds and in tortuous patterns when (presumably) foraging in shallow, structurally-complex areas (Hammerschlag et al. 2012).

Data on the movement patterns of targeted reef fish species, such as snappers, hogfish, and groupers, within BNP are unavailable, although some studies of movement patterns of these species have been conducted elsewhere in Florida (Feeley et al. 2010, Farmer & Ault 2011, Feeley et al. 2018).

ACTION ITEMS

a) Utilize acoustic telemetry methodologies to elucidate the movement patterns of large snappers (such as the mutton snapper), groupers, and hogfish within and across BNP boundaries. Studies should be designed so as to understand individual movement patterns (distances moved, habitats covered, home range sizes) and group dynamics (such as spawning aggregations, seasonal migration patterns, schooling behaviors). Estimates of the resources (such as staffing, field supplies, etc.) and budget needed to implement the plan should also be developed.

2. Investigate seasonal changes in size, density, and frequency of occurrence of reef fish populations.

Many fishermen anecdotally report that some species, particularly grouper, move across depths and habitats in response to changes in water temperatures throughout the year. If such seasonal movements do occur, a seasonal component to the RVC could be very beneficial for being able to detect and document seasonal shifts. Adding seasonal monitoring would require obtaining comparable numbers of samples in each season (summer and winter). Comparisons between summer and winter observations can determine if the reef fish community changes seasonally.

Previous and Existing Studies

The current multi-agency RVC effort generally occurs between May and October, when sea state and visibility are most amenable to conducting underwater surveys. Winter surveys are not currently completed for the RVC effort. Using a roving-diver method instead of a stationary diver point, Kellison et al. (2011) did not find any seasonal differences in the frequency of occurrences of reef fish on shallow (<40 feet depth) reefs within BNP. Additionally, the ongoing BNP creel survey occurs year-round (weather permitting), and thus provides a second source of data to examine differences in landings of targeted reef fish species.

ACTION ITEMS

a) Design an adequate sampling plan to expand the current RVC to include a winter season. The sampling design should include details on the sample size (ensuring a sample size large enough to be able to make statistically meaningful comparisons between seasons) and stratification of sites by reef habitat type. Estimates of the resources (such as staffing, field supplies, etc.) and budget needed to implement the plan should also be included. During winter months, weather and sea conditions are often not ideal for underwater work, so the window of opportunity for sampling is much reduced during the winter season. Thus, divers might have to take advantage of whatever decent dive days are available, and extend the time required in the field to maximize the number of samples that can be obtained. Visibility is often reduced during the winter months too, so the diameter of the sample cylinder for the RVC survey may need to be reduced, with this reduced sample area accounted for in the analyses).

b) Implement a winter seasonal RVC survey program.

c) Compare data on density, frequency of occurrence, and average size of targeted species from summer and winter RVC survey data.

d) Analyze the BNP creel survey database to determine if there are seasonal (summer vs. winter) differences in CPUE, HPUE and average size of landed species.

e) Compare RVC data to creel data to see if seasonal patterns overlap.

3. Research the habitat and depth utilization patterns associated with different life history stages of targeted species.

BNP provides a variety of habitat types, including patch reef, spur-and-groove reef, reef terrace, rubble, seagrass, mangroves and sand habitats. Furthermore, the water depth in BNP generally increases from west to east, with the eastern boundary of the park located along the contiguous 60-foot depth contour. Many reef species are known to undergo ontogenetic habitat shifts, with early life stages being spent in mangrove and/or seagrass habitats, followed by a transition to deeper reef habitats (Chittaro et al. 2005, Dahlgren & Eggleston 2005).

Additionally, utilization of habitats and depths may vary seasonally, in response to factors such as water temperatures or timing of spawning. Understanding habitat and depth utilization patterns as a function of life history stage and season will guide interpretation of results of data on the distribution and sizes of fish species from different areas of the park.

Previous and Existing Studies
The ongoing RVC surveys within BNP include the collection of abiotic information (including basic habitat characterization data and water depth) and biotic data (including abundances and sizes of each species). However, there are, to date, no published studies utilizing these data to examine the depth utilization patterns of different species and life history stages within BNP. Additionally, these surveys are, by design, restricted to hardbottom habitats and do not include surveys of other habitat types.

ACTION ITEMS
a) Utilize existing RVC data to analyze depth and habitat utilization patterns of different life history stages of targeted reef species.

b) Utilize data collected from seasonal RVC surveys (if completed, as described in "Investigate seasonal changes in size, density, and frequency of occurrence of reef fish populations") to explore if depth and habitat utilization patterns vary seasonally.

c) Utilize tagging data (if completed, as described above in "Research the immigration and emigration of targeted species into and out of BNP utilizing telemetry and other approaches" above) in concert with habitat and bathymetry maps to better understand the depth and habitat utilization patterns of targeted species.

4. Examine seagrass habitat utilization patterns of reef fish species.

Reef fish species, especially juveniles, can utilize seagrass habitats as their preferred feeding grounds (see Hammerschlag & Serafy 2010, and references therein). Information about reef fish species distribution and abundance patterns in seagrass beds may be an early indicator of the status of reef fish species.

Previous and Existing Studies
In a study designed to describe the spatial patterns of faunal community composition and species abundance in relation to salinity in the shallow, nearshore habitats of southern Biscayne Bay, Kieckbush et al. (2013), using rollers trawls and throw traps in nearshore seagrass areas, observed very low abundances of reef-associated species, such as snappers, grunts, and parrotfish, in the seagrass of Biscayne Bay. Published studies using visual approaches to specifically examine the presence, abundance, and/or size-structure of juvenile reef fish species, or fish species in general, in seagrass habitats of BNP were not available.

