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The 16th International Symposium on Integrated Field Science

"Future of Marine Aquaculture: Finding Solutions to Challenges"

March 22, 2019 Lecture Room No. 7 in Aobayama Commons, Tohoku University, Sendai, Japan

Objective

Since the Romans started oyster and fish culture in Mediterranean lagoons around 500 BCE, marine aquaculture has brought enormous bounties to humankind. Hence its importance has continued to be recognized globally. However at present, serious challenges such as environmental pollution, fish health issues, genetic contamination and negative ecological impact of farmed fish escapees on wild populations as well as the lack of appropriate measures to adapt to global warming need to be addressed. Future marine aquaculture should therefore effectively address these problems to enable sustainable harvests while minimizing adverse impacts on the environment and considering the limited natural resources. In the coastal areas affected by the 2011 Tohoku earthquake and tsunami, attempts to establish new marine aquaculture systems have commenced, taking stock of the aforementioned problems. The aim of this symposium is to review recent efforts in foreign countries and the affected areas, and subsequently we discuss about future desirable marine aquaculture.

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Symposium mini review

Biological Control of Sea Lice Infestation in the Norwegian Salmon Aquaculture: Are Cleaner Fish a Solution?

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Keywords
Atlantic salmon, *Salmo salar*, delousing, lumpfish, wrasse

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Abstract

Norway leads the world aquaculture production of Atlantic salmon (*Salmo salar*). However, salmon lice infestation remains a major challenge for the industry which is continuously evolving towards mitigating the sea lice problem. Among the different prevention and treatment measures available, the biological control of sea lice infestation by cleaner fish has been suggested to be the most economic and environmentally friendly option. However, the intensive fishing pressure on natural populations and the potential risks of genetic introgression associated to fish translocations have questioned this perception. Moreover, the increasing number of transparent lice as well as cleaner fish health and welfare issues have raised concerns regarding current cleaner fish practices. This manuscript provides a general overview of the biological control of sea lice infestation through the use of cleaner fish in Norway, and highlights recent concerns regarding this approach to tackle the sea lice problem.

1. Norwegian salmon production and the sea lice problem

Norwegian annual Atlantic salmon (*Salmo salar*) aquaculture production exceeds 1.2 million tons and a value of approximately 800 bilion JPY (Anonymous, 2019). In line with the other main salmon producer countries, further growth of Norwegian salmon aquaculture industry is constrained to reduce sea lice infestation which has become a growing economic burden (Liu and Bjelland, 2014; Abolofia *et al*., 2017). A wide range of prevention and treatment measures have been developed and tested against parasitic sea lice; including the use of chemotherapeutants, administered either orally or bathing the fish, and non-medical approaches such as mechanical, thermal and biological treatments using cleaner fish (Overton *et al*., 2018). Salmon delousing by cleaner fish has increased popularity in recent years as it has been considered the most sustainable approach (Treasurer, 2012; Liu and Bjelland, 2014). Indeed, the efficiency of several cleaner fish species for lice removal is currently investigated in several countries worldwide.

2. Cleaner fish species used for sea lice removal in Norwegian salmon aquaculture

In Norway, the group of cleaner fish used for sea lice removal comprises five main species which can be divided in two major groups. In northern regions, salmon farms use the cold-water adapted lumpfish, *Cyclopterus lumpus*, a species traditionally harvested for their roe. Wild lumpfish populations are believed to be small, and display significant phenotypic differences and low genetic variability (Whittaker *et al*., 2018). Their supply to the salmon industry (over 30 million fish in 2017, Anonymous, 2019) relies on commercial production from wild broodstock whose eggs are often translocated over long distances (Jonassen *et al*., 2018). Further south, the use of lumpfish decreases in favor of mainly four temperate wrasses: ballan (*Labrus bergylta*); corkwing (*Symphodus melops*), goldsinny (*Ctenolabrus rupestris*), and rock cook (*Centrolabrus exoletus*) wrasse to a lesser extent. Commercial rearing techniques for wrasses are limited to ballan wrasse which represented less than 5% of the over 22 million wrasses deployed in salmon cages in 2017 (Anonymous, 2019). Rising sea water temperatures registered in the last decades have favored a drastic increase in abundance of wrasses in southern Norway (Knutsen *et al*., 2013). The mismatch between the

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large number of wrasses available and the low number of salmon farms operating along the Skagerrak coast of Norway and Sweden, has promoted that millions of adult wrasses fished annually in southern regions are translocated to salmon farms located in northern areas where local stocks cannot cope with their high demand (Blanco Gonzalez and de Boer, 2017).

3. Major concerns of the recent expansion in the use of cleaner fish

The biological control of sea lice through the use of cleaner fish is expected to be the main salmon delousing treatment over the next years (Bolton-Warberg, 2018; Brook *et al*., 2018). However, the large number of cleaner fish recently employed in the salmon industry, and the sex- and size-selectivity of the fishery have raised concerns regarding the vulnerability of natural populations to overfishing (Blanco Gonzalez and de Boer, 2017; Halvorsen *et al*., 2017; Powell *et al*., 2018). The strong spatial patterns of phenotypic and genetic differentiation and high proportion of potentially translocated individuals escapees in the proximities of salmon farms raised additional concerns in relation to putative genetic introgression (Blanco Gonzalez *et al*., 2016; Jansson *et al*., 2017; Faust *et al*., 2018; Whittaker *et al*., 2018). Ongoing efforts to develop selective breeding programs for lumpfish and ballan wrasse may help to reduce the fishing pressure on wild populations; yet, increase the risk of genetic introgression. In this regard, the low proportion of lumpfish feeding actively on sea lice (Imslad *et al*., 2016) is one of the main issues to be solved. The rapid increase in number of transparent sea lice found in some regions has also questioned previous perceptions promoting the use of cleaner fish due to the inability of sea lice to develop resistant mechanisms against them. Cleaner fish health and welfare is another point of concern requiring further research (Rimstad *et al*., 2017).

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Symposium mini review

Genetic Research Initiatives for Sustainable Aquaculture Production in the Philippines

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Keywords
selection, genetic diversity, broodstock management, inbreeding, genomics

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Abstract

The Philippines is one of several countries in Southeast Asia that has, for several decades, made steady contributions to world aquaculture production both from inland and marine waters. In recent years, fish production has been on the decline mainly because of the lack of quality seedstock, limited stocks of captive breeders or spawners of major aquaculture commodities, adverse effects of climate change and other environmental factors on fish breeding and rearing, fish diseases caused by pathogenic organisms and prohibitive cost of aquaculture inputs such as feeds, etc. Genetic researches have been conducted mostly through local grants with the aim of addressing the aforementioned constraints. Such initiatives focused on developing and applying methods in (a) selective breeding; (b) marker-assisted genetic strain assessment for broodstock development and for monitoring inbreeding in farmed stocks and (c) genomics to understand and enhance on-farm stock performance through the identification of genes that are responsible for nutrition, stress and immune responses, among others. This paper highlights examples of local genetics applications in tilapia, mangrove crab, shrimp, milkfish and abalone aquaculture. The significance of implementing genetic interventions to boost and sustain aquaculture production in the Philippines is likewise discussed.

1. Introduction

In the past decade, aquaculture production has gradually increased to levels that represent almost 50% of the total global fish production (FAO, 2018). Of the total world aquaculture production, 89.2% or 71.5 million tonnes come from Asia, with Philippines ranking as the 7th major contributor, having 796,000 tonnes produced in 2016. This, in spite of the challenges that the aquaculture industry has faced, is currently experiencing. FAO (2018) has projected a growth in Philippine aquaculture production of 36,300 tonnes by the year 2030. This can be achieved if the industry finds solutions to problems pressing both aquaculture and fisheries, such as poor quality seedstock and broodstock, costly and/or inferior diets, poor husbandry methods, among others. Recognizing the problems besetting aquaculture, local research and academic institutions have continuously worked on either environmental and/or genetic interventions to ensure sustainable aquaculture.

2. Environmental interventions to increase aquaculture production

Farmed fish production involves four phases, namely: (a) broodstock development, management and breeding, (b) hatchery seed production, (c) nursery rearing, and (d) grow-out culture. Each phase requires environmental interventions to optimize fish yield. Knowledge on proper nutrition and maintaining optimal water quality conditions are essential from broodstock development and management to grow-out. However, the major phases that can benefit from appropriate environmental interventions are at the nursery and grow-out phases since these are when one needs skills in good aquaculture practices and/or husbandry such as applying the correct fish stocking rate, feeding schemes, water quality and fish health management etc.

