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# Red tide mortality on red grouper (*Epinephelus morio*) between 1980 and 2009 on the West Florida Shelf

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# Introduction

Ecosystem models can produce estimates of natural mortality that take into account the ecological effects of harmful algal blooms caused by *Karenia brevis* on the West Florida Shelf ecosystem. In this working paper, we present an estimate of natural mortality on red grouper (*Epinephelus morio*) caused by *K. brevis* blooms on the West Florida Shelf, as originally produced for gag grouper (*Mycteroperca microlepis*) during SEDAR 33 (Gray et al., 2013). Anecdotal evidence of red tide mortality has been documented on large serranids including red grouper. During the most recent red tide event in 2014, sixteen dead red grouper were recovered from the Big Bend region during August by the Panama City laboratory (L. Lombardi, pers. comm.). From these specimens, estimated ages ranged from 5 to 9 years old (L. Lombardi, unpublished data). Dead red grouper, in addition to a Warsaw grouper (*E. nigritus*), were also observed in August during the 2005 severe red tide event by the National Marine Fisheries Service bottom longline survey (Walter et al., 2013).

The modeling platform used is Ecopath with Ecosim (EwE), an aggregate system modeling approach implemented worldwide to address specific questions such as impacts of fishing and environmental processes on ecosystem dynamics (Pauly et al. 2000; Christensen and Walters, 2004). The West Florida Shelf Red tide EwE (WFS Red tide EwE) model was developed specifically to assess the effect of episodic events of non-fishing mortality on community structure and to determine whether fishing pressure exacerbated this effect (Gray et al., 2013; Gray, 2014). The model itself is an extension of a West Florida Shelf EwE model originally designed to explore lower trophic level dynamics (Okey and Mahmoudi, 2002; Okey et al., 2004) and later modified to focus on commercially important reef fish (Chagaris, 2013). The modeled area covers 170,000 $km^2$ from the coast to the 200 m isobaths.

Red tide mortality makes up a component of natural mortality, which is best represented when the ecosystem as a whole is considered. Red tide events can be ichthyotoxic either by absorption across gill membranes (Abbott et al., 1975; Baden, 1988) or ingestion of toxic biota (Landsberg, 2002). It remains unclear whether all red tide events induce mortality or if negative effects only occur under conditions where a red tide exceeds a threshold (Walter et al., 2013). Brevetoxins produced by *K. brevis* can remain a stable source of toxicity even in the absence of *K. brevis* cells, potentially introducing a lag in natural mortality of affected fauna (Landsberg et al., 2009). Episodic red tide events act synergistically with predation and fishing mortality, and therefore the simultaneous consideration of these influences can enhance the robustness of reconstructed population dynamics.

In WFS Red tide EwE, red tide mortality is forced across a realistic range of species using a forcing pattern developed from a combination of two data sources: *K. brevis* cell counts (FWRI, 2012) and a composite red tide index including reflectance and other features (Walter et al., 2013). Using the ecosystem framework, red tides affect the species of interest (i.e. red grouper) in addition to a full suite of predator and prey species (Table 1) that may indirectly influence the productivity and reproductive success of red grouper. Nutrients from fish killed by red tide are liberated and enter the detritus pool where they can be recycled within the ecosystem.