Hammerschlag & Serafy (2010) used seine nets to assess nocturnal species movements from mangroves to seagrass within Biscayne Bay. Using this method, they examined patterns of movement for juvenile stages of various fish species, including some that are reef-associated as adults. Nocturnal species movements varied by species and season.

ACTION ITEMS
a) Determine the most appropriate method (such as visual surveys, throw traps, trawls etc.) to assess the density, frequency of occurrence, and average size of targeted reef fish species in seagrass habitats. Studies to assess the abundance and size structures of fish species in seagrass meadows of BNP should adopt widely accepted methodologies for sampling this habitat type.

b) Design a seagrass survey program to census reef fish species utilizing seagrass habitat. The sampling design should include details on the sample size, frequency and timing of sampling, and stratification by seagrass habitat types (for examples, sparse vs. dense, coastal, bay, vs. offshore seagrass beds). Estimates of the resources (such as staffing, field supplies, etc.) and budget needed to implement the plan should also be included.

c) Implement a seagrass survey program to census reef fish species utilizing seagrass habitat.

5. Assess reproductive potential of exploited species by evaluating egg production, larval dispersal, and recruitment.

Reduced reproductive success may be one factor challenging the long-term sustainability of many targeted species. Fishing mortality, particularly fishing activity that selectively targets larger individuals and truncates the population (Ault, Smith & Tilmant, 2007) can have significant impacts on species that are long-lived with delayed onset of sexual maturity, species that undergo ontogenetic gender changes, or species that rely on spawning aggregations for reproductive success. Furthermore, because the larval stage for many targeted species can last weeks to months, larvae produced in BNP might likely not be retained there, and early-stage individuals recruiting to BNP are likely coming from upstream sources. Drifter studies are useful for simulating larval transport and exploring patterns of larval dispersal.

Previous and Existing Studies
Plankton tows and hydrographic studies were made in Biscayne Bay and Card Sound to determine the numbers and kinds of larval fishes occurring at various locations, in different seasons, and in a variety of habitats (de Sylva 1976). Studies at a single station in Biscayne Bay examined temporal characteristics of ichthyoplankton patchiness, as well as variability and

seasonality of food sources for ichthyoplankton (Houde & Lovdal 1982, Houde & Lovdal 1984, Houde & Lovdal 1985).

In 2012, Dr. Evan D'Alessandro used light traps and channel nets to collect late-stage lionfish from the vicinity of Ball Buoy Reef. Since collections were focused on the invasive lionfish, information about native larvae was not provided to the park.

In 2017, Laura Bracken conducted portions of the Biscayne Bay Drift Card Study within park waters. In this study, 72 bio-degradable wooden drift cards were released within BNP. All together, only one (1.3%) of these 72 cards was ever retrieved (compared to a 7% retrieval rate for cards released at other sites). The low retrieval rate was attributed to outgoing tides carrying the cards out to sea and the lack of beaches and easily-accessible coastal areas where visitors could encounter washed-ashore drift cards. The study has continued in 2018, but results are not yet available.

ACTION ITEMS

a) Develop a list of potential methods (such as plankton tows, light traps, fin clip, gonad biopsies, and otolith sampling from recreationally harvested specimens, etc.) that could be used to assess egg production and reproductive potential (such as condition and fecundity) of targeted species. From this list, select the most appropriate and feasible method(s) to be able to assess egg production and reproductive potential of targeted species.

b) Develop a list of potential methods (such as plankton tows, light traps, drift card releases (see Klinger & Ebbesmeyer (2001) that could be used to assess targeted species' larval dispersal and recruitment. From this list, select the most appropriate and feasible method(s) to be able to assess larval dispersal and recruitment.

c) Design sampling programs for both Action Item a and Action Item b above. Each sampling program design should consider details such as spawning seasonality, spawning frequency, historic and current spawning aggregation locations within and outside the park when developing plan specifics such as sample size, timing/seasonality/frequency of sampling, locations (bay, inshore, offshore) of sampling, and use of a stratified random sample approach to determine where to sample. Estimates of the resources (such as staffing, field supplies, etc.) and budget needed to implement each plan should also be included.

d) Implement the programs to assess i) egg production and reproductive potential (for examples, condition, fecundity) of targeted species and ii) targeted species' larval dispersal and recruitment.

6. Research the impacts of the invasive Indo-Pacific lionfish on targeted species abundance and distribution.

Lionfish are noted for their voracious appetite, lack of natural predators, and high fecundity, all of which allow them to thrive in their invaded environment (Morris and Whitfield 2009). Lionfish have been documented to cause significant declines in the recruitment of native reef species (Albins & Hixon, 2008). The presence of the highly invasive Indo-Pacific Lionfish (*Pterois volitans/miles*) within the park was first documented by park staff in 2009. Since then,

park biologists have observed lionfish increasing in abundance, size, and distributional range. Lionfish have now been observed in just about every habitat type within the park, from coastal mangroves to deep ledges, although they are far more common in hardbottom habitats and artificial habitats (such as shipwrecks) than in softbottom habitats like seagrass meadows and mangrove coastlines (BNP unpublished data).