3. Genetic solutions for improved fish production

Genetic technologies have for some time, provided options for aquaculturists to improve their fish farm output. The Philippines have embarked on several projects, some internationally funded, to boost local fish production by way of genetic programs. Such projects focused on major aquaculture species such as tilapia, milkfish, shrimp and mangrove crabs. Apart from these, species that may not be widely farmed but are important (e.g. abalones) have been subjects of genetic studies in view of the need for their populations to be genetically characterized and propagated for resource conservation and enhancement. Some of the genetic methods include selective breeding, DNA marker assisted broodstock development and management and the more advanced technologies such as genomics. Applications of these methods shall be discussed in the foregoing sections, that is, according to species.

4. Increasing tilapia production through genetic strain improvement

Tilapias, particularly of the genus *Oreochromis,* have been introduced into Asia from Africa as early as in the 1950s, starting with the highly prolific *Oreochromis mossambicus*. Three species, namely *O. mossambicus*, *O niloticus* and the red tilapia hybrids (*Oreochromis* spp) are important in Philippine aquaculture however of the three, the Nile tilapia (*O. niloticus*) has been farmed widely, not minding if the species is not indigenous as it has been cultured in different enclosures (tanks, lake-based cages, and ponds) and are now found in freshwater lakes and other inland waters. The popularity of the species peaked in the early to mid-1980s when the Philippines even became the highest tilapia producing country in the world. Gradually, tilapia farm yields declined and the reduction has been attributed to factors that primarily include genetically depauperate (e.g. inbred) stocks that have become slow-growing and less fit. This has prompted the government fisheries agency, public as well as private academic and research institutions to work together to develop genetically enhanced tilapia stocks to support the need of the tilapia farms for quality, fast growing seedstock (SEAFDEC, 2017). **Table 1** lists some of the tilapia strains (GIFT, GMT, FaST) that have been developed in the Philippines (SEAFDEC, 2017; Asian Development Bank, 2005; WorldFish Center, 2004; Mair *et al*., 1995). The improved strains have been disseminated locally and have also been exported to other tilapia producing countries after private entities (GIFT Foundation International Incorporated, Genomar, PhilFishGen) took over the operations from the agencies that developed them. In 2004, several of the improved Nile tilapia strains and red tilapia hybrids have been genetically characterized using mtDNA-RFLP and microsatellite markers (Romana-Eguia *et al*., 2004). Results have been used to confirm which among the strains have high genetic diversity and such information have been used to validate the good performance the strains have in culture. Information as well on the use of genetic markers to monitor inbreeding in selected stocks have been generated (Romana-Eguia *et al*., 2005). This has generally been used to demonstrate evidence of increased inbreeding rate in subsequent generations of a mass selected tilapia strain developed from a limited founder stock. Such studies could have practical implications on how selected fish in general should be managed especially when kept and used as hatchery broodstock.

Overall, the tilapia genetic improvement programs have been beneficial to the tilapia industry in that during the period that several selected breeds were disseminated, tilapia production gradually increased not only in the Philippines but also in Bangladesh, China etc. where some of them were made available (FAO, 2018).

5. Marker-aided broodstock management to improve milkfish production

Milkfish is a commercially important commodity in the Taiwan, Indonesia and in the Philippines (where it is

Table 1. List of genetically improved strains of Nile tilapia (*Oreochromis niloticus*) developed in the Philippines (modified from SEAFDEC, 2017).

STRAIN	GENETIC PROGRAM/METHOD
GIFT Tilapia	Genetically improved farm tilapia (GIFT) program: Combined family and within family selection for improved growth
Genomar Supreme Tilapia (GIFT-derived)	Genomar Project: Combined selection for improved growth, marker assisted selection
GET Excel and **iExCEL** or improved GET Excel stocks	GET-Excel Program:Outcrossing two fast-growing strains (FAST and GIFT) for improved growth
Genetically Male Tilapia or YY supermale tilapia	Genetically Male Tilapia (GMT) Program: selective breeding and sex reversal methods
Brackishwater Enhanced Selected Tilapia (BEST) and i-BEST or improved BEST	Brackishwater Enhanced Selected Tilapia Program: hybridization and outcrossing; size-specific selection for salinity tolerance
Cold tolerant tilapia	Cold tolerant tilapia: hybridization
FAST Tilapia	Freshwater Aquaculture Center Selected Tilapia Program: rotational mating and hybridization
SaltUno tilapia straina	Molobicus or SaltUno project: hybridization to produce salt tolerant tilapia

considered as a national fish). In the Philippines, successful completion of the life cycle in captive milkfish stocks was achieved in 1975 and several generations have been produced from thence owing to research breakthroughs at the Aquaculture Department of the Southeast Asian Fisheries Development Center (SEAFDEC/AQD) where milkfish R&D work continues to date. Earlier studies focused on milkfish reproductive physiology and later, on the development of hatchery, nursery and grow-out methods. At one point, the government attempted to harmonize efforts in milkfish seedstock production among public hatcheries by establishing a National *Bangus* (local term for milkfish) Breeding Program. This initiative met some funding problems well into a decade and a half from the time the program was established that prompted the government hatcheries to sell their breeders to private farms. At present, SEAFDEC/AQD has broodstock that are close to four decades old and are still spawning. Several private milkfish farms either procure stocks for culture and/or propagation from Indonesia, which has a well-organized system of fry production that enables them to sell their fry at a cost lower than Philippine sources. It has been noted that in the past few years, the Philippines has been importing more than 50% of its two billion annual fry requirements from Indonesia. This has therefore encouraged some work on the DNA marker-based genetic assessment of wild and hatchery stocks to enable local farmers to identify good sources of either broodstock. material and/or seedstock for on-growing to marketable sizes, in their farms. A study on milkfish genetic variation showed that the local milkfish breeders (both from the wild and from the hatchery) except those kept as mixed generation stock in a government hatchery facility, have genetic diversity levels comparable to the imported Indonesian stock (Romana-Eguia *et al*., 2018). It is indicative therefore of the fact that since the imported stock is initially perceived to be better than our own, the Philippine farmers can very well rely on the domesticated stocks for providing fry/fingerlings to address the increasing industry demand for good quality milkfish seedstock.

6. Genetic and genomic applications in Mangrove crab farming

Mangrove crab aquaculture in the Philippines is a growing industry although mangrove crab production ranks 9th among the commonly farmed aquatic species in terms of quantity. Nonetheless, the local and export market demand for this commodity (either live and hard-shelled or frozen and soft-shelled forms) has been increasing thus warranting particular attention in terms of improving its current supply. The mangrove crab species found in the Philippines are three, namely *Scylla serrata* (a fast growing hence most preferred species), *S. tranquebarica* and *S. olivacea*. *S. serrata* has been well-studied; from domestication, genetic stock characterization (Quinitio *et al.*, 2011) and recently, selective breeding. These notwithstanding, more studies are still being conducted and these involve basic researches that are geared towards the development of technologies that have practical applications. For example, juvenile stages of the three local species are difficult to distinguish from each other. Hence, a mobile phone application, known as “Crabifier” was developed for crab collectors, traders and crab farmers. This is based on molecular marker data and image analysis (Vince Cruz-Abeledo *et al*., 2018). Other genetic/genomic tools that have been applied in mangrove crab farming research have generated valuable data described in what the proponents conveniently refer to as “CrabMAP”, “CrabADAPT”, “CrabMOLT” and “CrabSNP” (DOST-PCAARRD, in press). Briefly, “CrabMAP” refers to temperature vulnerability maps for local key areas where mangrove crabs are farmed. Such information will be valuable in developing climate smart aquaculture, in this case for rearing *Scylla* crabs. On the other hand, “CrabADAPT” refers to information on genetic adaptability of certain mangrove crab populations when exposed to wider temperature range and anomalies. The idea is based wholly on gene expression patterns across populations that are exposed to different temperature profiles. Meanwhile, “CrabMOLT” refers to the study where optimal salinity and temperature combinations that would favor frequent molting in crabs were investigated. Frequent molting would be indicative of crabs that could be fast growing. It is in this study where the ratios of a molt-promoting hormone (ERK) to a molt-inhibiting hormone (MIH) were established for the different molting stages of the mangrove crabs. Finally, “CrabSNP” is a study on the identification of single nucleotide protein (SNP) variants associated with adult sized immature female crabs, and identified genome markers that may be associated with such phenotypes. Immature female mangrove crabs command a high price in the local trade. All these novel genetics based technologies shall be further validated with more farmers the aim of helping them improve their production.