## Methods

The WFS Red tide EwE model contains 81 functional groups (Gray, 2014), 37 of which have been directly linked to episodic events of red tide mortality based on Florida's Fish and Wildlife Research Institute's (FWRI) fish kill database (http://research.myfwc.com/fishkill/) (Table 1). Ecosystem functional groups are trophically-linked biomass pools which can reflect (1) a group of species exhibiting similar life history, dietary or niche preferences (e.g. forage fish); (2) a single species of commercial importance (e.g. red snapper (*Lutjanus campechanus*)); or (3) a life-history stage ontogenetically distinct in diet and/or habitat (e.g. estuarine juveniles versus coastal adults) (Pauly et al., 2000). Sources of mortality include predation and fishing mortality derived from eleven fishing fleets (trawl, gill/trammel net, hook/line, purse seine, haul seine, long line, trap, spear/gig, recreation, headboat and unknown). A pseudo-fishing fleet, referred to as the Harmful Algal Bloom (HAB) fleet, is used to impose non-fishing mortality on susceptible functional groups. Effort data were used to force the effort on all fleets in the model (Gray et al., 2014). This arrangement is a work-around that allows all species, with the exception of gag and red groupers, to be driven by multiple independent effort series without prescribing the amount of catch or red tide mortality, allowing instead for Ecosim to estimate these. As for gag grouper, the Walter et al. (2013) offshore index was used since it was less affected by bottom reflectance, and because adult red grouper habitat was primarily offshore. Further details on model specification and the HAB fleet are provided in Gray (2014).

### Modifications to original WFS Red tide EwE model

To enable investigation of red tide mortality solely on adult red grouper, a "Red grouper fleet" was added to the original WFS Red tide EwE model. This fleet was created so that red grouper fisheries mortality could be manipulated separately. Red grouper catch was driven separately from other species in the model by forcing fishing mortality using catch values (SEDAR, 2009), a method assumed most accurate in representing catch of red grouper. Due to the lack of reported landings in 1980, an average value (1981−1985) was used. Parameterization of the HAB fleet was identical to that in Gray (2014) with the exception of red tide discards of red grouper. Initial HAB discard estimates of red grouper (0.000144 tons per squared kilometer (t $km^{-2}$)) were an order of magnitude lower than gag grouper (0.00149 t $km^{-2}$) and resulted in annual red tide mortality estimates near 0.

To more accurately capture red grouper discards within the HAB fleet, adjustments were made after looking at the source data. Original allocation of grouper within the database did not separate out red grouper from potential "unidentified grouper" observations. Here, relative biomasses of red grouper (0.1574 t $km^{-2}$) and gag grouper (0.03435 t $km^{-2}$) and HAB discards of gag grouper (lower limit (10%): 0.0008 t $km^{-2}$; anchor point (15%): 0.001427 t $km^{-2}$; upper limit (20%): 0.0020 t $km^{-2}$) were used to estimate HAB discards of red grouper. Additional details on scaling the effort of the HAB fleet can be found in Gray et al. (2013) and Gray (2014).

### Fitting to time series

The updated time series for gag grouper catch developed during SEDAR 33 was used in the fitting process. The ability of the WFS Red tide EwE model to replicate observed trends in biomass and catch was validated using a historical model (1980, $t = 1$) and a thorough tuning process documented in Gray (2014). Once the red grouper fleet was parameterized and incorporated into the model, Ecosim's optimization test was run as described in Gray (2014). Updated fits to time series are shown for biomass and catch in Figures A1 and A2, respectively

## Estimation of red tide mortality

Two Ecosim models were run, one with the HAB fleet acting upon the ecosystem and the other with the HAB fleet effort set to 0. The difference between total mortality for red grouper was used as an estimate of mortality imposed by the blooms only. This method was used so that food web dynamics that might affect bloom mortality were considered (Gray, 2014).

## Results and Discussion

The red tide mortality trend reported in Figure 1 is on the order of 0.010 to 0.095 $yr^{-1}$, with high variability throughout the simulation (Table 2). Although the peak estimate of red tide mortality in 2005 corresponds to the well-documented severe red tide event, 1992 was not a year with a severe red tide event. The HAB forcing prior to 1998 was realistic in terms of amplitude and frequency, however, there is concern regarding this time period. Therefore, estimates prior to 1998 are not recommended.

