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Towards effective coral community restoration for sustainable fishery of a coral reef grouper *Epinepherus ongus*: implications of ecosystem-based management

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Abstract: Spawning aggregations of coral reef fishes are particularly vulnerable to fishing since only conspecific individuals gather at specific sites in restricted seasons and lunar phases. Since capturing spawning aggregations leads to significant negative impacts for both local stock and reproductive success, protection of spawning aggregations has been an urgent need recently for coral reefs all over the world. Furthermore, conservation of habitat in the non-spawning season is also essential for species that form spawning aggregations since habitat loss at their home ground would also lead to a reduction in their population. In the present paper, the focus is on a coral reef grouper species (*Epinephelus ongus*), that is a very important fishery target and forms spawning aggregations in an Okinawan coral reef. Effective coral community restoration is discussed to establish a sustainable fishery of the species. This author's previous studies have shown: (1) their home ground was several kilometers around the spawning ground; (2) their home range was very limited around a coral colony during non-spawning periods; (3) juveniles preferentially used corals with fine structure (*e.g.* bottle-brushed acroporid corals) whereas adults were mainly found at corals with coarse structure (*e.g.* massive corals and staghorn acroporid corals); and (4) very precise returning ability was observed after spawning migration (*i.e.* species would return to the coral colonies that were used before the spawning migration). These results suggest that: (1) conservation of the coral community around the spawning ground is indispensable; (2) coral species that are preferentially used by *E. ongus* should be selected for coral community restoration; (3) the area several kilometers around the spawning ground should be the proposed area for coral community restoration. Since the spawning ground of the species has already been assigned as a marine protected area, coral community restoration around the spawning ground would be useful to enhance the *E. ongus* stock.

Key words: coral community restoration, sustainable fishery, spawning aggregation, white-streaked grouper, *Epinephelus ongus*

Introduction

Habitat restoration is one of the essential tools for fisheries management, since almost all marine organisms require appropriate habitat space to complete their life cycle (*e.g.* settlement, growth and reproduction). Thus, an ecosystem-based management approach is needed. In coral reefs, numerous fisheries target species rely on the coral communities as their refuge space and resting site. However, recent coral degradation has caused significant negative impacts on populations of fisheries target species. Thus, coral community restoration has been urgently needed for sustainable fisheries in coral reefs.

Among the diverse fish species, at least 80 species have been reported to form spawning aggregations (Sadovy de Mitcheson and Colin, 2012). Domeier (2012) has defined reef fish spawning aggregations as consisting of only conspecific

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individuals where spawning is highly predictable in time and space. Spawning aggregations are usually found in restricted seasons and lunar phases at particular sites (Nemeth, 2009). Due to the ecological characteristics, spawning aggregations have great vulnerability to fishing (Sadovy de Mitcheson and Erisman, 2012). In addition, spawning aggregation fishing could decrease reproductive success of the species, leading to decreased larval supply and juvenile settlement. Thus, effective protection of spawning aggregations is needed for sustainable fisheries and reproductive success. Recently, marine protected areas have been applied to protect spawning aggregations all over the world.

However, if habitats around the spawning ground are degraded, the effects of spawning ground protection would decrease. This is because the species that form spawning aggregations inhabit their home ground around the spawning ground in the non-spawning periods. The habitat loss in the home ground would decrease population size of the species in the non-spawning periods and this would decrease the magnitude of spawning aggregations, even if the spawning aggregation is protected from fishing (**Fig. 1**). Thus, habitat restoration (*i.e.* coral community restoration) around spawning grounds should be considered as part of effective spawning aggregation protection. The protection of these restored habitats (*e.g.* marine protected areas) is an important additional step to ensure their longevity and success.