7. Genetic tools in shrimp health management

The tiger shrimp *Penaeus monodon* has for some time been a major export income earner for the Philippines prior to the industry experiencing production slumps due to shrimp viral diseases e.g. AHPND or acute hepatopancreatic necrosis disease (De La Peña *et al*., 2015). Several large-scale commercial shrimp producers have access to imported specific pathogen free (SPF) shrimp from e.g. Hawaii, however small to medium scale shrimp growers have no recourse but to procure wild and/or hatchery-bred seedstocks with the risk of using juveniles that are highly susceptible to diseases. In this regard, local shrimp culturists are advised to report pathogens found in Penaeid shrimps in their farms through a website referred to as Online Philippine Shrimp Pathogen Information Resource (OPSPIR; opspir.seafdec.org.ph) developed by UP, Ateneo de Manila University, the Philippine Genome Center, the Bureau of Fisheries and Aquatic Resources, the Department of Science and Technology and SEAFDEC/AQD. This initiative is a countrywide bio-surveillance system that will enable the documentation and mapping of areas where shrimp farms are affected by specific pathogens. Once reported, validation of the reported occurrence can be made on samples collected on-site by using PCR-based diagnostic tools while referring to genome sequences in the OPSPIR database.

8. Genetics for abalone aquaculture and stock enhancement

The abalone or “awabi” in Japanese is a highly-priced marine mollusk. In the Philippines, SEAFDEC/AQD has, since 1994, studied the indigenous species known as donkey’s ear abalone or *Haliotis asinina*. Although culture techniques and requirements have already been established locally, the industry has yet to achieve steady growth. The lack of information on good sources of quality abalone seedstock and broodstock could somehow explain its limited production from aquaculture. A study aimed to generate a preliminary database on possible sources of genetically diverse *Haliotis asinina* stock was conducted. Samples from one hatchery-bred and nine wild sourced founder stocks and their F_1 offsprings were analysed for genetic variability using microsatellite markers. Together with growth data from the same, information from this study shall be used to identify local stocks most suitable for breeding and farming.

9. Conclusion

It is with much optimism that the Philippine aquaculture industry views the foregoing genetic initiatives to boost fish production. The impact created by the adoption of genetic improvement schemes on tilapia production in recent years could prove the advantage/benefits of using such interventions. Aside from conventional selective breeding methods, recent developments and tools in genetics research such as genomics, gene editing etc. as applied in aquaculture could hasten and sustain its growth and ultimately address the global need for food security.

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Symposium mini review

The 2011 Tohoku Tsunami, Marine Ecosystem Dynamics, and the Re-establishment of Coastal Aquaculture Facilities in Onagawa Bay, Japan

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Keywords
benthic macrofauna, coastal aquaculture, marine ecosystem ecology, environmental disturbance, 2011 Tohoku earthquake and tsunami, anthropogenic influence, spatio-temporal dynamics, Onagawa Bay

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Abstract

For many towns and villages along the Pacific coast of northern Japan, also locally known as the “Sanriku Coast”, fishing and aquaculture had been the primary industries. However, the 2011 Great East Japan Earthquake and tsunami devastated these communities, destroying most of fishing vessels, and severely damaged fishery related infrastructure including entire aquaculture installations. Reconstruction of coastal aquaculture facilities was therefore a pressing issue for many of the tsunami-affected areas. However, recent studies report, to a varying degree, negative effects of marine aquaculture operations on the surrounding environment. There are mainly two methods that are widely used for aquaculture operations along the Sanriku Coast. One is hanging culture using a long-line system to cultivate shellfish and edible ascidians. The other method is fish cages for farming finfish. In connection with aquaculture operations, benthic communities are often used as indicators of environmental health and trends in coastal marine ecosystems. This study thus reviews the general impacts of both fin and shellfish mariculture operations on the surrounding environment and considers the implications of the rehabilitation of coastal aquaculture facilities in Onagawa Bay for marine ecosystem dynamics following the 2011 Tohoku earthquake and tsunami with particular reference to the dynamics of benthic macrofaunal communities.

Introduction

On 11 March 2011, the Great East Japan Earthquake and subsequent tsunami severely damaged extensive areas of the Pacific coast of the Tohoku region in northern Japan. This region is locally known as the “Sanriku Coast”, and offshore of the coast is lying the intersection of major warm and cold ocean currents, providing some of the most productive fishing grounds on earth. Many towns and villages in the Sanriku region are therefore renowned for its commercial fishing and aquaculture industry. Major ports, such as Onagawa, are locally famous for a variety of wild-caught and farmed seafood including flatfish, Pacific cod, salmon, shellfish and cultured ascidians. In Onagawa Bay alone, there used to be over 1200 long-lines for culturing scallops, oysters and edible ascidians as well as around 120 fish cages for farming salmonids. However, the 2011 earthquake and tsunami destroyed the entire aquaculture installations in the embayment. Rebuilding coastal aquaculture was therefore a pressing issue for many of the tsunami-affected coastal communities for the potential positive social and economic effects.

Recent studies, however, often demonstrate, to a varying degree, negative effects of marine aquaculture operations on the environment through changes in the physical, chemical and biological attributes of sediments below and the water column around aquaculture facilities (e.g., Tovar *et al*., 2000; Borja *et al*., 2009; Forchino *et al*., 2011; Sarà *et al*., 2011; Farmaki *et al*., 2014; Tomassetti *et al*., 2016). After the 2011 Tohoku disaster, both fin and shellfish aquaculture facilities have been steadily re-established in Onagawa Bay, mainly along low-energy coastal waters where organic material may readily accumulate, and questions regarding the potential effect of such rebuilding activities on coastal ecosystems have arisen.

This study first reviews change in the spatial coverage of fin and shellfish aquaculture facilities following the 2011 Tohoku earthquake and tsunami in Onagawa Bay. This is followed by a brief account of the general impacts of fin and shellfish aquaculture operations on the surrounding environment. Benthic communities have long been used as indicators of environmental health and trends in coastal marine ecosystems (Borja *et al*., 2009; Forchino *et al*., 2011; Tomassetti *et al*., 2016). Simple schematic representation is thus constructed to summarise the impacts of changes in multiple environmental factors on the recovery of coastal ecosystem based on a case study of benthic macrofaunal community dynamics in Onagawa Bay. This paper provides the implications of the rehabilitation of coastal aquaculture facilities for marine ecosystem dynamics following the 2011 Tohoku earthquake and tsunami with particular reference to the dynamics of benthic macrofaunal communities in Onagawa Bay.

Spatio-temporal change in fin and shellfish aquaculture facilities in Onagawa Bay

There are mainly two methods that are commonly used for aquaculture operations in Onagawa Bay. One is hanging culture using a long-line system in which cultured organisms such as oysters, scallops and edible ascidians are suspended on vertical ropes, typically down to around 15 to 20 m in depth below buoys floating on the surface. The other method is floating fish cages for farming salmonids, usually made of mesh framed with steel and/or plastic and with floating modules fixed along the cage boundaries.

Prior to the 2011 disaster, there were 1217 long-lines and 119 fish cages for aquaculture operations in Onagawa Bay. After the complete removal of the aquaculture facilities by the disaster, 135 long-lines and 56 fish cages were re-constructed by February 2012 (nearly a year later), which accounted for the recovery of 11.1% and 47.1%, respectively (Fujii *et al*., 2019). In March 2017, the number of the respective aquaculture facilities were recovered by 60.0% (730 long-lines) and 58.8% (70 fish cages), which corresponded to the total surface areas of 0.115 km^2 and 0.016 km^2, respectively (Fujii *et al*., 2019). This also reveals that the spatial extent of shellfish/ascidian culture covers 87.5% of the total area used for aquaculture operations, in comparison with finfish farms (12.5%), in Onagawa Bay.