The overall scale of the red tide mortality trend relative to predation mortality and fishing mortality for red grouper is minor (Figure 2). Resulting estimates of red tide mortality are slightly lower compared to the estimated red tide mortality for gag grouper (Gray et al., 2013). Numerous field observations of red grouper kills suggest a significant impact on red grouper, whereas evidence of gag grouper in fish kills remains sparse. Within the HAB database, 10 red grouper were observed whereas only 6 gag grouper were observed. The vast majority of fish kills were labeled as "grouper" and not identified to species. The resulting red tide mortality estimated for red grouper may be a result of the allocation of red tide fishing effort which used the 15% mortality rate for gag grouper as an anchor point. It may be fruitful to invest additional efforts into re-estimating fishing effort using a red grouper anchor point and comparing the results to the time series created using gag grouper as an anchor point.

Red tide mortality affects many of red grouper's competitors as well, and thus higher consumption rates in red grouper under stress from red tides occur due to a compensatory mechanism from foraging arena theory (Figure 3). A reduction in biomass of red grouper due to red tide mortality leads to increased consumption of individual predators to compensate for the reduction in abundance. A similar increase in consumption was observed for gag grouper and was suggested to result from a combination of prey release and a reduced mean age of gag grouper (Gray, 2014). Severe red tides may potentially lead to increased productivity of red grouper (as younger fish have higher production rates than older fish). As observed for gag grouper, the lowest annual natural mortality rate from red tides (occurring in 1998, 0.01 $yr^{-1}$ under the 15% anchor point) is approximately 1/10 of the highest mortality rate (occurring in 2005, 0.095 $yr^{-1}$) (Table 2).

As with gag grouper, this assessment assumes a linear functional response between *K. brevis* cell counts and fish/invertebrate mortality, and assumes that mortality occurs in the adult age classes. Additional research should focus on specific mechanisms regarding how red tide events affect grouper. It also remains unclear how red tide events interact with younger groupers, which reside in inshore regions. The Walter et al. (2013) inshore red tide index may be a useful effort driver of the HAB fleet for juvenile groupers. However, the challenge will be parameterizing HAB discards for this life-history stage.

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**Table 1**. Functional groups considered within the West Florida Shelf Red tide EwE model. Asterisks indicate functional groups impacted by red tide events based on the Fish and Wildlife Research Institute's (FWRI) harmful algal bloom fish kill database (http://research.myfwc.com/fishkill/). Additional details are given in Gray (2014).

| No | Functional Group | No | Functional Group |
|---|---|---|---|
| 1 | Dolphins | 42 | Benthic oceanic invertebrate eaters |
| 2 | Seabirds | 43 | Benthic coastal piscivores* |
| 3 | Turtles* | 44 | Benthic coastal invertebrate eaters* |
| 4 | Manatees | 45 | Surface pelagics* |
| 5 | Large oceanic piscivores* | 46 | Structurally associated coastal piscivores* |
| 6 | Large oceanic planktivores | 47 | Large groupers* |
| 7 | Coastal sharks* | 48 | Structurally associated invertebrate eaters* |
| 8 | Rays/skates* | 49 | Structurally associated coastal omnivores* |
| 9 | Pelagic oceanic piscivores | 50 | Structurally associated coastal planktivores* |
| 10 | Pelagic coastal piscivores* | 51 | Nearshore associated piscivores* |
| 11 | Adult mackerel | 52 | Nearshore associated planktivores* |
| 12 | Juvenile red grouper* | 53 | Other fishes |
| 13 | Adult red grouper* | 54 | Squid |
| 14 | Juvenile spanish mackerel | 55 | Adult shrimps |
| 15 | Adult spanish mackerel | 56 | Lobsters |
| 16 | Juvenile gag grouper | 57 | Large crabs* |
| 17 | Adult gag grouper* | 58 | Juvenile blue crab |
| 18 | Juvenile red drum* | 59 | Adult blue crab* |
| 19 | Adult red drum* | 60 | Octopods |
| 20 | Juvenile striped mullet* | 61 | Stomatopods |
| 21 | Adult striped mullet* | 62 | Echinoderms/large gastropods |
| 22 | Juvenile lane snapper | 63 | Bivalves |
| 23 | Adult lane snapper* | 64 | Sessile epibenthos |
| 24 | Juvenile gray snapper | 65 | Small infauna |
| 25 | Adult gray snapper* | 66 | Small mobile epifauna |
| 26 | Juvenile crevalle jack* | 67 | Meiofauna |
| 27 | Adult crevalle jack* | 68 | Small copepods |
| 28 | Juvenile pinfish* | 69 | Other mesozooplankton |
| 29 | Adult pinfish* | 70 | Carnivorous zooplankton |
| 30 | Juvenile mojarra* | 71 | Ichthyoplankton |
| 31 | Adult mojarra* | 72 | Carnivorous jellyfish |
| 32 | Juvenile ladyfish | 73 | Microbial heterotrophs |
| 33 | Adult ladyfish* | 74 | Macroalgae |
| 34 | Sardine/herring* | 75 | Microphytobenthos |
| 35 | Pelagic oceanic jelly eaters | 76 | Phytoplankton |
| 36 | Pelagic oceanic planktivores | 77 | Sea grasses |
| 37 | Demersal oceanic invertebrate eaters | 78 | Dead carcasses |
| 38 | Demersal coastal piscivores* | 79 | Sediment detritus |
| 39 | Demersal coastal invertebrate eaters* | 80 | Watercolumn detritus |

