

# PNAS

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Supplementary Information for

Recovery of Critically Endangered Nassau Grouper (*Epinephelus striatus*) in the Cayman Islands Following Targeted Conservation Actions

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**This PDF file includes:**

Figures S1  
Tables S1  
SI References

**Other supplementary materials for this manuscript include the following:**

Movies S1 to S2

**Supplementary Information Text**  
**Supplement A.**

**Table S1.** Chronology of fishery and management actions related to the Cayman Nassau grouper fishery made by Caymanian fishermen, Cayman Islands Department of the Environment (CI-DoE), and Cayman Island Marine Conservation Board (CIMCB). The CIMCB is the statutory authority responsible for administration of the Marine Conservation Law. Summary of management actions is largely based on Bush et al, 2006(1).

Year	Action
Early 1900s	Aggregations at eastern end of islands exploited by Caymanians – typically using small open boats and hand lines.
1980s	Caymanian fishermen raise concerns of declining catch of Nassau grouper.
1984 - 1990	Cayman Brac east-end site dormant. Cayman Brac fishing fleet targets east-end FSA of Little Cayman.
1985	General license issues under Restricted Marine Areas (Designation) Regulations allowing take by residents using only hook and line.
1986	Marine protected areas (MPAs) established on all 3 Cayman Islands under Marine Conservation Regulation. Protected 14.8% of all area shore to 150 foot depth.
1987	CI-DoE begins collecting data during spawning season from three main spawning sites, including: catch, catch-per-unit-effort, size, and age.
1990	Southwest FSA site on Grand Cayman abandoned by Caymanian fishermen.
1991	FSA found 1.2km north of dormant Cayman Brac site, and is heavily fished.
1992	CI-DoE validates aging technique for Nassau grouper with oxytetracycline study (2).
1993	Caymanian fishermen abandon the east-end Little Cayman site when the aggregation ceases to form.
1995	Recommendation of “Alternate Year Fishing” strategy to reduce fishing mortality by half, was not implemented due to lack of support.
1998	FSAs at eastern ends of Grand Cayman, Cayman Brac, and Little Cayman formally demarcated “Restricted Marine Areas” and require licenses by CIMCB.
2001	Spawning site on west-end of Little Cayman found by fishermen, estimated to be over 7,000 (3). Last year that catch and size data are collected at three main aggregation sites.
2001 & 2002	Spawning site on west-end of Little Cayman heavily fished. CIMCB and CI-DoE campaign to protect Nassau grouper FSAs.
2002	February - CIMCB passes rule defining spawning season as November 1 to March 31. The “Alternate Year Fishing” law (proposed in 1995) is passed with first non-fishing year being 2003. A catch limit of 12 Nassau grouper per boat per day and a minimum size limit of 12 inches is set during fishing years. Established one nautical mile no trapping zone around each spawning site. CIMCB given power to change restrictions to any or all of designated spawning areas (designated in 1998). December – Three more spawning areas given “Restricted Marine Areas” designation: west-end Little Cayman, southwest corner of Grand Cayman, and the southeast corner of Twelve Mile Bank west of Grand Cayman. Two potential spawning sites also given this designation: southwest end of 12 Mile Bank and southwest end of Cayman Brac.
2003	December 29 - CIMCB changed Alternate-Year-Fishing portion of law to eight-year ban on fishing within FSAs.
2007	Revoked prior rule, and established rule for next four years of November through March, inclusive, ban on taking Nassau grouper from FSA. During open season, maximum take of 12 Nassau grouper from FSA areas (4).
2011	Two rules renewed for another eight years, eight-year ban on fishing in designated FSAs during November through March, inclusive, and limit of 12 Nassau grouper taken from FSAs during the open season (5).
2013	Update to Marine Conservation Law. Rules and regulations upheld (6).

2016	August 15 – Cayman Island government passes regulations to protect Nassau grouper, including: all take, possession, or sale of Nassau grouper prohibited December through April (inclusive); slot limit of 16"-24" during open season (May to November) and limit of 5 Nassau grouper per fishing vessel per day; and a ban on spear guns (7).
2019	March - new enhanced MPAs passed in Cabinet. Increased no-take zones across all 3 islands to 45.2% of all area shore to 150 foot depth.