Environmental impacts of finfish aquaculture

In coastal aquaculture, finfish farming normally requires a significant amount of feed and nutrients input into the ocean. This can change pelagic-benthic energy fluxes. Overfeeding often leads to excessive flux of organic matter onto the seafloor, potentially altering local sediment characteristics and benthic community composition (Crawford *et al*., 2003). Chemicals and excess nutrients from formulated feeds as well as feces associated with bio-deposition can therefore not only enrich sediments but even disturb and/or smother benthic communities dwelling below the associated farming facilities (Borja *et al*., 2009; Forchino *et al*., 2011; Tomassetti *et al*., 2016).

Recent studies also suggest that bio-deposits produced from finfish mariculture can disperse and spread through the water column and thereby affect benthic communities at a much broader spatial scale than the immediate vicinity of aquaculture facilities (up to several kilometres) (Borja *et al*., 2009; Yokoyama, 2010; Sarà *et al*., 2011).

Although the spatial extent of finfish farms is significantly smaller than that of shellfish culture in Onagawa Bay, the degree of environmental impact exerted by finfish farming is likely to depend primarily on environmental conditions such as: hydrography; average current speed; depth under farm facilities; distance to farm; sediment granulometry, as well as anthropogenic/operational factors such as: the size of the farm; the cultured species; years of production; annual production; type of feed; culture methods (Wu, 1995; Borja *et al*., 2009; Yokoyama, 2010; Forchino *et al*., 2011; Sarà *et al*., 2011; Tomassetti *et al*., 2016).

Environmental impacts of shellfish/ascidian aquaculture

Environmental effects of shellfish and ascidian aquaculture on seafloor may be somewhat different from those associated with finfish culture in cages (Weise *et al*., 2009). Cultured shellfish and ascidians feed entirely on naturally occurring phytoplankton in the water column. Consumed organic material and nutrients then return to the environment as feces or undigested waste, which falls onto the seafloor and may become important food source for benthic deposit feeders (Shumway *et al*., 2003; McKindsey *et al*., 2006). Shellfish/ascidian culture is generally considered to have less environmental impacts than finfish aquaculture because cultured organisms do not require any input of external feed or fertilizers and are grown at comparatively lower intensity (Shumway *et al*., 2003; McKindsey *et al*., 2006; Weise *et al*., 2009).

However, overstocking of these cultured organisms may deplete phytoplankton locally and affect the seafloor environment directly through their feeding activities (Crawford *et al*., 2003). Further, abrupt change in cultivation intensity may lead to an unbalanced ecosystem (Shumway *et al*., 2003). For example, in Ofunato Bay located on the Sanriku Coast, significant increase in phytoplankton biomass, which was followed by significant decrease in nutrients, was considered to be caused by the massive reduction in the number of shellfish mariculture rafts following the 2011 Tohoku earthquake and tsunami (Yamada *et al*., 2017).

Re-establishment of coastal aquaculture and ecosystem response in Onagawa Bay

Fujii *et al.* (2019) examined spatio-temporal dynamics of benthic macrofaunal communities in relation to changes in multiple environmental factors with particular reference to the rehabilitation process of coastal aquaculture facilities in Onagawa Bay, following the 2011 Tohoku earthquake and tsunami. They showed well-defined increases in macrofaunal abundance, biomass, and species diversity during the study period between 2012 and 2018 (Fujii *et al*., 2019). Comparison with the pre-tsunami data (2008-2011) also confirmed that the benthic macrofaunal community largely recovered over the duration of this period (Fujii *et al*., 2019). These community changes correlated significantly with a combination of both natural and anthropogenic factors, namely: (1) proximity to the nearest aquaculture facilities; (2) wind fetch length (exposure); (3) sediment grain size; (4) the total area of the aquaculture facilities (Fujii *et al*., 2019). These findings suggest: (a) the physical presence of aquaculture facilities has significant positive effects on benthic macrofaunal populations; (b) wind fetch length, as an indicator of exposure, significantly affects benthic macrofaunal communities; (c) changes in sediment granulometry significantly influence the dynamics

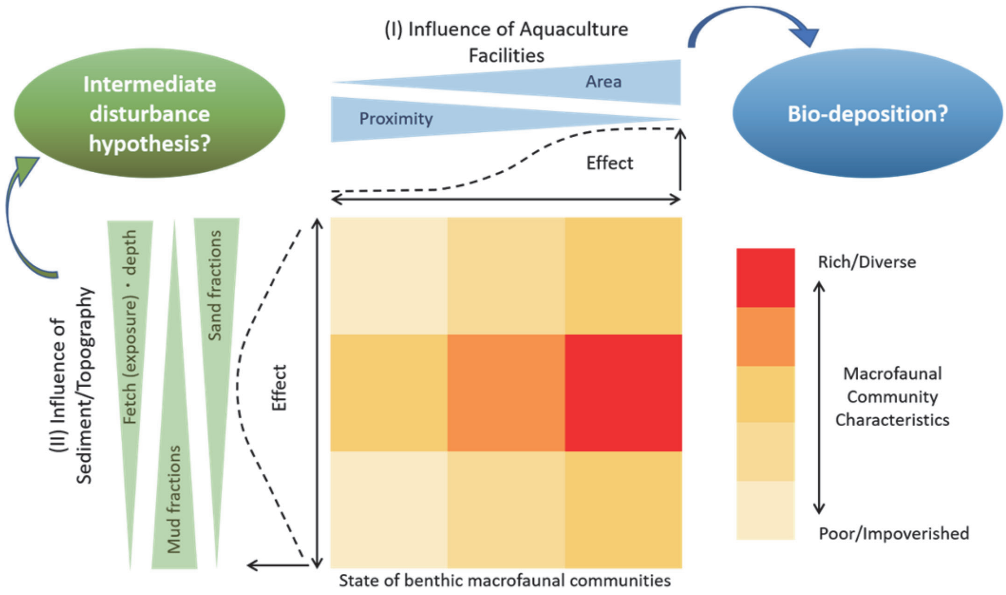

Fig. 1. Schematic representation of relations between benthic macrofaunal communities and key environmental variables illustrating their likely effects and possible mechanisms: (I) along a gradient of aquaculture facilities; (II) along a gradient of sediment/topography.

of macrofaunal community structure; (d) increasing extent of aquaculture facilities has significant positive effects on benthic macrofaunal populations (**Fig. 1**).

Before the 2011 disaster, the sand fractions were significantly higher at some locations in Onagawa Bay. However, the disaster brought anomalous deposition of mud across the whole bay following vigorous erosion and deposition of fine-grained sediments associated with a strong tsunami-induced current (Seike *et al*., 2016). Abrupt increase in fine-grained sediment could adversely affect benthic community through smothering and clogging feeding structures of suspension-feeders (Thrush *et al*., 2004). Spills of toxic chemicals (e.g., heavy oil) may also have exacerbated impacts on subtidal benthic communities immediately after the 2011 tsunami (Abe *et al*., 2015). However, the combination of local hydrodynamic processes and the flux of organic matter (bio-deposit) generated by the re-establishment of aquaculture operations in Onagawa Bay may have counteracted such negative impacts and thereby positively influenced the dynamics of benthic macrofaunal populations and fuelled benthic recovery (Fujii *et al*., 2019).

Conclusion

In Onagawa Bay, coastal aquaculture operations may well have played a significant role in shaping the occurrence and distribution patterns of benthic macrofauna and thereby influencing recovery of benthic community at an ecosystem-scale following even a catastrophic natural disaster such as the 2011 Tohoku earthquake and tsunami in Japan. To better understand the mechanisms of such marine ecosystem dynamics, there is a need for future research on how distribution of aquaculture operations relates to the physical, chemical and biological attributes of the surrounding water and sediments below and how other environmental parameters such as coastal topography and/or hydrodynamic processes interrelate benthic-pelagic dependencies across Onagawa Bay.