| | | | |
|---|---|---|---|
| 40 | Demersal coastal omnivores* | 81 | Drift macrophytes |
| 41 | Benthic oceanic piscivores* | | |

**Table 2**. Predicted natural mortality ($M_{RT}$) as a result of red tides for red grouper between 1980 and 2009. 10%, 15% and 20% anchor points have been used to scale the absolute effect of red tides in Ecopath with Ecosim for the year 2005 (gray cells). Total natural mortality (M) at the 15% anchor point for red tide mortality is also given.

| Year | 10% | 15% | 20% | M |
|---|---|---|---|---|
| 1980 | 0.024 | 0.040 | 0.056 | 0.181 |
| 1981 | 0.018 | 0.031 | 0.044 | 0.175 |
| 1982 | 0.022 | 0.038 | 0.053 | 0.185 |
| 1983 | 0.011 | 0.020 | 0.028 | 0.170 |
| 1984 | 0.022 | 0.037 | 0.052 | 0.190 |
| 1985 | 0.007 | 0.012 | 0.017 | 0.167 |
| 1986 | 0.018 | 0.031 | 0.044 | 0.188 |
| 1987 | 0.014 | 0.025 | 0.035 | 0.183 |
| 1988 | 0.021 | 0.036 | 0.050 | 0.194 |
| 1989 | 0.023 | 0.040 | 0.057 | 0.199 |
| 1990 | 0.022 | 0.038 | 0.054 | 0.198 |
| 1991 | 0.018 | 0.032 | 0.045 | 0.192 |
| 1992 | 0.056 | 0.095 | 0.133 | 0.255 |
| 1993 | 0.024 | 0.041 | 0.058 | 0.201 |
| 1994 | 0.016 | 0.029 | 0.041 | 0.188 |
| 1995 | 0.021 | 0.036 | 0.052 | 0.194 |
| 1996 | 0.010 | 0.018 | 0.026 | 0.175 |
| 1997 | 0.021 | 0.036 | 0.051 | 0.192 |
| 1998 | 0.006 | 0.011 | 0.016 | 0.165 |
| 1999 | 0.018 | 0.031 | 0.044 | 0.183 |
| 2000 | 0.015 | 0.025 | 0.036 | 0.176 |
| 2001 | 0.021 | 0.036 | 0.051 | 0.186 |
| 2002 | 0.024 | 0.041 | 0.057 | 0.189 |
| 2003 | 0.023 | 0.040 | 0.056 | 0.187 |
| 2004 | 0.019 | 0.033 | 0.047 | 0.179 |
| 2005 | 0.056 | 0.095 | 0.134 | 0.241 |
| 2006 | 0.025 | 0.042 | 0.060 | 0.188 |
| 2007 | 0.018 | 0.030 | 0.042 | 0.176 |
| 2008 | 0.022 | 0.038 | 0.053 | 0.185 |
| 2009 | 0.012 | 0.020 | 0.028 | 0.167 |

**Figure 1**. Predicted natural mortality as a result of red tides on red grouper between 1980 and 2009. The red line represents a 15% anchor point trend. Lower and upper error bars were created by assuming a maximum mortality of 10% and 20%, respectively.