Previous and Existing Studies

Within BNP, numerous lionfish studies have been conducted or are currently underway. Park staff assessed the abundance and sizes of lionfish from 300 randomly-selected hardbottom sites and found that lionfish are far more numerous in deeper reef sites (sites along the park's eastern boundary) than in shallower hardbottom sites elsewhere throughout the park (BNP unpublished data). Furthermore, a significant relationship between lionfish size and depth has been confirmed (BNP unpublished data). In his independent research project, park intern Michael Hoffman found that post-removal recolonization rates by lionfish on natural reef sites increased with depth (M Hoffman unpublished data). From a micro-habitat perspective, lionfish are most commonly observed immediately adjacent to a ledge or hard substrate, and are only rarely associated with biotic relief, sand or a benthic depression (BNP unpublished data). Gut content analyses on lionfish collected from BNP have shown a dietary shift from a crustacean-based diet to a fish-based diet with increasing lionfish size (Sancho et al., 2018).

Two separate but similar studies examining ecological impacts of lionfish and management implications were recently completed at the park. Both studies compared control sites, where lionfish were not removed, to treatment sites, where lionfish were actively removed. Dr. Stephanie Green and colleagues are using this study approach to develop an effective method for setting quantitative lionfish removal targets within priority areas and estimates of the resources required to achieve removal. Drs. Chris Stallings and Mark Albins (University of South Florida) partnered with BNP biologists to examine impacts to native fish species and the frequency at which lionfish removals should be conducted in order to minimize impacts to native reef assemblages. Their preliminary findings suggest that frequent removal efforts are needed to reduce lionfish populations and that sporadic events such as "lionfish derbies" will likely not significantly affect the number of lionfish in BNP (SeaGrant 2016)

ACTION ITEMS

a) Utilizing published results and unpublished data from above-described studies, as well as any newly designed projects, generate an estimate of lionfish population size within BNP.

b) Utilizing published results and unpublished data from above-described studies, as well as ongoing RVC data and any newly designed projects, generate qualitative and/or quantitative estimates of ecological impacts of lionfish on native reef fish species, such as estimating the number of targeted fish species lost annually to lionfish predation, or identifying correlative patterns between lionfish occurrences/sizes and the occurrences/sizes of targeted reef species.

Performance Topic 6: Development of new monitoring programs for under-studied species

Summary and Justifications: There is a noticeable lack of basic fishery-independent data for those targeted species that utilize reef habitat minimally (if at all), and/or are not amenable to being accurately assessed through the stationary diver method used in the RVC. As a result, data needed to assess baseline conditions and monitor long-term changes are deficient. New approaches are needed to monitor those targeted species that utilize primarily non-reef habitats and/or which might not be properly assessed through the stationary diver method used in the RVC.

Performance Measures: abundance (possibly using density *and* frequency of occurrence as proxies) and size structure for each of the listed species

1. Develop and implement fishery-independent monitoring of blue crab and stone crab.

Previous and Existing Studies

No current records of fishery-independent stone crab monitoring could be located. The only studies found were Bert et al. (1983) and Bert et al. (1986). Those studies collected one year of data from BNP and Everglades National Park to document the life history patterns of stone crab in these areas. The findings for stone crab life history patterns in BNP suggest that stone crabs are not locally recruited and the population may be sustained by immigration from outside the park.

No records of any fisheries independent studies or monitoring projects for blue crab within and/or around BNP could be located. An unpublished study conducted by FWRI scientists in the 1980's found that adult blue crabs tagged in waters south of BNP in Barnes Sound and Manatee Bay routinely migrated northward into BNP and beyond.

ACTION ITEMS

a. Develop a list of potential fishery-independent methods to assess blue crabs and stone crabs. From this list, select the most appropriate and feasible method(s) to be able to monitor each species.

b. Design a sampling program for each species. As each species has unique life cycle, habitat utilization, and mode(s) of detectability considerations, each species should be studied independently of the other. Expert advice and opinions will be needed to ensure development of appropriate fishery-independent means to monitor these species. Each sampling design should include details on the sample size, frequency and timing of sampling, and randomization and

stratification of sampling across habitat types. Estimates of the resources (such as staffing, field supplies, etc.) and budget needed to implement each plan should also be included.

c. Implement sampling programs to monitor blue crabs and stone crabs.

2. Develop and implement fishery-independent monitoring of cero and great barracuda.

Cero and great barracuda are both only rarely encountered in the reef-based RVC surveys, currently the primary mode of collecting fishery-independent data within BNP. Data on observations of cero and barracuda are available from the RVC database, however records of both species are relatively sporadic. Since there is general consensus among marine scientists that neither species is a true reef-associated species, the RVC approach should not be considered an adequate approach for monitoring either species. Therefore, different fishery-independent methodologies should be employed to adequately monitor cero and barracuda.

Previous and Existing Studies

Serafy et al. (2003) explored patterns of shoreline fishes (abundance and sizes) along mainland and island shorelines. They found no difference in barracuda sizes between the two shoreline types. In a study examining mangrove use by barracuda that focused on seasonal patterns in terms of density, concentration, and selection (if available habitat was utilized), Faunce & Serafy (2008) reported that barracuda density was higher in the wet season than in the dry season. During the wet season, barracuda favored mangroves adjacent to islands over mangroves along the mainland shoreline. Barracuda showed random habitat use during the dry season.

Hammerschlag & Serafy (2010) used seine nets to monitor early juvenile barracuda and other species, although their work was confined to the nocturnal movement patterns along a continuous distance gradient from mangroves across adjacent seagrass habitat. They found that early juvenile barracuda density decreased with distance from the mangrove shoreline in the dry season but was fairly uniform along that distance gradient in the wet season.

Other than the RVC surveys, we could find no published studies utilizing fishery-independent means to examine the presence, abundance, or size structure of cero within and/or around BNP.