Acknowledgements

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Symposium mini review

Possible Use of Blue Light in *Undaria Pinnatifida* Aquaculture

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Keywords
blue LED light, growth, kelp, *Undaria*, *Eisenia*, isopod, *Cymodoce japonica*

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Abstract

Latest studies have shown that blue light promotes the growth of both gametophytes and sporophytes of laminarian kelps (Xu *et al*., 2005; Wang *et al*., 2010; Murase *et al*., 2014). On the contrary, insects and some other invertebrate animals are negatively affected by the blue light emission (Hori *et al*., 2014; Xiaolong *et al*., 2015). Therefore, we aimed to promote the growth of cultured *Undaria pinnatifida* and also to deter the herbivorous grazing isopod *Cymodoce japonica* by the emission of blue light. *Cymodoce japonica* grazes on the young sporophytes of cultured *U. pinnatifida* and often causes great loss of its production (Yamaguchi and Nishioka, 1998; Kiriyama, 2007). Water-proof blue LED light capable of emitting in every night time for more than two months was developed and employed underwater for the growth experiment of *U. pinnatifida* in the field from January to April 2018. In the laboratory, alternative selection experiments from four conditions: red, green and blue LED lights and dark were conducted in a container for 30 individuals of *C. japonica*. The nocturnal blue light emission in the field promoted the growth of *U. pinnatifida.* In the laboratory choice experiments, *Cymodoce japonica* apparently avoided blue light. Therefore, the blue light emission to young sporophytes will largely contribute to the rise of *U. pinnatifida* production through the promotion of growth and the exclusion of grazers.

Acknowledgments

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Symposium mini review

Recent Challenges for Developing Barnacle Aquaculture Techniques in Japan

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Keywords
aquaculture, *Balanus rostratus*, barnacle, larval culture, tourism resources

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Abstract

More than ten species of barnacles are distributed in the market worldwide. In Japan, they have high potentials as tourism and fishery resources. Small scale aquaculture has been conducted in Aomori prefecture, Japan, since about 20 years ago. However, it needs high quality of skills and only a few fishermen are engaged in the aquaculture. Authors and colleagues have made efforts to develop novel techniques by using Japanese species to achieve efficient production of spats in hatchery and well-shaped barnacles with flat bottoms, by which each individual is easily harvested from the substratum. In addition, there has been increasing interest in developing efficient aquaculture techniques of barnacles worldwide since the resources are declining because of overexploitations. While further efforts are needed, our studies will contribute to activate the local tourisms and economies, as well as conserving resources.

Introduction

Thoracican barnacles (hereafter referred as barnacles) are sessile crustacean that dominate many intertidal and subtidal environments. Barnacles consist of two orders, Pedunculata (goose barnacles) and Sessilia (acorn barnacles). Goose barnacles attach themselves by means of a stalk while acorn barnacles lack the stalk and their shells directly attach to the substratum. Today, more than ten species of barnacles are distributed in the market worldwide and most of them are consumed by local communities (López *et al*., 2010; 2012a). A goose barnacle *Pollicipes pollicipes* 'percebes' is popular in Iberian Peninsula (López *et al*., 2010; 2012a). The production of this species is 300 to 500 tonnes / year in recent years (López *et al*., 2010), and resources are decreasing because of the overexploitation (Jacinto *et al*., 2011; Carvalho *et al*., 2017). An acorn barnacle *Austromegabalanus psittacus* 'picoroco' is harvested by local fishermen with average landings of 200 t/y in Chille (López *et al*., 2010). It is also suggested that overexploitation driven resource decline occurs in this species (López *et al*., 2012b). Such resource declines increased interest to the aquaculture of barnacles (Franco *et al*., 2015; 2017; López *et al*., 2012b). However, López *et al*. (2010) reported that aquacultures of barnacles are conducted only in acorn barnacles in progress at a pilot or a semi-industrial level. The large-scale production of barnacles by aquaculture depends on the optimization of spat collection from the wild and/or the development of mass production techniques for larvae (López *et al*., 2010).

Both acorn and goose barnacles are commercially viable in Japan (López *et al*., 2010; Oshino, 2006). Recently, authors and colleagues made efforts to develop barnacle aquaculture techniques with using Japanese barnacles. In this paper, we introduce recent topics involved in barnacle aquaculture in Japan.

Potency of barnacles as tourism and fishery resources in Japan

Barnacles have high potentials to be a popular food sources for Japanese people because of the good taste (**Fig. 1**) while it is less common at present. A goose barnacle, *Capitulum mitella* 'kamenote (**Fig. 2a**)' is exploited by local fishermen in western part of Japan (Oshino, 2006). In Aomori prefecture (northeast part of Honshu, Japan), small scale aquaculture of an acorn barnacle *Balanus rostratus* 'mine-Fujitsubo (**Fig. 2b**)' has been conducted by suspended systems with using spat that produced in the ocean (Tsurumi, 2015). This species

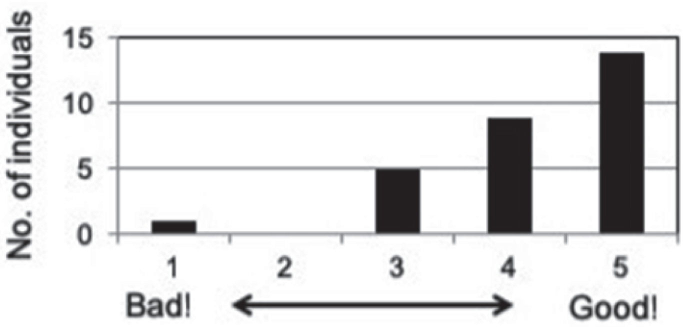

Fig. 1. Result of taste test of an acorn barnacle *Megabalanus rosa* 'aka-fujitsubo' conducted in Ehime, Japan in 2015 (Tsurumi, unpublished).

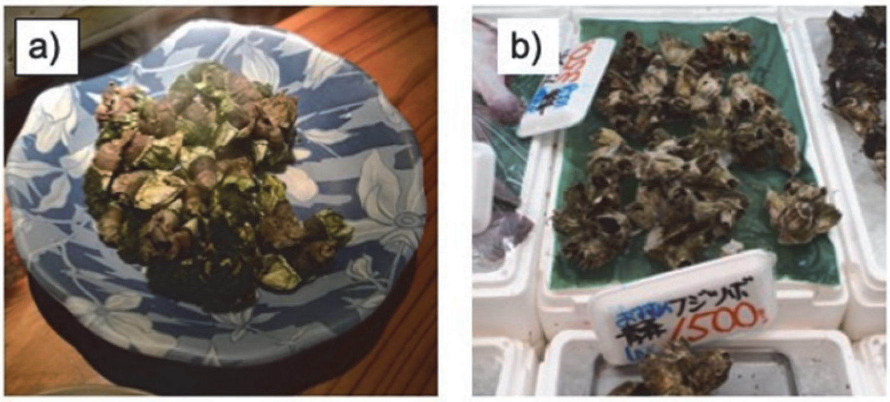

Fig. 2. Commercially viable barnacles in Japan. (a) *Capitulum mitella* 'kamenote' served at a restaurant in Wakayama, Japan. (b) *Balanus rostratus* 'mine-fujitsubo' at a market in Aomori.

distributes north part of Japan and is known as "one of the eight delicacies" in Aomori. Selling price of this species can be 7,000 yen/kg (Tsurumi, 2015; 2016) and therefore, it has potentials to activate the tourisms and the economy in Aomori and neighboring areas (Sanriku region that consists of Aomori, Iwate, Miyagi prefectures): if 30% of the tourists who stay at least one night in Sanriku eat two barnacles, the estimated sale is up to 2.7 - 5.5 billion yen/year.

Recent progress in barnacle aquaculture techniques in Japan

Balanus rostratus was recognized as potential food sources by a local chef and has spread in Aomori in 1990s (Tsurumi, 2015). This species has, then, suffered heavy exploitation pressure in 1990s and the resources have declined (Tsurumi, 2015). In 2000s, studies have been conducted to verify the feasibility of *B. rostratus* aquaculture in Mutsu Bay (Nakanishi *et al*., 2003), and Okkirai Bay, Iwate (Kado *et al*., 2009a). Today, most *Balanus rostratus* individuals in the market are from the aquaculture in Mutsu Bay. However, it needs skills of highly experienced persons to collect spat in the wild even though ecological properties, such as reproductive season and seasonal patterns of larval distribution, of *B. rostratus* were well studied in Shizugawa Bay, Miyagi (Yamauchi *et al*., 2007) and Mutsu Bay in Aomori (Kado *et al*., 2009b). Only a few fishermen are, therefore, engaged in the aquaculture (Tsurumi, 2016).