There are at least two aspects that determine success of coral community restoration: "How" and "Why". "How" means the techniques used to enhance survival rates or scale up coral communities. In contrast, "Why" is related to the purpose of restoration (*e.g.* biodiversity conservation or sustainable fishery). In the latter case, we should

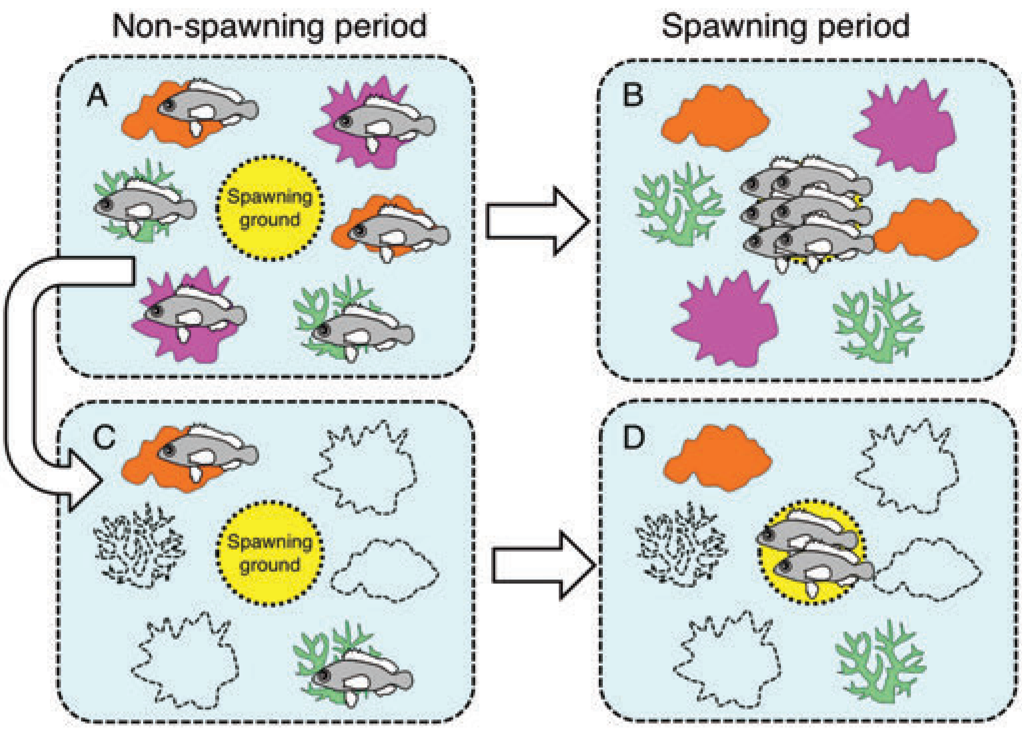

Fig. 1. Schematic diagram showing the reason why coral community should be conserved or restored around the spawning ground. If little damage to the coral community around the spawning ground and a large population size of the fish is found in a non-spawning season (A), then a large spawning aggregation would be found at the spawning ground during spawning season (B). If coral community degradation occurs around the spawning ground, the population size of the fish would decrease around the spawning ground (C), and only a small spawning aggregation would be found even if the spawning ground is protected from catch (D).

determine strategies such as "what is the target species to enhance?", "what types of corals should be restored?" and "which area is proposed for coral community restoration?" In order to determine the strategy, we should clarify ecological aspects for the target species or target communities before conducting coral community restoration. In the present paper, the focus is on a coral reef grouper in an Okinawan coral reef. Subsequently, the effective coral community restoration needed to achieve stock enhancement of the grouper is discussed.

Materials and Methods

Study species

White-streaked grouper *Epinephelus ongus* is one of the important fishery targets around the Okinawan region and is known to form spawning aggregations (Ohta and Ebisawa, 2015) (**Fig. 2A**). The spawning of the species was found to occur during the last-quarter moon in only one month (May) or two consecutive months (April-May or May-June). In order to protect the spawning aggregation of the species, the spawning ground has been protected during spawning periods since 2010 (Nanami *et al.*, 2017) (**Fig. 2B**).

In order to achieve effective spawning aggregation protection of the species, several ecological traits should be clarified such as (1) spawning migration distance, (2) microhabitat association and (3) returning ability after spawning migration of the species.