ACTION ITEMS

a. Develop a list of potential methods to conduct fishery-independent monitoring of great barracuda and cero. Options should include the methods used by Serafy et al. (2003) and Faunce and Serafy (2008). From the list, select the most appropriate and feasible method(s) to monitor great barracuda and cero, keeping in mind that a combination of visual surveys and collection (via seining or trawling) methodologies may be most appropriate.

b. Design a sampling program for monitoring great barracuda and cero. Expert advice and opinions will be needed to ensure development of sound fishery-independent means to adequately monitor these two species within BNP. Whether the two species could be co-

monitored using the same plan or if each species warrants its own sampling plan needs to be determined. The sampling plan(s) should include details on the sample size, frequency and timing of sampling, and randomization and stratification of sampling across habitat types. Estimates of the resources (such as staffing, field supplies, etc.) and budget needed to implement the plan(s) should also be included.

c. Implement sampling program(s) to monitor great barracuda and cero.

3. Develop and implement fishery-independent monitoring of gamefish species (tarpon, permit, bonefish).

Gamefish are not reef-associated species and thus are not typically encountered during RVC surveys, currently the primary mode of collecting fishery-independent data within BNP. These gamefish species will require completely different approaches to obtain accurate estimates of their distribution, abundances, and size structures within BNP.

Previous and Existing Studies

Fishery-dependent data on these gamefish are available (see Performance Topic 3), but limited in scope since the large majority of fishing for these species is catch-and-release in nature. Fishery-independent studies specifically focusing on bonefish, permit and/or tarpon within and around BNP are noticeably lacking. The Bonefish and Tarpon Trust (BTT) sampled mangrove shorelines, seagrass beds, and rocky shorelines in numerous areas, including (but not limited to) the Florida Keys and South Florida (BTT unpublished data). After tagging more than 10,000 juvenile bonefish, the BTT found that more than 95% of the tagged individuals represented the Bigeye Bonefish (*Albula goriensis*), not the Common Bonefish (*A. vulpes*), which is the species that supports the local fishery. Thus, very little is known about the presence and distribution of the targeted *A. vulpes*, and different methods to assess this and other targeted gamefish species must be considered.

ACTION ITEMS

a. Develop a list of potential methods to conduct fishery-independent monitoring of gamefish species (tarpon, permit, bonefish). From the list, select the most appropriate and feasible method(s) to monitor gamefish, keeping in mind that a combination of visual surveys and collection (via seining, trawling) methodologies may be most appropriate.

b. Design a sampling program for monitoring gamefish. Expert advice and opinions will be needed to ensure development of sound fishery-independent means to adequately monitor these species within BNP. Whether the three species could be co-monitored using the same plan or if each species warrants its own sampling plan needs to be determined. The sampling plan(s) should include details on the sample size, frequency and timing of sampling, and randomization and stratification of sampling across habitat types. Estimates of the resources (such as staffing, field supplies, etc.) and budget needed to implement the plan(s) should also be included.

c. Implement sampling program(s) to monitor gamefish species (tarpon, permit, bonefish).

Schedule of Deliverables

Because many of the species being monitored are slow-growing, long-lived fish that have long generation times and that have been under considerable fishing pressure for some time, we recommend that a full assessment of the efficacy of implementation of FMP-related actions will require six years of sampling. To that end, an interim status report will be provided after three years of sampling and the full assessment after six years of sampling. Based on the expected effective date of July 1, 2020 for the new Biscayne National Park fishing regulations, the delivery dates for these reports will be:

Interim Report deliverable due date: April 1, 2023
Full Assessment Report deliverable due date: April 1, 2026

Each report will provide a detailed summary of each monitoring activity described in this science plan. At a minimum, the summary for each monitoring activity should include:

- the activity status (ongoing, complete, not initiated (and reason for not being initiated, such as if adequate funding or staffing was unavailable),
- a comparison of baseline and post-implementation values for the metrics associated with the activity,
- as applicable, a determination of whether or not the 20% benchmark (as listed in Tables 2-4) has been met, and if it was determined to have been met in a previous status report, if the benchmark was maintained through the next three-year time period,
- recommendations for adaptive management (additional regulatory changes) to address any instances where the 20% goal was not met, and,
- determination of need for continued monitoring, and/or if alterations to the scope or methods utilized are suggested.

Literature Cited

Aiken, K.A., J. Dooley, J. Marechal, F. Pina Amargos, B. Russell, and S. Singh-Renton. 2015. *Sphyraena barracuda* (errata version published in 2017). The IUCN Red List of Threatened Species 2015: e.T190399A115319634. http://dx.doi.org/10.2305/IUCN.UK.2015-4.RLTS.T190399A15603115.en. Downloaded on 12 April 2018.

Albins, M. A., & M.A. Hixon. 2008. Invasive indo-pacific lionfish *Pterois volitans* reduce recruitment of Atlantic coral-reef fishes. *Marine Ecology Progress Series, 367,* 233 - 238.

Allen, G.R. 1985. Snappers of the World: An Annotated and Illustrated Catalogue of Lutjanid Species Known to Date. FAO Fisheries Synopsis. Food and Agriculture Organization of the United Nations, Rome, Italy.

Araújo, J.N. de, A.G. Martins and K.G. da Costa, 2002. Idades e crescimento da cioba, *Ocyurus chrysurus*, da Costa Central do Brasil. Rev. Bras. Oceanogr. 50(1): unpaged.

Ault, J., Bohnsack, J. and G. Meester. 1998. A retrospective (1979-1996) multispecies assessment of coral reef fish stocks in the Florida Keys. Fisheries Bulletin 96(3): 395-414.