To promote the aquaculture by fishermen, development of mass production techniques for larvae and spat is necessary. We have succeeded in producing mass culture of larvae in 500 L tanks by feeding *Skeletonema costatum*, and production of spat (Tsurumi *et al*., 2015). However, there are still problems to be solved for the consistent production. It is suggested that optimizing lipid condition is important for the cultures of planktonic crustaceans (Yamada *et al*., 2017). Recently, authors and colleagues identified lipid profiles during the ovary maturation process in *B. rostratus* (Yamada *et al*., 2019). Such efforts may contribute to improve the larval culture conditions.

Barnacle larvae show gregarious settlement (Clare, 2010) that causes variabilities in adult shell morphologies due to density-dependent effects. In addition, it is practically impossible to separate individuals from each other. Unit of barnacles in the market is, therefore, mass of individuals on a plate (**Fig. 2b**), which likely leads to decrease the likelihood of purchases by tourists and persons who want to buy just one or two individuals. To solve the problem, we have developed a novel technique to produce barnacles that are uniform in morphology with flat bottoms by which each individual is easily harvested from the plate (Tsurumi, 2016). In this technique, plates are covered with silicone paint with making uncovered spots at regular intervals (**Fig. 3a**). Because the paint inhibits the settlement of barnacle larvae, settled larvae on the silicone-free spots can grow without competition with neighboring individuals (**Fig. 3b**). In addition, the paint inhibits the fouling of other organisms during the culture in

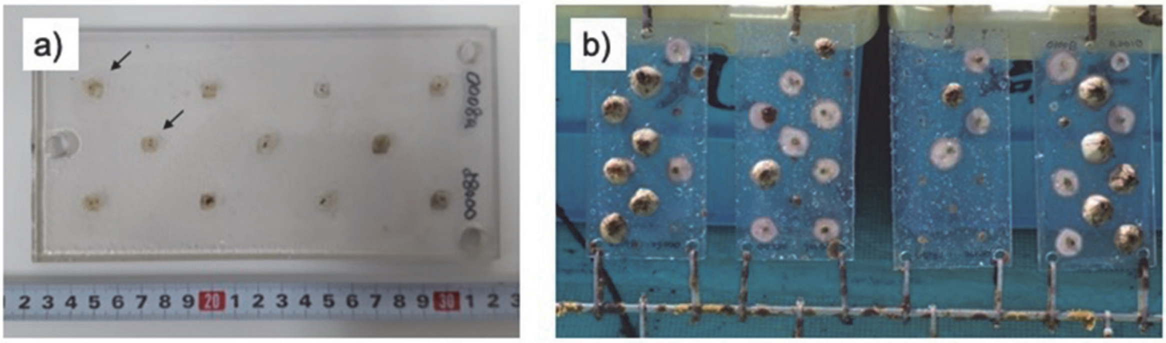

Fig. 3. Novel plates to produce well-shaped barnacles. (a) A plastic plate covered with silicone paint. Arrows indicate silicone-free spots. (b) Adult barnacles attached on the plates and cultured in the ocean. Bottom of each barnacle individual is flat and it is easily harvested by inflecting the plate.

the ocean, which drastically reduces the maintenance cost of the plates. It is possible to re-attach the harvested barnacles with flat bottoms to protecting sheets by keeping them in sea water for a day, which reduces the risk of damages during transportation.

Similar efforts have also been made to develop the aquaculture systems in another acorn barnacle *Megabalanus rosa* ‘aka-Fujitsubo’ which distributes western part of Japan (Oshino, 2006; Tsurumi, 2015). Thus, barnacles can be important tourism and fishery resources all over Japan by improving larval culture conditions as well as establishing the business models.

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Field Science Center, Graduate School of Agricultural Science, Tohoku University

Symposium mini review

New Technology to Facilitate the Aquaculture of Marine Invertebrates –Using Embryology, Genetics and Hydrodynamics–

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Keywords
stock enhancement, gastropod, cavitation, gene knockdown, microinjection

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Abstract

In the fisheries of Japan, the importance of aquaculture of marine invertebrates such as oysters, sea cucumbers and sea urchins, has increased for establishing stable productions. For improving productivity, several new techniques to control maturation, spawning, growth and taste, are developed. Here, I introduce new techniques for aquaculture using embryology, genetics and hydrodynamics. 1) In the genomic era, we can easily access to the spatio-temporal gene expression pattern using NGS RNA-seq regardless of model/non-model organisms. On the other hand, gene functional itself is still poorly understood due to lack of gene functional analysis. I showed some cases of gene knockdown experiments in shellfish embryogenesis using microinjection of dsRNA(RNAi) and Morpholino oligo. 2) Small planktonic crustaceans, which contaminated from supplying sea water, cause serious problems in invertebrate aquaculture tanks through predatory damage or competition for food resources with the aquaculture species. To solve this problem, our team developed a novel method for eradicating small planktonic crustaceans using a 'cavitation' shock wave. Cavitation treatment killed more than 90% of planktonic crustaceans present in supplied sea water. The result suggests that cavitation treatment is an effective method for controlling planktonic crustaceans without using chemicals.

Introduction

The catches in the Japanese coastal fishery has been decreased by almost 30% in the last three decades (Fisheries agency of Japan 2017). The decreasing is by the complex causes such as environmental changes of Ocean, over fishing, aging of fisherman and increasing the fuel fee. With the coastal fishery catches have become unstable, the importance of aquaculture and stock enhancement in the fishery industry has increased. Now, Japanese fisheries agency recommends aquaculture and seed releasing of invertebrates such as oysters, sea urchins and sea cucumbers.

For improving productivity of aquaculture, several new techniques to control maturation, spawning, growth and taste, are developed. In this review, I introduce new techniques for aquaculture using embryology, genetics and hydrodynamics.

Gene function analysis in the molluscan embryos

In the genomic era, we can easily access to the genome and gene expression data without any restrictions by the species of organisms using Next generation sequencers (NGS). In the commercially important species, information of the spatio-tempral gene expression has been increasing for the last decade (Zhang *et al*., 2012; Nakamura *et al*., 2013; Wan *et al*., 2017). As examples of the molluscs, the comparative study of the gene expression among different developmental stages, and different tissues is conducted in the pacific oysters (Zhang *et al*., 2012), pearl oysters (Takeuchi *et al*., 2016) and the tropical abalone (Jackson *et al*., 2003). These studies found that many genes expressed in a developmental stage and/or a tissue specific. These genes are estimated playing important roles such as the morphogenesis and retaining the homeostasis in specific stage/tissue. However, the function of these genes in molluscs is mostly inferred from the functions revealed in genes of model organisms.

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Identification of the gene function in each species will become the great help on aquaculture. The quantitative differences of gene expression, and mutations in the DNA sequences underlying such differences, will be a good indicator for selection in the breeding. Furthermore, a mutation positively affecting the useful traits of breeding organisms can be inserted by gene-editing tools. For using these benefits, identification of gene function should be conducted with the gene expression analysis.

Now, some studies established gene function analysis in molluscs. Rabinowitz *et al*. (2008) firstly succeeded to identify the gene function by the gene knockdown experiment using microinjection of Morpholino Oligonucleotide (MO). They inhibited translation of Nanos in embryogenesis of the marine snail *Ilyanassa obsoleta*, and elucidated Nanos involves in differentiation of the tissues derived from 4d blastomare lineage (e.g. main larval retractor muscle, intestinal organs and heart). On the shell formation, Hashimoto *et al*. (2012) revealed that BMP2/4 involves in the shell formation by RNAi (injection dsRNA into the fertilized eggs) in the limpet *Nippoacmea fuscovilidis*. On the adult shell formation, Suzuki *et al*. (2009) presented that genes Pif 97 and Pif 80 regulate nacre formation by injecting dsRNA into the adductor muscle of pearl oyster *Pinctada fucata*. The inhibitor treatment assay revealed Nodal signaling pathway involves in the formation of left-right asymmetry (Grande and Patel, 2009; Kurita and Wada, 2011) in the marine snails and limpets.

The technical base of gene function assay in the mollusca is mostly organized. On the other hand, the great missing is still remained like cephalopods (squids and octopus). In order to make effective use of the big data of gene expression information for improving the productivity of aquaculture, functional assay should be conducted.