Definition of ecological terms

Four ecological terms are defined as follows (**Fig. 3**): (1) home ground: the area that are used by fishes in non-spawning period; (2) home range: the area that are used by a focal fish individual (*i.e.* territory); (3) spawning ground: the area that are used by fishes in spawning event; (4) microhabitat: the habitat that are associated by fishes in fine scale within several-tens centimeters (e.g. coral species and coral morphology). This is contrary to landscape-level habitat categorization (*e.g.* reef flat, reef crest and reef slope).

Spawning migration distance

Migration distance is defined as the distance between home ground and spawning ground for the focal individual. Clarification of the spawning migration distance would provide useful information to estimate the home ground area around the spawning ground. Namely, "how many areas should be considered for coral community restoration around the spawning ground?" Using a tag-and release method, the spawning migration distance was estimated. In total, 1157 *E. ongus* individuals were tagged and released at their home grounds in the non-spawning period and 350 were tagged at the protected spawning ground in the spawning period.

Microhabitat association

Understanding the microhabitat association would provide useful information to clarify what types of corals should be restored. Microhabitat associations

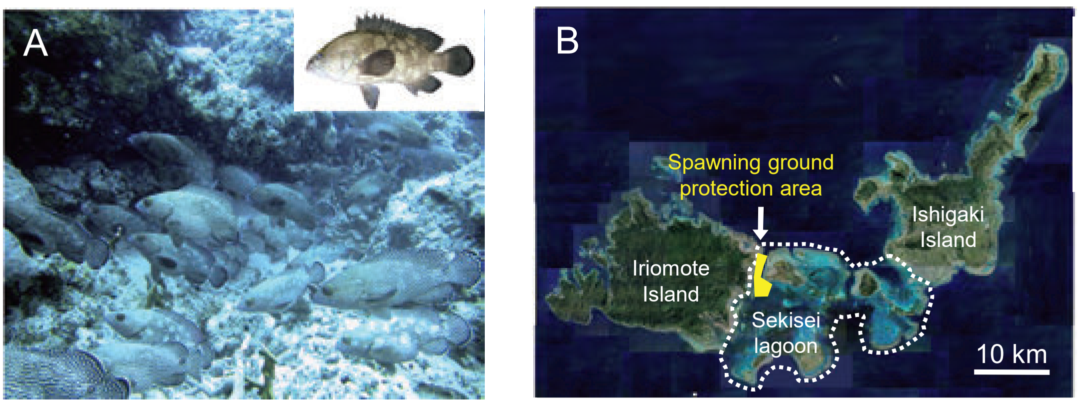

Fig. 2. Spawning aggregation of white-streaked grouper (A). Location of the spawning ground protection area in Sekisei lagoon, Okinawa, Japan (B). The aerial photograph was provided by the International Coral Reef Research and Monitoring Center.