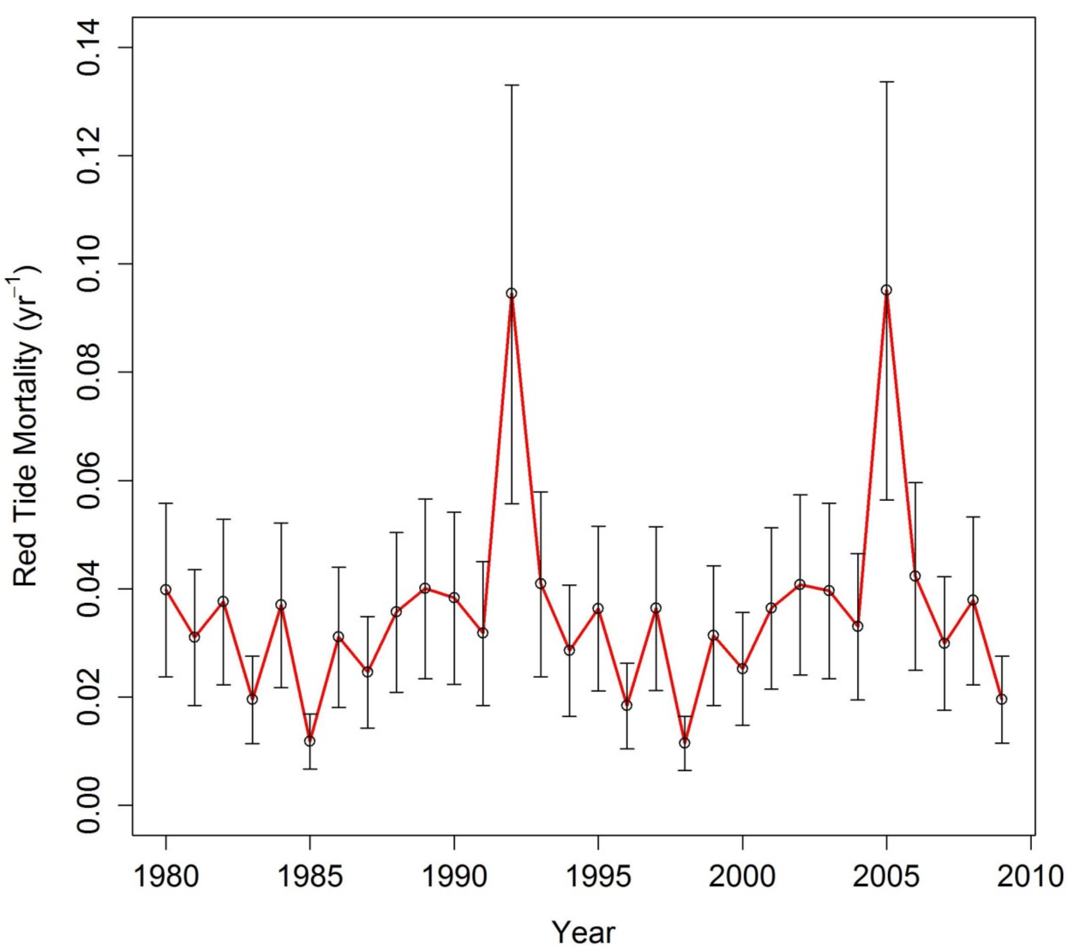


**Figure 2**. Temporal comparison of mortality ($yr^{-1}$) components including predation (blue), fishing (green), and red tide (red) mortalities. Values shown are based on monthly means.