Physical eradication system of contaminated harmful planktons using "shockwave of cavitation"

In recent years, the aquaculture using oceans often takes economic damages caused by the mass death and suspension of shipping of the aquaculture products due to the occurrence of high water temperature, red tides and shellfish poisoning. For avoiding these problems, the production of release seeds and farming of products in "onshore aquaculture tanks" is conducted. The onshore aquaculture tank is usually supplied natural seawater filtered by sand filter tank to maintain the water quality. However, in many cases, zooplankton in seawater passes the sand-filtration and contaminates large amounts into the aquaculture tank, causing serious damage to culturing organisms.

Planktonic crustaceans negatively affect the larvae and juveniles of some invertebrates in aquaculture tanks as predators or food resource competitors. A notorious case is copepods prey on and compete for food with juveniles of the Japanese common sea cucumber, *Apostichopus japonicus*. *A. japonicus* is one of the most commercially important sea cucumbers in Japan. In recent years, the annual catch has been 7~10 thousand tons (wet weight) and has been increasing mainly in response to a growing demand for dried sea cucumber products for export to China (Fujiwara *et al*., 2010). Therefore, the sustainable production of sea cucumbers is a crucial economic issue. However, several organizations have reported mass mortality of the cultured cucumber juveniles caused by copepods (Katano 2011; Noguchi and Noda, 2011).

To eradicate copepods, filtration has high economic and labor costs and is usually not sufficient to prevent contamination of aquaculture tanks by copepods. A recent study reported that seawater aerated with CO_2 will kill copepods (Noguchi and Noda, 2013). However, CO_2 also negatively affects several invertebrates (Kurihara and Shirayama, 2004; Dupont *et al*., 2011). Therefore, CO_2 treatment is limited to use in aquaculture tanks and attachment substrates without breeding organisms.

Here, we investigated the ability of a physical eradication system using cavitation to kill small planktonic crustaceans, including copepods (**Fig. 1**). 'Cavitation' is a phenomenon that is a consequence of the formation and disruption of vapor cavities in a liquid, i.e., micro- and nanosize bubbles. Cavitation can damage the surface of metallic devices such as propellers and impellers inside pumps via the shock waves that occur with the disruption of macro/nano-bubbles (Soyama, 1998).

First, we evaluated the relationship between the water pressure used for the cavitation treatment and its ability to kill planktonic crustaceans. Collected planktonic crustaceans were added to each tank. After the treatment, numerous broken crustacean bodies were observed (**Fig. 1**). After the

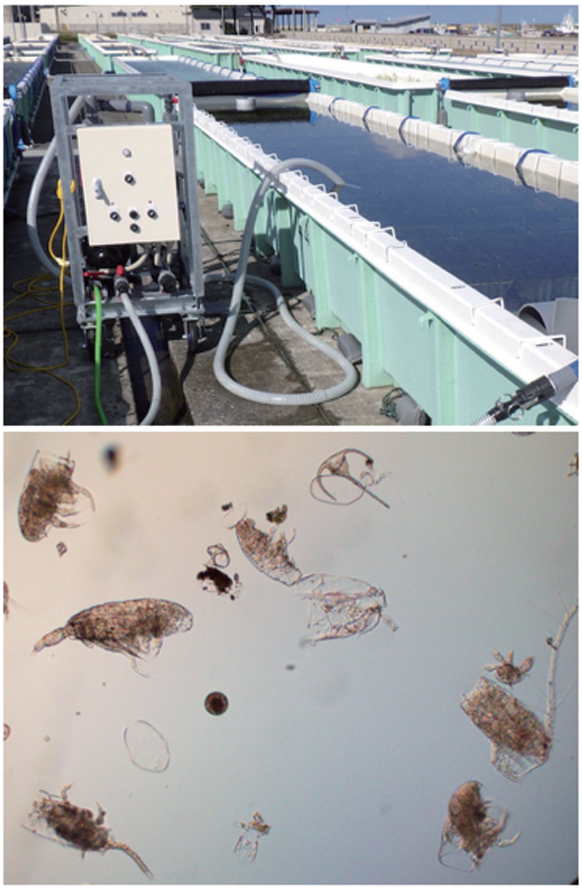

Fig. 1. A machine for physical eradication of planktonic crustaceans (upper) and broken copepods by cavitation treatment of this machine (lower).

treatments, the rate of reduction was significantly higher in the tanks treated with the high-pressure condition than with the low-pressure condition (89.9 ± 2.0% vs. 76.7 ± 5.2%, Mann–Whitney U-test, $P < 0.01$).

Next, we assessed the relationship between the number of treatment cycles and the reduction in surviving individuals. When collected planktonic crustaceans were added to each tank, the rate of reduction increased with the number of water volumes treated. The rate of reduction exceeded 80% on treating a volume equal to six times that of the tank (3000 L, 60 min) and reached about 95% on treating a volume eighteen times the volume of the tank (9000 L, 180 min).

Because there is no easy way to eradicate large numbers of planktonic crustaceans from aquaculture tanks, eradication efforts have focused on preventing contamination of the tanks (Sakai and Konda, 2008; Noguchi and Noda, 2013). The new method using cavitation treatment showed high eradication efficiency and can be adopted for the eradication of planktonic crustaceans in tanks containing cultured organisms not only sea cucumber, but also shellfishes and sea urchins. The combined use of cavitation treatment with conventional methods might facilitate the sustainable seed production of several marine organisms for stock enhancement by preventing damage from copepods and other planktonic crustaceans.

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Field Science Center, Graduate School of Agricultural Science, Tohoku University

Symposium mini review

Fisheries-based Evaluation of Carrying Capacity for Scallops in Ogatsu Bay

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Keywords
scallop, productivity, growth, food availability

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1. Introduction

Scallop farming is one of major aquaculture industries in the Sanriku coast of northern Japan. The earthquake and huge tsunami on March 11 in 2011 brought devastating losses in the scallop culture as well as oyster, sea squirt and marine algae etc. In the process of recovering and reconstructing the aquaculture farm lost by the natural disasters, evaluation of environmental carrying capacity in each farming site is an essential task to guarantee a sustainable production of filter feeders like a scallop in the future. The environmental carrying capacity of the cultured filter feeders is basically considered by food availability based on a primary production in aquaculture waters. We focused on a transition of scallop farming after the disaster in Ogatsu Bay where scallops are predominantly produced and recovering began first in the coast of Miyagi prefecture. We monitored productivity based on the number of facility and annual production in the bay, and growth state (e.g., size, weight and indices of adductor muscle and gonad) were compared to pre-quake state with annual food availability.

2. Transition of productivity and growth state of scallop

The growth state was calculated as a production amount per rope based on the statistical data on the number of facilities and annual production in the bay provided by fisherman cooperative and compared to pre-quake level. In parallel, the scallops farmed by ear-hanging method at two farming sites of Ogatsu Bay were also used for another estimation of growth state. Shell size, weight of softbody, gonad and adductor muscle, and indices of each organ was evaluated and compared to the pre-quake data and between cultured depths divided into two layers each year. The overproduction of scallop beyond environmental carrying capacity in Ogatsu Bay was expected by a decline of growth state under certain level of food availability based on a primary production.

The number of facilities for scallop farming and the annual production of the farmed scallop in Ogatsu Bay recovered to about 66% and 76% in 2014, respectively, compared to the data in 2010 (before the earthquake disaster). This means the number scallop cultured under the facilities was increasing every year since 2012 just after tsunami disaster. The productivity of scallop, which was calculated as an amount of production per rope where scallops were ear-hanged, in 2014 showed at 23.7 kg per rope lower than 30.9 kg per rope shown in 2013, even though the annual productions in 2013 and 2014 were almost the same. Total amount of chlorophyll a (above 20 m depth) throughout a year did not differ between 2014 and 2013, suggesting the same fluctuation level of the primary production as past. In 2014, the low-growth scallops (i.e., shell size, soft body weight) cultured in deeper layer was observed at two different farming sites as previously found before the earthquake in 2010. The adductor muscle index (adductor muscle weight (g)/whole soft body weight without gonad (g) *100) was kept at about 38 in both layers higher than previous level before the earthquake.