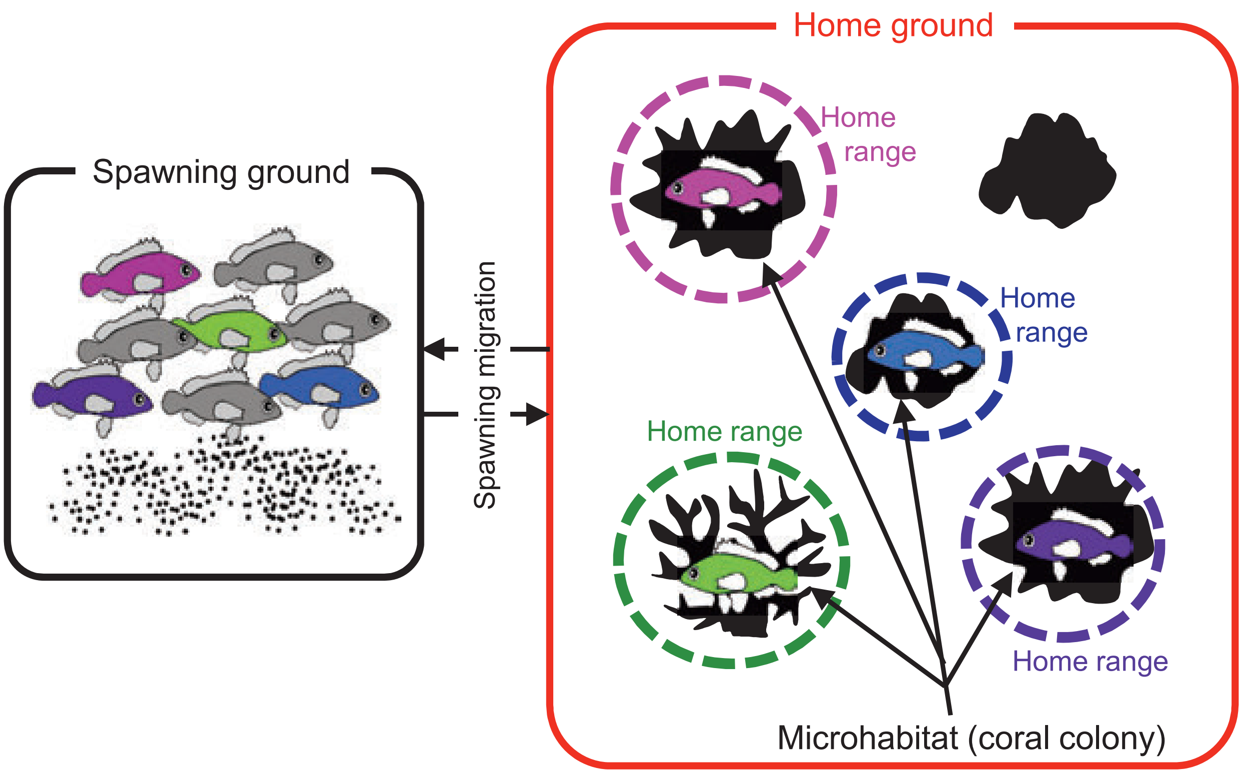

Fig. 3. Schematic diagram for four ecological terms (home ground, home range, spawning ground and microhabitat). (1) home ground: the area that are used by fishes in non-spawning period; (2) home range: the area that are used by a focal fish individual (*i.e.* territory); (3) spawning ground: the area that are used by fishes in spawning event; (4) microhabitat: the habitat that are associated by fishes in fine scale within several-tens centimeters (*e.g.* coral species and coral morphology).

for juvenile and adult white-streaked grouper were examined at home grounds by underwater observations.

Site fidelity and returning ability

Clarifying the site fidelity and returning ability would be useful to consider if the restored coral community would be used throughout the white-streaked grouper's lifetime. Seventeen individuals were captured and an acoustic coded transmitter was surgically implanted into the abdominal cavity of each fish. All tagged individuals were promptly released back to the site of their capture at the respective coral colony. In addition, 19 automated monitoring acoustic receivers were deployed at the release point. The location of each fish was detected using a VEMCO Positioning System.

Results

Migration distance

For the fish that were released at the home grounds, 23 individuals were recaptured at the spawning ground during the spawning periods (**Fig. 4A**). For the individuals that were released at the spawning ground, six individuals were recaptured outside the spawning ground (**Fig. 4B**) (Nanami *et al.*, 2015). The estimated migration distances from the home ground to the spawning ground ranged from 2.2 to 8.8 km (**Fig. 4C**).

Microhabitat association

Most juveniles (total length < 14 cm) were found in corals with fine structure (*e.g.* bottlebrush *Acropora* and arborescent *Acropora*), whereas most adults (total length > 18 cm) were found in corals with coarse structure (*e.g.* staghorn *Acropora*, massive *Porites* and branching *Porites*) (**Fig. 5**) (Nanami *et al.*, 2013; Nanami unpublished data).