Ault, J., J. Serafy, D. DiResta, and J. Dandelski. 1997. Impacts of Commercial Fishing on Key Habitats within Biscayne National Park. Annual Report on Cooperative Agreement No. CA-5250-6-9018.

Ault, J.S., Smith, S.G., and Bohnsack, J.A. 2005. Evaluation of average length as an estimator of exploitation status for the Florida coral-reef fish community. *ICES Journal of marine Science*, 62(3):417-423

Ault, J.S., S.G. Smith, D.B. McClellan, N. Zurcher, E.C. Franklin, and J.A. Bohnsack. 2008. An Aerial Survey Method for Estimation of Boater Use in Biscayne National Park during 2003-2004. NOAA Technical Memorandum NMFS-SEFSC-577. 87 p.

Ault, J.S., S.G. Smith, GA Meester, J Luo, and JA Bohnsack. 2001. Site Characterization for Biscayne National Park: Assessment of Fisheries Resources and Habitats. NOAA Technical Memorandum NMFS-SEFSC-468. 156 pp.

Ault, J.S., S.G. Smith, J.M. Manges, D. Bryan, and J. Luo. 2017. Aerial park and field marine surveys to estimate boater use within Biscayne National Park, 2016-2017. University of Miami, Rosenstiel Schools of Marine and Atmospheric Science. ,FL USA

Ault, J.S., S.G. Smith, and J.T. Tilmant. 2007. Fishery management analyses for reef fish in Biscayne National Park: Bag & size limit alternatives. Final report to the National Park Service.

Bert, T.M., J. Dodrill, G.E. Davis, and J.T. Tilmant. 1983. The population dynamics of the stone crab (*Menippe mercenaria*) in Everglades and Biscayne National Parks. Florida Scientist. 46(Suppl. 1):24.

Bert, T.M., J.T. Tilmant, J. Dodrill, and G.E. Davis. 1986. Aspects of the population dynamics and biology of the stone crab (*Menippe mercenaria*) in Everglades and Biscayne National Parks as determined by trapping. SFRC 86/04. South Florida Research Center, Everglades National Park, Homestead, FL. 77 pp.

Blackhart, K, D.G. Stanton, and A.M. Shimada. 2006. NOAA Fisheries Glossary, Revised Edition. NOAA Technical Memorandum NMFS-F/SPO-69.

Blue Ocean Institute 2018. http://blueoceaninstitute.com/seafood/species/147.html. Downloaded April 18, 2018.

Bohnsack, J.A. and S.P. Bannerot. 1986. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes. NOAA Technical Report NMFS 41, 15p.

Brandt, M.E., N. Zurcher, A. Acosta, J.S. Ault, J.A. Bohnsack, M.W. Feeley, D.E. Harper, J.H. Hunt, T. Kellison, D.B. McClellan, M.E. Patterson, and S.G. Smith. 2009. A cooperative multi-agency reef fish monitoring protocol for the Florida Keys coral reef ecosystem. Natural Resource Report NPS/SFCN/NRR—2009/150. National Park Service, Fort Collins, Colorado.

Bryan, D.R., A.J. Atkinson, J.S. Ault, M.E. Brandt, J.A. Bohnsack, M.W. Feeley, M.E. Patterson, B.I. Ruttenberg, S.G. Smith, and B.D. Witcher. 2013. A cooperative multiagency reef fish monitoring protocol for the U.S. Virgin Islands coral reef ecosystem. Natural Resource Report NPS/SFCN/NRR—2013/672. National Park Service, Fort Collins, Colorado.

Burton, M.L. 2001. Age, growth, and mortality of gray snapper, *Lutjanus griseus*, from the east coast of Florida. Fish. Bull. 99:254–265

Burton, M.L. 2002. Age, growth and mortality of mutton snapper, *Lutjanus analis*, from the east coast of Florida, with a brief discussion of management implications. Fish. Res. 59(1-2):31-41.

Burton, M.L., J.C. Potts, J. Page, and A. Poholek. 2017. Age, growth, mortality and reproductive seasonality of jolthead porgy, *Calamus bajonado*, from Florida waters. PeerJ, 5, e3774. http://doi.org/10.7717/peerj.3774

Butler, M., A. Cockcroft, A. MacDiarmid, and R.Wahle. 2011. *Panulirus argus*. The IUCN Red List of Threatened Species 2011: e.T169976A6697254. http://dx.doi.org/10.2305/IUCN.UK.2011-1.RLTS.T169976A6697254.en. Downloaded April 12, 2018.

Capote, A.M., 1971. About the age of the main industrial bottom-dwelling fishes of Campeche Bank. Soviet-Cuban fish industry researches 3:77-81.

Chávez, E.A. 2001. Policy Design for Spiny Lobster (*Panulirus argus*) Management at the Meso-American Barrier Reef System. Crustaceana 74: 1119-1137.

Chittaro, P.M., P. Usseglio, and P. Sale. 2005. Variation in fish density, assemblage composition and relative rates of predation among mangrove, seagrass and coral reef habitats. Environmental Biology of Fishes 72:175-187

Claro, R., & K.C. Lindeman. 2008. Biología y manejo de los pargos (Lutjanidae) en el Atlántico Occidental. La Habana: Instituto de Oceanología.

Claro, R., K.C. Lindeman, and L.R. Parenti. 2001. Ecology of the marine fishes of Cuba. Smithsonian Institution Press, Washington, USA.

