Managing Fish Spawning Aggregations in a Changing Climate: A Case Study of Red Hind (*Epinephelus guttatus*) in Bermuda

Manejo de las Agregaciones de Desove de Peces en un Clima Cambiante: El Ejemplo de Red Hind (*Epinephelus guttatus*) en las Bermudas

Gérer les Agrégations de Géniteurs de Poissons dans un Climat Changeant: L'exemple de Red Hind (*Epinephelus guttatus*) des Bermudes

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EXTENDED ABSTRACT

Many species of groupers (Serranidae) spawn in large aggregations that form in specific locations at predictable times, making them vulnerable to overexploitation. As a result, prohibiting fishing on spawning aggregations is now considered best practice. Bermuda has protected spawning aggregations of the Red hind (*Epinephelus guttatus*) since the 1970s, and was one of the first jurisdictions to enact such a measure, following input from experienced fishers who recognized the threat posed by excessive catches. Known Red hind spawning areas have therefore been closed to fishing from May 1 through August 31 each year since then, encompassing the peak spawning season (Burnett-Herkes 1975) and allowing for a buffer period. Currently, the seasonally closed areas protect key spawning sites to the northeast and southwest of the island, and cover 36.9 km^2 and 49.7 km^2 respectively. These closures have been supported by a seasonal bag limit of 10 fish per vessel per day from May 1 through August 31 since the 1990s. Together with the banning of fish traps in 1990 (Luckhurst 1996) and a minimum size for retention of 35cm fork length (FL), prohibiting fishing on the spawning aggregations appears to have allowed the Red hind population to recover significantly from the overfishing that occurred during the 1970s and 1980s. Further, studies have shown an increase in the average size of fish over time (Luckhurst and Trott 2009).

The timing of spawning is determined by a number of factors, but temperature and lunar phase are generally considered to be the primary drivers (Robertson 1991), reflecting environmental conditions that affect the survivorship and dispersal of larvae. It is now widely recognized that ocean temperature regimes are changing along with the global climate and impacts on the reproduction of marine organisms have been predicted (Pratchett et al. 2015). Such impacts could include shifts, expansions or contractions of the spawning season. Fisheries management will have to adapt accordingly.

The Bermuda Department of Environment and Natural Resources received reports of large catches of Red hind from the spawning aggregation areas during the month of April in both 2014 and 2016, although not in 2015. We therefore conducted a 27-year retrospective analysis of catch reports from the commercial fishery, looking at Red hind catches for the month of April by landed weight, by number of fish, and as a percentage of the total annual catch for the species. This was cross-referenced against climate records from the Bermuda Weather Service and moon phase data. We also examined commercial vessel catch reports from April of 2016 in order to describe daily and monthly catch rates of Red hind for individual fishing vessels, and to evaluate the extent to which this species was targeted by the industry at this time of year. To further describe fishing activity at the aggregation sites and help evaluate the relative impacts of commercial and recreational fishing, we utilized archived radar images from the Bermuda Maritime Operations Centre to describe vessel activity in the aggregation areas at two time points (9 am and 9 pm) for each day during April of 2016.

Commercial landings of Red hind averaged 8,538 kg per year from 1990 through 2011, then began to increase in 2012 (Figure 1). During April of 2016, the commercial fishing fleet reported catching 8,419 individual Red hinds weighing 17,354 kg, and 3,312 individual Red hinds weighing 7,851 kg were caught during April of 2014. These values compared to an average April catch of 959 fish weighing 1,909 kg for the period from 2000 through 2015. In 2016, the catch of Red hind in April exceeded the annual catches for all years from 1990 through 2011, and contributed 59% of the 29,568 kg caught during the year. In 2014, the Red hind caught in April contributed 34% of the annual catch of 27,117 kg. In typical years, the April catch of Red hind averaged 14% of the annual catch.

The climate data showed that in the two years with large April catches both March and April sea surface temperatures (SST) were substantially above the long term average. The monthly mean SST for April was 1.4°C and 1.7°C above the climate average of 20.1°C in 2014 and 2016 respectively, but did not exceed the average by more than 1°C in any other year (Figure 2). The monthly mean SST for March was 2.1°C and 1.5°C above the climate average of 18.4°C in 2014 and 2016 respectively, but March temperatures were more variable overall. The months of January and February also experienced higher than average temperatures in 2016 and 2014.