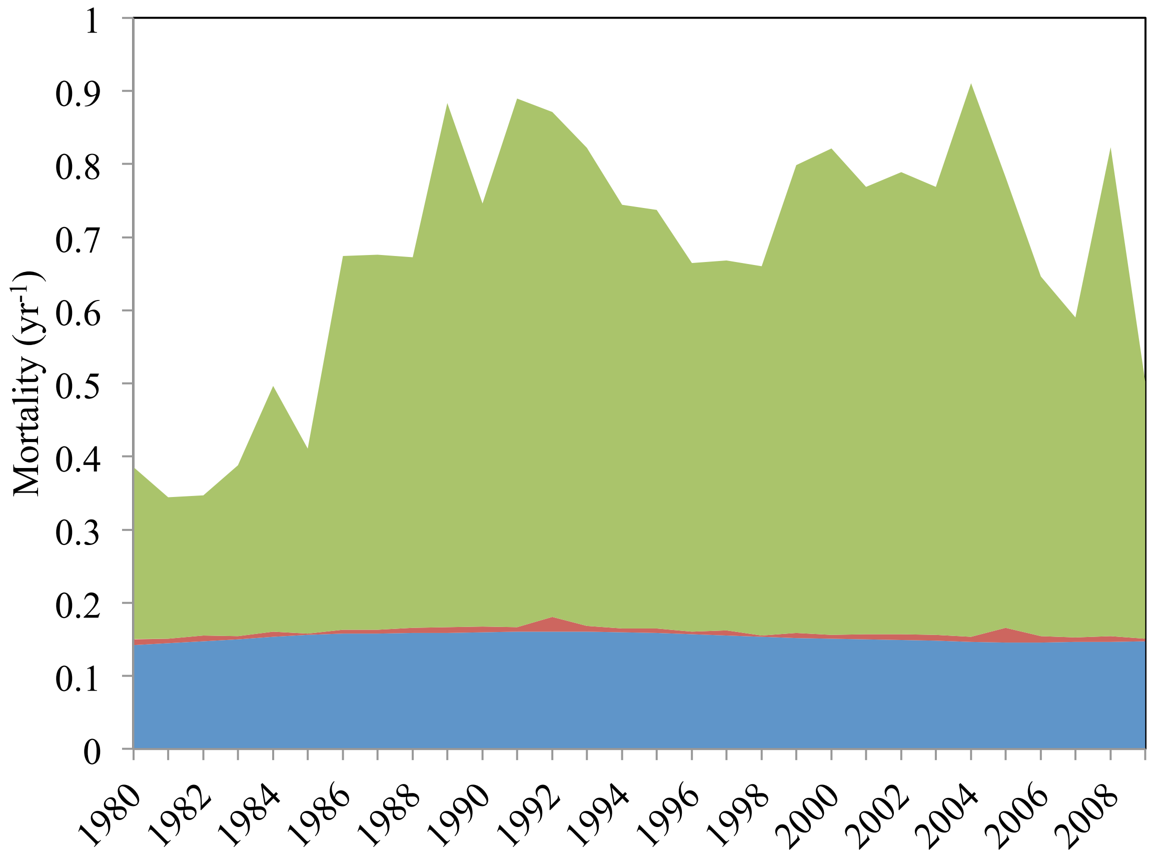