Cox, C. and J. Hunt. 2005. Change in size and abundance of Caribbean spiny lobsters *Panulirus argus* in a marine reserve in the Florida Keys National Marine Sanctuary. Marine Ecology Progress Series 294:227-239.

Crabtree, R.E. and L.H. Bullock. 1998. Age, growth, and reproduction of black grouper, *Mycteroperca bonaci*, in Florida waters. Fishery Bulletin 96:735-753

Dahlgren, C.P. and D.B. Eggleston. 2000. Ecological processes underlying ontogenetic habitat shifts in a coral reef fish. Ecology 81: 2227–2240

de Sylva, D.P. 1976. Ecology and distribution of larval fishes of Biscayne Bay, Florida. Prepared for the EPA Office of Research and Monitoring. Project R 800996-03, Program Element 1B1022; EPA-000/0-00-000. Rosenstiel School of Marine and Atmospheric Science, University of Miami, Miami, FL. 412 pp.

Ehrhardt, N.M. 2005. Population Dynamic Characteristics and Sustainability Mechanisms in Key Western Central Atlantic Spiny Lobster, *Panulirus Argus,* Fisheries. Bulletin of Marine Science 76(26): 501-526.

Farmer, N.A. and J.S. Ault. 2011. Grouper and snapper movements and habitat use in Dry Tortugas, Florida. Marine Ecology Progress Series. 433: 169–184

Faunce, C. and J. Serafy. 2008. Selective use of mangrove shorelines by snappers, grunts, and great barracuda. Marine Ecology Progress Series. 356: 153–162

Feeley M., A. Acosta, T. Switzer, J. Hunt, P. Barbera, D. Morley, M. Burton & M. Patterson. 2010. Spawning Aggregations and Migration Patterns of Mutton Snapper in Dry Tortugas, Florida. Linking Science to Management: A Conference and Workshop on the Florida Keys Marine Ecosystem. 2010.

Feeley, M., D. Morley, A. Acosta, P. Barbera, J. Hunt, T. Switzer, and M. Burton. 2018. Spawning migration movements of Mutton Snapper in Tortugas, Florida: Spatial dynamics within a marine reserve network. Fisheries Research 204, 209-223.

Ferreira, B.P., L. Rocha, A.L.B. Gaspar, Y. Sadovy, M. Craig. 2008. *Mycteroperca bonaci*. The IUCN Red List of Threatened Species 2008: e.T132724A3433339 http://dx.doi.org/10.2305/IUCN.UK.2008.RLTS.T132724A3433339.en. Downloaded April 12, 2018.

Fluech B. 2013. Stone Crabs…Did you Know? http://flseagrant.ifas.ufl.edu/newsletter/author/bryan-fluech/page/2/. Downloaded April 18, 2018

Garcia-Moliner, G. & A.M. Eklund (Grouper & Wrasse Specialist Group). 2004. *Epinephelus morio*. The IUCN Red List of Threatened Species 2004: e.T44681A10923778 http://dx.doi.org/10.2305/IUCN.UK.2004.RLTS.T44681A10923778.en. Downloaded April 12, 2018.

Gerhart, S.D. and T.M. Bert. 2008. Life-History Aspects of Stone Crabs (Genus Menippe): Size at Maturity, Growth, and Age. Journal of Crustacean Biology. 28(2): 252-261

Gold, J.R., E. Saillant, N.D. Ebelt, and S. Lem. 2009 Conservation Genetics of Gray Snapper (Lutjanus griseus) in U.S. Waters of the Northern Gulf of Mexico and Western Atlantic Ocean Copeia 2009, No. 2

Hammerschlag, N. and J.E. Serafy. (2010), Nocturnal fish utilization of a subtropical mangrove-seagrass ecotone. Marine Ecology, 31: 364–374.

Hammerschlag, N., J. Luo, D.J. Irschick, and J.S. Ault. 2012. A comparison of spatial and movement patterns between sympatric predators: bull sharks (Carcharhinus leucas) and Atlantic tarpon (Megalops atlanticus). PLOS ONE 7(9): 1-14.

Harper, D.E., J.A. Bohnsack, and B.R. Lockwood. 2000. Recreational Fisheries in Biscayne National Park, Florida, 1976 – 1991. Marine Fisheries Review 62(1): 8 – 26.

Hines, A.H., E.G. Johnson, M.Z. Darnell, D. Rittschof, T.J. Miller, L.J. Bauer, P. Rodgers, and 109 R. Aguilar. 2010. Predicting Effects of Climate Change on Blue Crabs in Chesapeake Bay. In: G.H. Kruse, G.L. Eckert, R.J. Foy, R.N. Lipcius, B. Sainte-Marie, D.L. Stram, and D. Woodby (eds.), Biology and Management of Exploited Crab Populations under Climate Change. Alaska Sea Grant, University of Alaska Fairbanks. doi:10.4027/bmecpcc.2010.22

Houde, E.D., and J.D.A. Lovdal. 1982. Variability in ichthyoplankton and microzooplankton abundances and feeding by fish larvae in Biscayne Bay, Florida. International Council for the Exploration of the Sea, Council meeting 1982/L:521-22.

Houde, E.D., and J.D.A. Lovdal. 1984. Seasonality of occurrence, foods and food preferences of ichthyoplankton in Biscayne Bay, Florida. Estuarine and Coastal Shelf Science. 18(4):403-419.

Houde, E.D., and J.D.A. Lovdal. 1985. Patterns of variability in ichthyoplankton occurrence and abundance in Biscayne Bay, Florida. Estuarine and Coastal Shelf Science. 20(1):79-103.