Together, these data suggested that the Red hind spawning aggregations are forming early when seawater temperatures are elevated relative to climate norms during April and the preceding months. The timing of the full moon within the month did not have a noticeable effect. In order to continue to provide effective protection to Red hinds while they are spawning, a variety of management responses were considered, focusing on a reactive model that would be triggered by elevated

seawater temperatures. Section 4(A) of the Fisheries Act 1972 provides for the emergency closure of a fish aggregation area, so the rationale was that this measure could be used when the aggregation might be expected to form early without the need to change existing legislation. The questions to be addressed during public consultation centred on:

i) The date on which an early closure might start,
ii) The extent of the area to be closed to fishing prior to May 1, and
iii) The role of bag limits in supporting any new management measures.

In addition, one fisher suggested that a ban on nighttime fishing could be effective, as it is believed that Red hind are more likely to "bite" at night. Additional data were examined to facilitate an informed decision.

Catch reports from April 2016 showed that 55 out of 172 commercial fishing vessels (32% of the fleet) reported catching Red hinds on at least one day, with up to 29

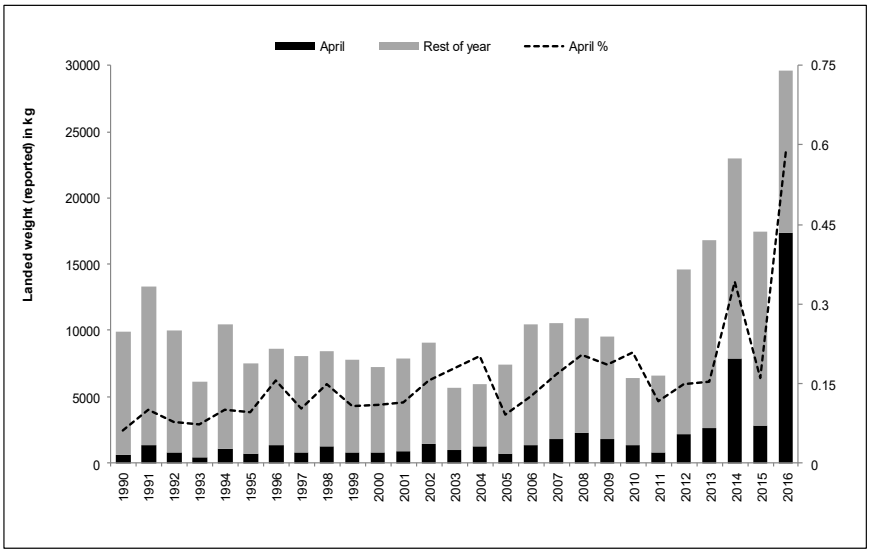

Figure 1. Reported commercial landings of Red hind, *Epinephelus guttta-tus*, by weight (kg) from 1990 through 2016, showing the total annual catch (grey), with the April catch superimposed (black), and the percentage contribution of the April catches shown by the dashed line, measured against the secondary vertical axis.