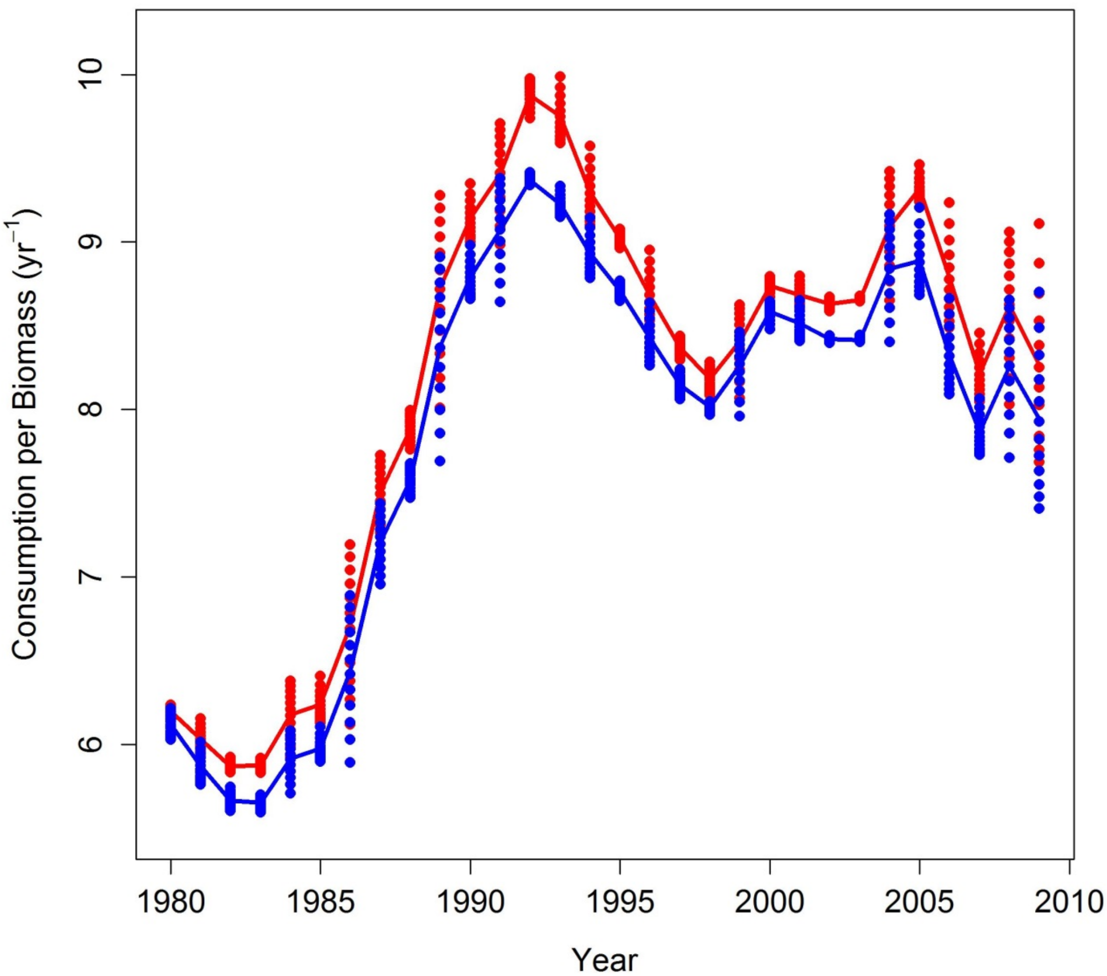