Ingram, Jr., G.W. 2001. Stock Structure of Gray Triggerfish, *Balistes capriscus*, on multiple spatial scales in the Gulf of Mexico. Department of Marine Science, University of South Alabama.

Kadison, E., E. D'Alessandro, G.O. Davis, and P.B Hood. 2010. Age, Growth, and Reproductive Patterns of the Great Barracuda, *Sphyraena barracuda*, from the Florida Keys. Bulletin of Marine Science 86(4): 773-784.

Kellison G.T., V.L. McDonough, D.E. Harper, J.T. Tilmant. 2011. Coral reef fish assemblage shifts and declines in the upper Florida Keys, USA. Bulletin of Marine Science 88(1): 147-182

Kieckbusch, N., J. Roblee, A. Daniels, J. Browder and J. Hall. 2013. Southern Biscayne Bay Nearshore Fish and Invertebrate Community Structure. Downloaded from http://sofia.usgs.gov/projects/comm_dynamics/bbcommstruct_03geerab.html.

Klinger T. and C. Ebbesmeyer. 2001. Using oceanographic linkages to guide marine protected area network design. Puget Sound Research, Puget Sound Action Team, Olympia, WA, 22 pp

Larkin, M.F. 2011. Assessment of South Florida's Bonefish Stock. Open Access Dissertations. Paper 632

Larkin, M.F., J.S. Ault, R. Humston, and J. Luo. (2008). Tagging of bonefish in south Florida to study population movements and stock dynamics. Chapter 19 in Ault, J.S. (ed.) *Biology and Management of the World Tarpon and Bonefish Fisheries.* Taylor and Francis Group. CRC Series on Marine Biology, Volume 9. Boca Raton, Florida. 441 p.

Levesque, J. 2009. Establishment and closure of the directed Florida whiting (*Menticirrhus americanus*) fishery and implications for North Atlantic right whale (*Eubalaena glacialis*) conservation and management. Marine Policy 33(2), 233-247.

Lindeman, K., W. Anderson, K.E. Carpenter, R. Claro, J. Cowan, B. Padovani-Ferreira, L.A. Rocha, G. Sedberry, and M. Zapp-Sluis. 2016a. *Lutjanus analis*. The IUCN Red List of Threatened Species 2016: e.T12416A506350. http://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T12416A506350.en. Downloaded on 12 April 2018.IUCN. http://www.iucnredlist.org/details/summary/12416/25 Downloaded April 12, 2018.

Lindeman, K., W. Anderson, K.E. Carpenter, R. Claro, J. Cowan, B. Padovani-Ferreira, L.A. Rocha, G. Sedberry, and M. Zapp-Sluis. 2016b. *Ocyurus chrysurus*. The IUCN Red List of Threatened Species 2016: e.T194341A2316114. http://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T194341A2316114.en. Downloaded April 12, 2018.

Lindeman, K., W. Anderson, K.E. Carpenter, R. Claro, J. Cowan, B. Padovani-Ferreira, L.A. Rocha, G. Sedberry, and M. Zapp-Sluis. 2016c. *Lutjanus synagris*. The IUCN Red List of Threatened Species 2016: e.T194344A2317059. http://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T194344A2317059.en. Downloaded April 12, 2018.

Lindeman, K., W. Anderson, K.E. Carpenter, R. Claro, J.Cowan, H. Espinosa-Perez, B. Padovani-Ferreira, L.A. Rocha, G. Sedberry, G. and M. Zapp-Sluis. 2016. *Lutjanus apodus*. The IUCN Red List of Threatened Species 2016: e.T155152A726254. http://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T155152A726254.en. Downloaded April 12, 2018.

Lindeman, K., W. Anderson, R. Claro, J. Cowan, B. Padovani-Ferreira, L.A.Rocha, and G. Sedberry. 2016. *Haemulon plumierii*. The IUCN Red List of Threatened Species 2016: e.T190132A1941346. http://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T190132A1941346.en. Downloaded April 12, 2018.

Liu, J., G. Zapfe., K.T. Shao, J.L. Leis, K. Matsuura, G. Hardy, M. Liu, and J. Tyler. 2015. *Balistes capriscus* (errata version published in 2016). The IUCN Red List of Threatened Species 2015: e.T193736A97662794. http://www.iucnredlist.org/details/summary/193736/0. Downloaded April 12, 2018.

Liubimova, T.G. and A.M. Capote, 1971. Características biológicas de la algunas especies comerciales del Banco de Campeche. p. 82-88. En A.S. Bogdanov (ed.) Investigaciones pesqueras soviético-cubanas, Pishevaia Promishliennost, Moscú, vol. 3.

Luckhurst, B.E., J.M. Dean and M. Reichert. 2000. Age, growth and reproduction of the lane snapper *Lutjanus synagris* (Pisces: Lutjanidae) at Bermuda. Marine Ecology Progress Series. 203:255-261.

Manooch, C.S. III, 1987. Age and growth of snappers and groupers. p. 329-373. In J.J. Polovina and S. Ralston (eds.) Tropical snappers and groupers: biology and fisheries management. Ocean Resour. Mar. Policy Ser. Westview Press, Inc., Boulder and London.

McBride, R.S. and A.K. Richardson, 2007. Evidence of size-selective fishing mortality from an age and growth study of hogfish (Labridae: *Lachnolaimus maximus*), a hermaphroditic reef fish. Bulletin of Marine Science. 80(2):401-417.