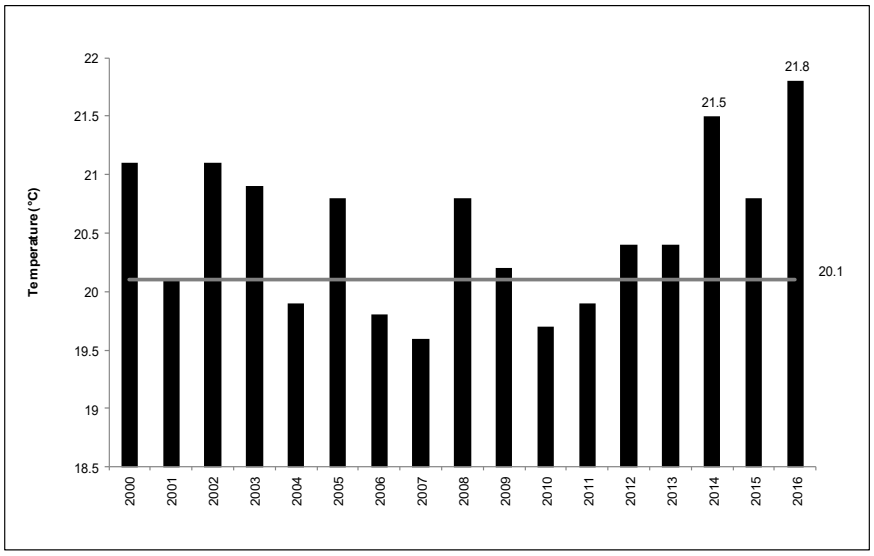

Figure 2. Mean temperatures for the month of April from the years 2000 through 2016, shown against the long term climate mean of 20.1°C (grey line), with the anomalously high temperatures in 2014 and 2016 highlighted.

vessels reporting Red hind catch on any given day. Based on the number of vessels reporting catch, fishing activity targeting Red hind peaked from the full moon on April 22 through the end of the month, with a lesser peak around the first quarter of the moon on April 14. The archived radar images supported these activity patterns, and did not show any increase in vessel activity on weekend days, as might be expected if there were significant numbers of recreational fishing vessels targeting Red hind in the aggregation area. Further, 74% of the vessel hits in the radar images came from the 9am images, indicating that most fishing activity in the aggregation area took place during the day. During this time period, most vessels (70%) reported catching 50 or fewer Red hind per day, although 5% of vessels reported catching more than 100 Red hind on a single day, and 78% of vessels reported catching fewer than 200 fish during the month, although 5% of vessels reported catching more than 500 individual fish during the month.

Based on these data and the initial suggestions received, two management proposals were developed. Early closure, two days before the full moon in April or on April 15 (whichever is earliest), would be triggered if SSTs for February and March were above average by 0.7°C or more. Option 1 would prohibit fishing in a 1 nm^2 area around each of the two main Red hind spawning aggregations during the early closure period. Option 2 would close both seasonally protected areas in their entirety to fishing from 6 pm to 6a m during the early closure period. Both options recommended a) A year round bag limit of 10 Red hind per boat per day for recreational fishers; and b) A bag limit of 50 Red hind per boat per day in April for commercial fishers, in addition to the May 1 – August 31 bag limit of 10 Red hind per boat per day.

These options were presented to stakeholder groups, including the Marine Resources Board, which has broad representation from the various marine sectors, the Commercial Fisheries Council, and the Fishermen's Association of Bermuda, as well as the fisheries wardens, who are responsible for enforcing fisheries management measures. There was wide support for the stricter bag limits proposed. A key point of feedback across groups was that, on top of the limited evidence of nighttime fishing, an overnight closure was not practical because it would be difficult to enforce and fishing activity would simply shift to the daytime. Further, closing the two areas in their entirety was considered easier to enforce, with some noting that it would compensate for the degree to which Red hind move around while aggregating. Interestingly, a fixed start to the closed season was preferred over a model that would only be triggered in certain years by elevated temperatures. However, it was felt that closing the areas earlier in the year should be balanced by an earlier re-opening time.

Red hind spawning capacity is limited by body size, and the month of August was included in the seasonal closure as a buffer period anyway, so balancing an early closure with an early reopening time was considered a reasonable compromise. Therefore, the Red hind spawning aggregation areas will now be closed to fishing from April 15 through August 14 each year, which did require legislative changes. This closure will be supported by the new bag limits and the existing minimum size of 35 cm FL. Going forward, catch reports from the commercial fishery will be closely monitored to look for deviations from typical catch patterns. This will be supported by sampling for gonad state, particularly during the month of April. A conventional tag-recapture study has been initiated to assess population size, and an acoustic tagging study is currently underway to monitor the presence of Red hinds at one aggregation site over the next 5 years. The effectiveness of the current measures will be reviewed after 5 years, once data are available.

KEYWORDS: Spawning aggregations, Red Hind, climate change, fisheries management

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