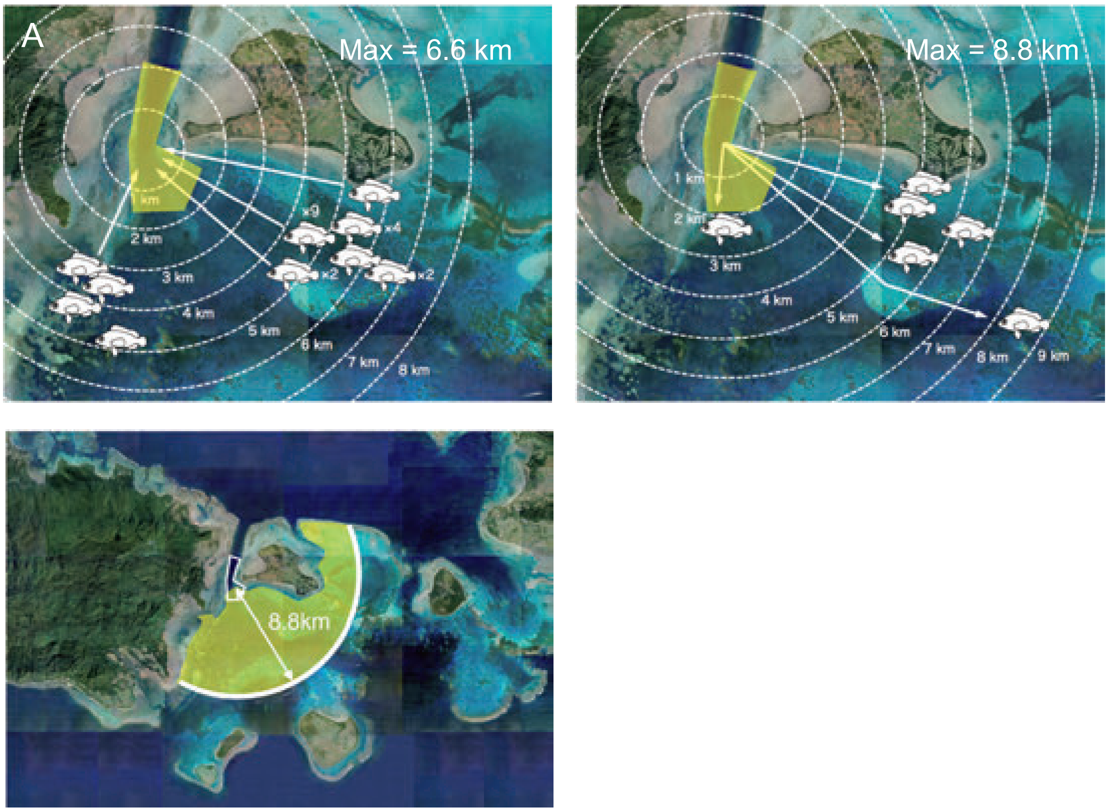

Fig. 4. Estimation of spawning migration distance by tag-and-release. Results of 23 individuals released outside the spawning ground (A) and 6 individuals released inside the spawning aggregation (B). The estimated home ground of white-streaked grouper around the protected spawning ground (C). Redrawn from Nanami *et al.* (2015). The aerial photographs were provided by the International Coral Reef Research and Monitoring Center.