McDonough, V. 2009. 2004 – 2008 Recreational Fisheries Report for Biscayne National Park

McDonough, V. 2012. A ten-year assessment of lobster mini-season trends in Biscayne National Park, 2002-2011. Natural Resource Technical Report NPS/BNP/NRTR—2012/560. National Park Service, Fort Collins, Colorado.

Morris, J.A. and P.E. Whitfield. 2009. Biology, ecology, control and management of the invasive Indo-Pacific lionfish: an updated integrated assessment. NOAA Technical Memorandum NOS NCCOS, 99, 1-57.

Murray and Bester. 2018. https://www.floridamuseum.ufl.edu/fish/discover/species-profiles/lutjanus-synagris/ Downloaded on April 12, 2018.

O'Hop, J, R.G. Muller, and D.T. Addis. 2015. Stock Assessment of Mutton Snapper (*Lutjanus analis*) of the U.S. South Atlantic and Gulf of Mexico through 2013. FWC Report IHR2014-005

Pauly D. 1978. A preliminary compilation of fish length growth parameters. Ber Inst Meereskd Christian-Albrechts-Univ Kiel. 55:1–200

Pitt, J.M., T.M. Trott, and B.E. Luckhurst. 2009. Bluestriped Grunt (*Haemulon sciurus*) in Bermuda: Age, Growth, and Reproduction Studies. Proceedings of the 62nd Gulf and Caribbean Fisheries Institute. November, 2009. Cumana, Venezuela.

Powell, D. 1975. Age, growth, and reproduction in Florida stocks of Spanish mackerel, *Scomberomorus maculatus*. Florida Marine Research Publications. 5: 1-21.

Sancho, G, P.R. Kingsley-Smith, J.A. Morris Jr, C.A. Toline, V. McDonough, and S.M. Doty. 2018. Invasive Lionfish (*Pterois volitans/miles*) feeding ecology in Biscayne National Park, Florida, USA. Biological Invasions. Published online 20 April 2018, https://link.springer.com/article/10.1007%2Fs10530-018-1705-4. DOI 10.1007/s10530-018-1705-4

Seagrant. 2016. Controlling Invasives: Sea Grant research provides insight into Lionfish Removal Efforts. SGEF 237, November 2016.

SEDAR 9. 2005. Gulf of Mexico Gray Triggerfish *Balistes capriscus*. In: J.S. Nowlis (ed.), Section II. Data Workshop Report. Developed by Data Workshop Panel. SEDAR, Charleston, SC.

Serafy, J, C.H. Faunce, and J. Lorenz. 2003. Mangrove shoreline fishes of Biscayne Bay, Florida. Bulletin of Marine Science. 72(1).

Slipke, J. Wr, and M. J. Maceina. 2001. Fisheries analysis and simulation tools (FAST). Auburn University, Auburn, Alabama.

Van Engel, W.A. 1958. The blue crab and its fishery in the Chesapeake Bay. Part I - Reproduction. early development, growth and migration. Marine Fisheries Review. 20(61:6-17).

Wilson, C.A., D.L. Nieland, and A.L. Stanley. 1995. Age, growth and reproductive biology of gray triggerfish (*Balistes capriscus*) from the northern Gulf of Mexico commercial harvest. Final Report. Coastal Fisheries Institute, Louisiana State University, Baton Rouge, LA.

Yeager, L. A. and J. Arias-Gonzalez. 2008. Preliminary Survey of Fish Community Composition in Seagrass Habitat in Two Back-Reef Lagoons of the Southern Mexican Caribbean. Gulf and Caribbean Research 20 (1): 41-47.

TABLE 5: Summary of Proposed Monitoring and Research Activities

Performance Topic	Activity	Determination of Need
Quantify changes in the abundance and size-structure of targeted species within BNP.	Reef-fish Visual Census Monitoring	Required
	Caribbean Spiny Lobster Assessment	Essential
Monitor changes in recreational fishing patterns within BNP	Recreational creel survey of visitors fishing within BNP	Essential
	Collect, via a logbook system, effort, catch, and landings data from charter boat and guide operations authorized to conduct business within BNP	Essential
	Estimate overall fishing activity in BNP using aerial surveys	Supplemental
Monitor changes in commercial fishing activity within BNP	Utilize existing commercial fishery-dependent monitoring programs to obtain and utilize data on commercially important species	Essential
	Track number of commercial fishers utilizing BNP	Essential
	Assess the size structure of commercial landings	Supplemental
Monitor fishing-related benthic habitat impacts	Monitor habitat and debris status in Coral Reef Protected Areas (CRPAs) and comparable unprotected reefs	Essential
	Monitor habitat and trawl injury status in No-Trawl areas and comparable trawled locations	Supplemental
Research to inform interpretation of responses of targeted species to regulatory changes	Research the immigration and emigration of targeted species into and out of BNP utilizing telemetry and other approaches	Supplemental
	Investigate seasonal changes in size, density, and frequency of occurrence of reef fish populations	Supplemental
	Research the habitat and depth utilization patterns associated with different life history stages of targeted species	Supplemental
	Examine seagrass habitat utilization patterns of reef fish species	Supplemental

	Assess reproductive potential of exploited species by evaluating egg production, larval dispersal, and recruitment	Supplemental
	Research the impacts of the invasive Indo-Pacific lionfish on targeted species abundance and distribution	Supplemental
Development of new monitoring programs for under-studied species	Develop and implement fishery-independent monitoring of blue crab and stone crab	Supplemental
	Develop and implement fishery-independent monitoring of cero and great barracuda	Supplemental
	Develop and implement fishery-independent monitoring of gamefish species (tarpon, permit, bonefish).	Supplemental