Spawning aggregation of white-streaked grouper *Epinephelus ongus*: spatial distribution and annual variation in the fish density within a spawning ground

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ABSTRACT

White-streaked grouper (*Epinephelus ongus*) is an important fisheries target and forms spawning aggregations at particular spawning grounds. The aims of the present study were to investigate the ecological characteristics of annual spawning aggregations such as (1) spatial variations in the density of *E. ongus* at the spawning ground, (2) the relationship between fish density and environmental variables, (3) inter-annual variations in the spawning aggregation, (4) the proportion of males to females at the spawning ground for several days pre—and post-spawning and (5) the relationship between male density and female density at the protected spawning ground, based on observations over five years at an Okinawan coral reef. Although the protected spawning ground area was large (ca. 2,500 m × 700 m), high density of *E. ongus* (over 25 individuals per 100 m^2) was found in a limited area (within c.a. 750 m × 50 m). Current velocity and coverage of rocks had significant positive effects on the spatial distribution of *E. ongus* at the spawning ground. Inter-annual variation in the degree of aggregation was found and this variation was explained by the annual variation of mean seawater temperature during 40 days before the spawning day. The male–female ratio (male:female) at the spawning ground was ca. 3:1 for three years (May 2012, May 2014 and May 2015) whereas >13:1 for one year (May 2013). Significant positive relationships between male density and female density were found at the aggregation sites. It is suggested that *E. ongus* use aggregation sites with greater current velocity to reduce the risk of egg predation and seawater temperature is one of the main factors that is responsible for determining the degree of aggregation. It is also suggested that females possibly select sites with a greater density of males and this selection behavior might be the reason why females arrived at the spawning ground after the arrival of the males. For effective management of spawning grounds, precise site selection as well as the duration of the protection period are suggested to be key aspects to protect the spawning aggregations of *E. ongus*, which have been currently achieved at the spawning ground.

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INTRODUCTION

Coral reef fishes are highly diverse and at least 80 species have been reported to form spawning aggregations among over 2,600 fish species (*Sadovy de Mitcheson & Colin, 2012*). *Domeier (2012)* has defined that reef fish spawning aggregations consist of only conspecific individuals and that spawning is highly predictable in time and space. Spawning aggregations are usually found in restricted seasons and lunar phases at particular sites (*Nemeth, 2009*). Spawning aggregations can be categorized into two types such as resident spawning aggregations and transient spawning aggregations (*Domeier & Colin, 1997*). Resident spawning aggregations are characterized by a short migration distance (<2 km), small size species (e.g., Acanthuridae, Caesionidae, Labridae and Scaridae), short duration of the spawning event (1–5 h) and high spawning frequency (daily or monthly). In contrast, transient spawning aggregations are characterized by a long migration distance (2 to >100 km), large size species (e.g., Lethrinidae, Epinephelidae and Lutjanidae), long duration of the spawning event (>2 to 10 days) and low spawning frequency (annually) (*Nemeth, 2009*).

Among the transient spawning aggregation species, over 40 species of groupers (Epinephelidae) are regarded to form spawning aggregations (*Sadovy de Mitcheson & Colin, 2012*). Some ecological characteristics of groupers in terms of spawning aggregation have been studied such as migration distance (*Nemeth et al., 2007*; *Nanami, Ohta & Sato, 2015*), spawning migration behavior (*Zeller, 1998*; *Zeller & Russ, 1998*; *Starr et al., 2007*; *Rhodes et al., 2012*), spawning behavior (*Colin, 1992*; *Samoilys & Squire, 1994*; *Donaldson, 1995*; *Sadovy, 1996*; *Nanami et al., 2013a*), reproductive activity (*Robinson et al., 2008*; *Ohta & Ebisawa, 2015*) and location of spawning aggregations (*Kobara & Heyman, 2010*; *Golbuu & Friedlander, 2011*; *Colin, 2012*; *Erisman et al., 2012*). For fisheries aspects, the effective protection of the spawning aggregations of groupers is needed (*Beets & Friedlander, 1999*; *Sala, Ballesteros & Starr, 2001*; *Nemeth, 2005*; *Sadovy & Domeier, 2005*; *Russell, Luckhurst & Lindeman, 2012*) due to their predictability in time and space and vulnerability to fishing (*Samoilys, 1997*; *Rhodes & Tupper, 2008*; *Sadovy de Mitcheson et al., 2008*; *Sadovy de Mitcheson & Erisman, 2012*).

White-streaked grouper *Epinephelus ongus* is one of the important fisheries targets around the Okinawan region (*Ohta & Ebisawa, 2016*) and known to form spawning aggregations in the region (*Ohta & Ebisawa, 2009*; *Ohta & Ebisawa, 2015*; *Ohta & Nanami, 2009*; *Nanami et al., 2013a*; *Nanami et al., 2014*; *Nanami, Ohta & Sato, 2015*) (Fig. 1, Videos S1 and S2). *Ohta & Ebisawa (2009)*; *Ohta & Ebisawa (2015)* examined the reproductive biology using gonadal histology, oocyte development and catch data analysis. They showed clear seasonality of spawning of *E. ongus* and the spawning was found during the last-quarter moon in only one month (only May) or two consecutive months (April–May or May–June). Spawning migration behavior (*Nanami et al., 2014*; *Kawabata et al., 2015*) and spawning migration distance (*Nanami, Ohta & Sato, 2015*) have also been clarified for *E. ongus*. However, other ecological aspects such as spatial variation in the density within the spawning ground in relation to environmental characteristics, annual variations in the degree of aggregation, the proportion of males to females at the spawning ground and