**Figure 3**. Comparison of red grouper consumption rates both with red tide mortality (red line and red dots) and without red tide mortality (blue line and blue dots). Points reflect monthly estimates and lines representing mean values. The red line shows a slightly higher consumption rate when red tide mortality is included, suggesting higher prey availability and potentially higher productivity of red grouper. The blue line shows the consumption rate by red grouper when there is no red tide mortality.



**Appendix A**. Fits to time series for the updated West Florida Shelf Red tide Ecosim model focused on estimating red tide mortality for adult red grouper.

**Figure A1**. Observed (dots) versus predicted trends (line) in biomass. Sums of squares are provided for each group. See Gray (2014) for specifics on functional groups and fitted time series.

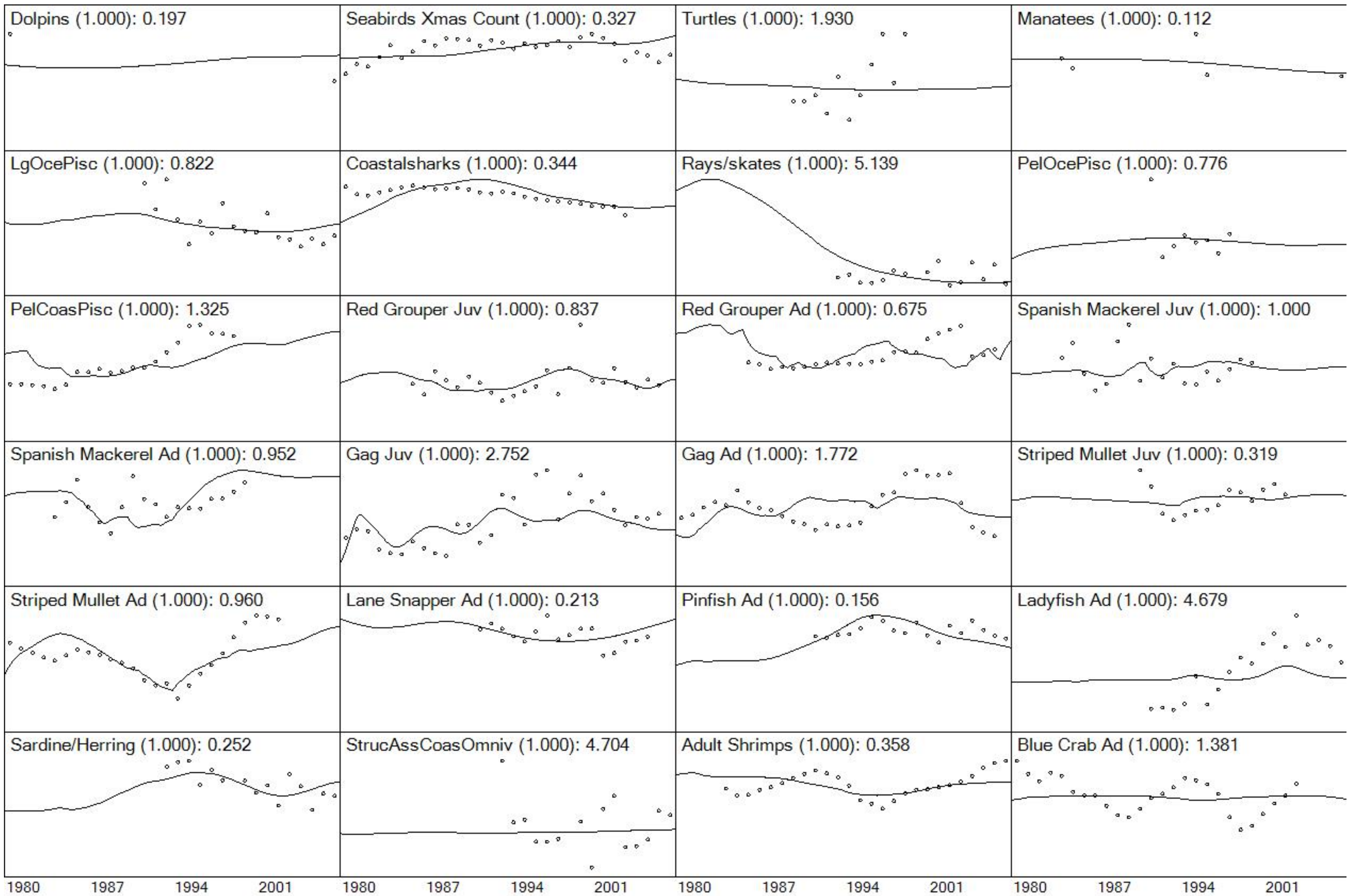


**Figure A2**. Observed (dots) versus predicted trends (line) in catch. Sums of squares are provided for each group. See Gray (2014) for specifics on functional groups and fitted time series.