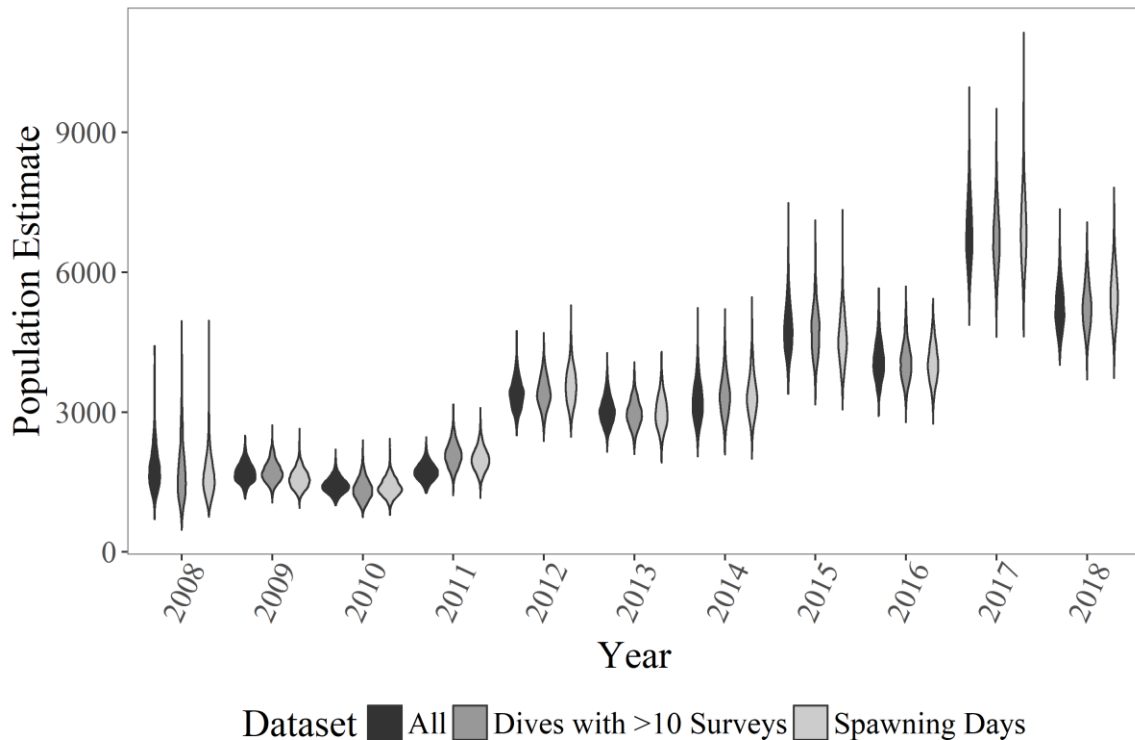
**Supplement B.**

For an example video pan, please see the supplement (Movies S1 and S2) or L. Waterhouse's github repository. The example videopan was shot by Berkley White:  
[http://github.com/WaterLynn/IntegratedStateSpace\\_tagvideodata](http://github.com/WaterLynn/IntegratedStateSpace_tagvideodata)

**Supplement C.**

The mark-resight model formulation we describe relies on the assumption that the mean proportion of tagged fish in the population remains constant across surveys collected throughout the spawning period. However, because we tagged fish early in the spawning period, it is possible that these fish leave the FSA earlier than others. Additionally, the FSA site stretches over half a kilometer or more, and on some dives the surveyors had difficulty finding fish at the FSA site. When surveyors accessed only a small portion of the population, it is possible that the accessible fish had a different tag proportion than the rest of the population. While we cannot directly test the accuracy of the assumption of equal tag proportions across days, we can indirectly assess the robustness of this assumption by fitting our model framework to subsets of the data that omit certain dates. Prior tagging work has shown that leading up to the night of peak spawning, Nassau grouper will continue to transit around the island of Little Cayman, but that all fish attend the FSA on peak spawning nights (nights during which the greatest number of spawning bursts (or rushes) occur). As such, to evaluate the robustness of the assumption of equal tag proportions across survey dates within years, we re-ran the basic model and the model incorporating surveyor effect on the tag data only for Little Cayman using (1) all of the tagging data, (2) surveys from dives on which more than 10 surveys were completed, and (3) surveys from the day prior to, on, and after peak spawning night (i.e. surveys conducted around peak spawning). Our assumption is that consistency in the state estimates of year-specific population sizes resulting from the above 3 data scenarios will validate the assumption of a constant mean proportion of tagged fish throughout the spawning period.

Across the three data sub-sets we generated to verify if we needed to subset the tagging data, posterior estimates of annual population size differed minimally (Figure S1), suggesting we can use all the tag counts when fitting the model.



**Fig. S1.** Violin plot of posterior population estimates from the model with surveyor effect fit to the tagging data only and the binomial distribution applied to three datasets: all data (black fill), dives with more than ten surveys completed (dark gray fill), and data just from days where spawning occurred in the evening (light gray fill).

**Movie S1 (separate file).** Video pan from 2018 on Little Cayman Islands. Note that the quality has been downgraded to meet the PNAS requirement of being less than 10MB in size. To watch the higher quality video file look for instructions on the GitHub site.

**Movie S2 (separate file).** Video pan from 2018 on Cayman Brac. Note that the quality has been downgraded to meet the PNAS requirement of being less than 10MB in size. To watch the higher quality video file look for instructions on the GitHub site.

## References

1. Bush PG, et al. (2006) The Nassau Grouper Spawning Aggregation Fishery of the Cayman Islands – An Historical and Management. *57th Gulf and Caribbean Fisheries Institute Proceedings*, pp 515–524.
2. Bush PG, Lane ED, Ebanks GC (1996) Validation of Ageing Technique for Nassau Grouper (*Epinephelus striatus*) in the Cayman Islands. *Biology, Fisheries and Culture of Tropical Snappers and Groupers. Proceedings EPOMEX/ICLARM International Workshop on Tropical Snappers and Groupers. October 1993*, eds Arrequin-Sanchez FA, Munro JL, Balgos MC, Pauly D, pp 150–157.
3. Whaylen L, Pattengill-Semmens C V., Semmens BX, Bush PG, Boardman MR (2004) Observations of a Nassau grouper, *Epinephelus striatus*, spawning aggregation site in Little Cayman, Cayman Islands, including multi-species spawning information. *Environ Biol Fishes* 70(3):305–313.
4. The Marine Conservation Law (2003 Revision) - The Marine Conservation (Grouper Spawning Areas) Notice, 2007 (2007) (Cayman Islands).
5. The Marine Conservation Law (2007 Revision) The Marine Conservation (Grouper Spawning Areas) Notice, 2011 (2011) (Cayman Islands).
6. Marine Conservation Law (2013 Revision) (2013) (Cayman Islands).
7. The National Conservation Law, 2013 (Law 24 of 2013) (2016) (The National Conservation (General) Regulations, Cayman Islands).