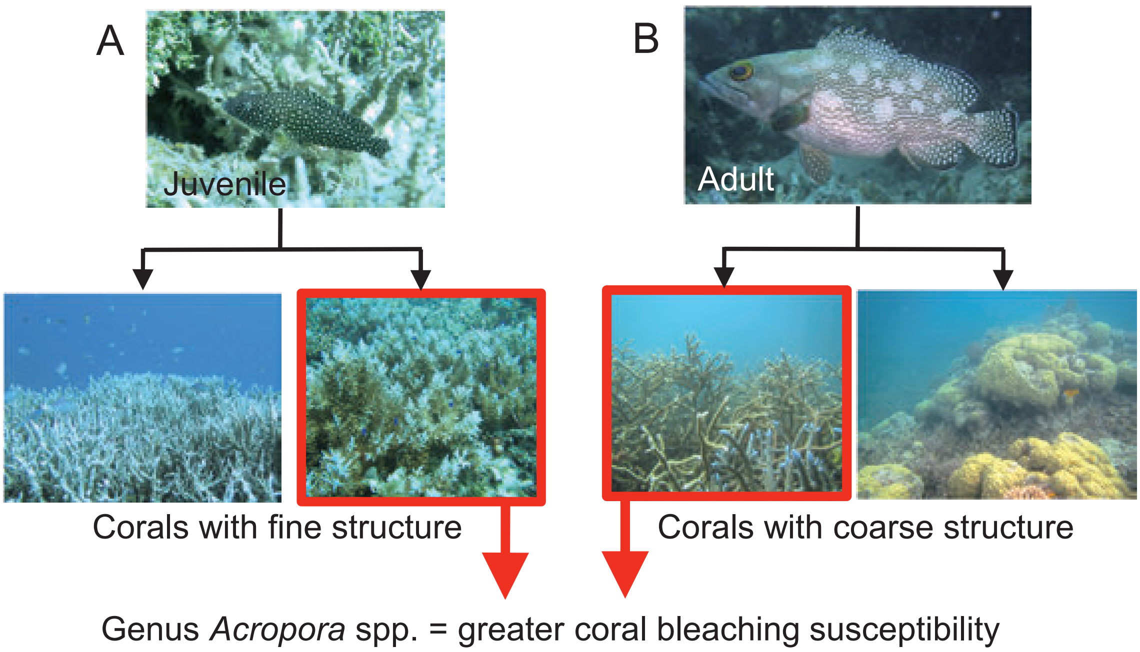

Fig. 5. Microhabitat association of juveniles (A) and adults (B) of the white-streaked grouper. Both fine-structure and coarse-structure corals included genus *Acropora*, which has greater coral bleaching susceptibility and subsequent death.

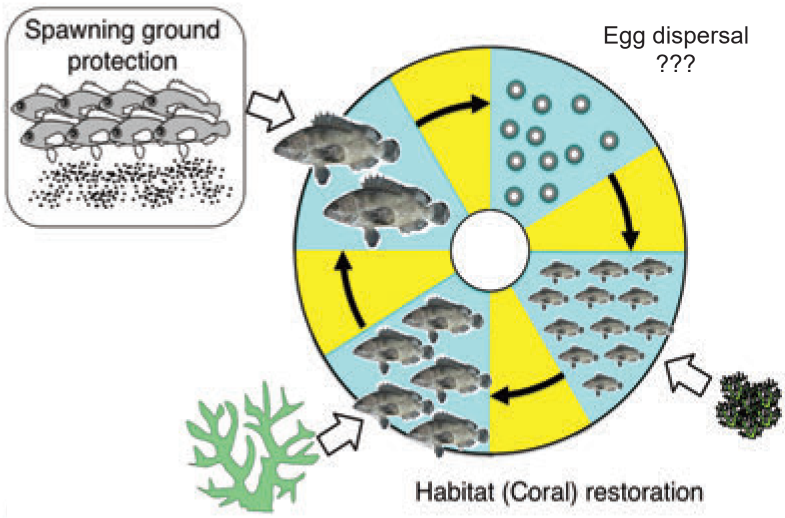

Fig. 6. Schematic diagram showing the strategy to enhance spawning aggregation protection by coral community restoration. Since the spawning ground has already been protected, other protective actions at earlier life stages would be effective. If appropriate, corals are selected and when these coral communities are successfully restored, fish population size would increase at their home ground resulting in large spawning aggregations at the protected spawning ground during the spawning season. The manner in which egg dispersal occurs should be clarified in the future.

Site fidelity and returning ability

Tagged individuals showed high site fidelity to their release point (patchy coral substrates). For returning ability, 10 individuals were analyzed and 8 out of the 10 individuals showed precise returning after the spawning migration to the patchy coral substrates that were used before the spawning migration (Nanami *et al.,* 2018).

Discussion

The results of the present study showed several strategies for coral restoration to enhance spawning aggregation protection (**Fig. 6**): (1) conservation of coral communities around the spawning ground is indispensable; (2) coral species that are preferentially used by *E. ongus* should be selected for coral community restoration. In particular, restoration of genus *Acropora* is urgently needed due to the greater susceptibility to coral bleaching; (3) the area that is c.a. 8.8 kilometers around the spawning ground should be the proposed area for coral community restoration. Since high site fidelity and returning ability after spawning migration were found, it follows that the successfully restored coral communities would be used by the species throughout their lifetime. One of the future challenges is to clarify the manner of egg dispersal from the protected spawning ground (*e.g.* Almany *et al.,* 2013). If the eggs produced from the protected ground arrive at a restored coral community, it is expected that greater settlement at the restored corals would be exhibited.

Acknowledgments

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Annotated Bibliography of Key Works

(1) Almany G. R., Hamilton R. J., Bode M., Matawai M., Rotuku T., Saenz-Agudelo P., Planes S., Berumen M. L., Rhodes K. L., Thorrold S. R., and Russ G. R., 2013: Dispersal of grouper larvae drivers local resource sharing in a coral reef fishery. *Current Biol.*, **23**, 626–630.

This study examined the dispersal distance of larvae from the spawning ground for a coral reef grouper, *Plectropomus areolatus*. The parentage analysis revealed that 50% of larvae settled within 14 km of the spawning ground. The noteworthy point of the study is that spawning ground protection would be effective at a local scale (within several to ten kilometers) for larval dispersal.

(2) Nanami A., Sato T., Takebe T., Teruya K., and Soyano K., 2013: Microhabitat association in white-streaked grouper *Epinephelus ongus*: importance of *Acropora* spp.. *Mar. Biol.*, **160**, 1511–1517.

This study quantified microhabitat associations for juvenile and adult white-streaked grouper. For juveniles, most individuals showed a significant positive use of bottlebrush *Acropora*. For adults, most individuals showed a significant positive use of staghorn *Acropora*. A habitat choice experiment, using pre-settlement individuals, revealed that both bottlebrush *Acropora* and staghorn *Acropora* were used as settlement sites, whereas coral rubble was rarely used as a settlement site.

(3) Nanami A., Ohta T., and Sato T., 2015: Estimation of spawning migration distance of the white-streaked grouper (*Epinephelus ongus*) in an Okinawan coral reef system using conventional tag-and-release. *Environ. Biol. Fish.*, **98**, 1387–1397.

Using a tag and release method, this study estimated the migration distance and the degree of unified movement of white-streaked grouper associated with the spawning migration. In total, 1157 *E. ongus* individuals were tagged and released at their home grounds in the non-spawning period and 350 were tagged at a known spawning ground in the spawning period. The estimated migration distances from the home ground to the spawning ground ranged from 2.2 to 8.8 km.

(4) Nanami A., Sato T., Kawabata Y., and Okuyama J., 2017: Spawning aggregation of white-streaked grouper *Epinephelus ongus*: spatial distribution and annual variation in the fish density within a spawning ground. *PeerJ,* **5**, e3000.

This study revealed 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.

(5) Nanami A., Mitamura H., Sato T., Yamaguchi T., Yamamoto K., Kawabe R., Soyano K., Arai N., and Kawabata Y., 2018: Diel variation in home range size and precise returning ability after spawning migration of a coral reef grouper *Epinephelus ongus*: implications for effective marine protected area design. *Mar. Ecol. Prog. Ser.*, **606**, 119–132.

This study examined the diel variation in home range size and the degree of precision for returning ability of white-streaked grouper by acoustic telemetry. Seventeen individuals were studied, and nighttime home range sizes were over 5-times greater than the respective daytime home ranges. Returning ability for 10 individuals that showed clear spawning migration behaviour was also analyzed and 8 out of the 10 individuals showed precise returning after the spawning migration to the patchy coral substrates that were used before the spawning migration.