3. Discussion

A food availability during study period was stable and kept at the same level as pre-quake period. The decline of productivity was observed in 2014 during the process of an increasing number of scallops. In the same year the low growth of deeper layer group compared with shallow layer group, which was markedly different from previous year, but similar to low growth at deeper layer in pre-quake year of 2010. It was suggested that the decreasing productivity was resulted from low growth of scallop cultured in lower layer of ear-hanging rope and a food availability for good growth of scallop was not sufficient for the scallops farmed in deeper layer in Ogatsu

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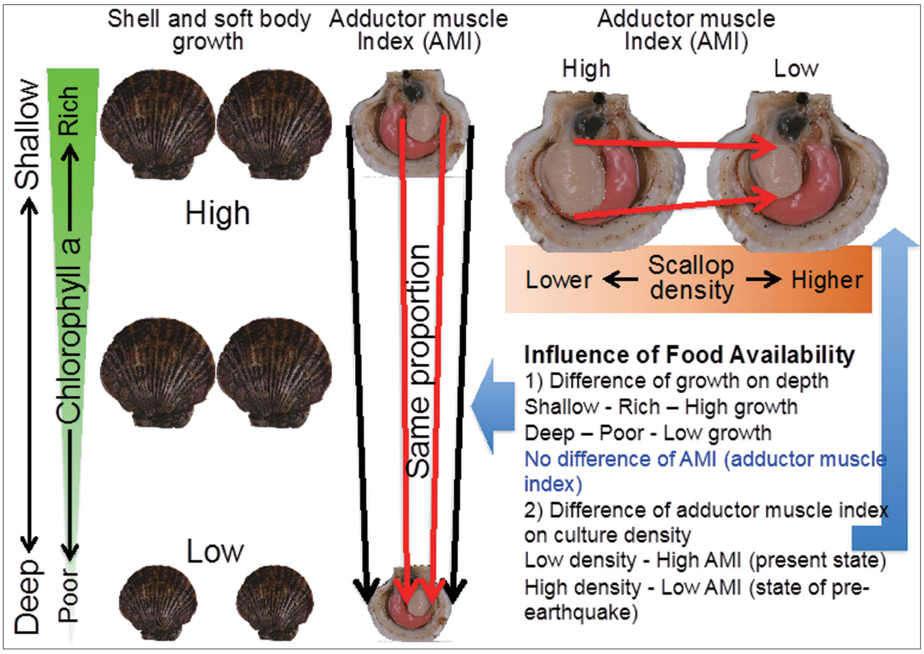

Fig. 1. Present state of productivity and growth characteristic of scallop farming in relation to food availability and scallop density in Ogatsu Bay.

Bay in 2014. The state of scallop farming in 2014 was thought to reach first stage of overproduction showing low productivity with low growth at deeper layer, but still kept the same level of adductor muscle proportion as an indicator for second stage overproduction (**Fig. 1**).

It may be a time that the producers need to re-consider and regulate the amount of production to accomplish a sustainable and efficient production of scallop as a filter feeder on the basis of environmental carrying capacity estimated in Ogatsu Bay.

Acknowledgements

We are grateful to the farmers of Fishery Cooperative in Ogatsu Bay for their support to collect cultured scallops and the staff of the Onagawa Field Science Center of Tohoku University for their assistance. This work was supported by the Tohoku Ecosystem-Associated Marine Sciences (TEAMS) from the Japanese Ministry of Education, Culture, Sports, Science and Technology. This work has been published in Nippon Suisan Gakkaishi, 82 (3), 321-329, 2016.

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The 16th International Symposium on Integrated Field Science
"Future of Marine Aquaculture: Finding Solutions to Challenges"

Program

Date: March 22, 2019

Venue: Lecture Room No. 7 in Aobayama Commons, Tohoku University
(*468-1 Aramaki Aza Aoba, Aoba-ku, Sendai 980-0845, Japan*)

12:30-	**Registration**
13:00-13:05	**Opening Address** Makoto OSADA (*Chief of the Integrated Field Science Center, Graduate School of Agricultural Science, Tohoku Univ.*)
13:05-13:20	**Introduction** Minoru IKEDA (*Onagawa Field Center, Graduate School of Agricultural Science, Tohoku Univ.*)
13:20-13:50	**Current Challenges in the Norwegian Salmon Aquaculture: Are Cleaner Fish a Solution?** Enrique BLANCO GONZALEZ (*Norwegian College of Fishery Science, UiT The Arctic University of Norway*)
13:50-14:20	**Genetic Research Initiatives for Sustainable Aquaculture Production in the Philippines** Maria Rowena R. ROMANA-EGUIA (*Aquaculture Department, Southeast Asian Fisheries Development Center*)
14:20-14:30	**Break**
14:30-15:00	**The 2011 Tohoku Tsunami, Marine Ecosystem Dynamics, and the Re-establishment of Coastal Aquaculture Facilities in Onagawa Bay, Japan** Toyonobu FUJII (*Tohoku Ecosystem-Associated Marine Sciences, Graduate School of Agricultural Science, Tohoku Univ.*)
15:00-15:30	**Possible Use of Blue Light in Aquaculture and Kelp Forest Ecology** Masakazu AOKI (*Graduate School of Agricultural Science, Tohoku Univ.*)
15:30-16:00	**Potency of Barnacles as Aquaculture Organisms** Takefumi YORISUE (*Onagawa Field Center, Graduate School of Agricultural Science, Tohoku Univ.*)

16:00-16:30 **New Technology to Facilitate the Aquaculture of Marine Invertebrates -Using Embryology, Genetics and Hydrodynamics-**
Yoshihisa KURITA (*Fishery Research Laboratory, Kyushu Univ.*)

16:30-17:00 **Fisheries-based Evaluation of Carrying Capacity for Scallops in Ogatsu Bay**
Makoto OSADA (*Graduate School of Agricultural Science, Tohoku Univ.*)

17:00-17:25 **General Discussion**

17:25-17:30 **Closing Address**
Akihiro KIJIMA (*Representative of Tohoku Ecosystem-Associated Marine Sciences, Graduate School of Agricultural Science, Tohoku Univ.*)

18:30-20:30 **Banquet**

Organizing Committee:
Minoru IKEDA (*Onagawa Field Center, Graduate School of Agricultural Science, Tohoku Univ*.)
Takefumi YORISUE (*Onagawa Field Center, Graduate School of Agricultural Science, Tohoku Univ.*)

Host:
- *Integrated Field Science Center, Graduate School of Agricultural Science, Tohoku University*
- *PICS (Project of Integrated Compost Science), Graduate School of Agricultural Science, Tohoku University*

1-1. Current Challenges in the Norwegian Salmon Aquaculture: Are Cleaner Fish a Solution?

Enrique BLANCO GONZALEZ

Norwegian College of Fisheries Science, UiT-The Arctic University of Norway, Tromso N-9037, Norway

Norway leads the world aquaculture Atlantic salmon (*Salmo salar*) production with 1.2 million tons a year and a value of approximately 800 billion JPY. However, salmon lice infestation remains a major challenge for the industry which is continuously evolving towards mitigating the sea lice problem. A broad range of approaches have been tested, and nowadays the use of cleaner fish is recognized to be the most economic and environmentally friendly option. This biological treatment is expected to be the most important lice treatment over the next years and the industry is moving towards shelf-sufficiency fostering selective breeding programs. Here, I will present the most pressing challenges in this context and introduce an innovative approach, RACleanFish-Aqua. This approach proposes a paradigm shift for cleaner fish culture, moving from "selection" to "diversification" by incorporating key broodstock management procedures recommended for stock enhancement programs into the protocols for cleaner fish aquaculture production. This new approach is foreseen to provide a continuous supply of cleaner fish to the salmon farms and ensure the sustainability of the wild populations, while minimizing putative risks of introgression in case of fish escapees.

Enrique BLANCO GONZALEZ (E-mail: enrique.blanco@uit.no)

Associate professor at the Norwegian College of Fisheries Science, University of Tromsø in Norway. Dr. Blanco Gonzalez is interested in combining genetics and ecological approaches to understand fundamental questions in marine ecology, fisheries and aquaculture. He intends to deepen into the adaptive fitness of marine organisms to environmental, anthropogenic and evolutionary forces. Over the last years, his research has focused on stock enhancement and translocation on several marine species in Japan, Norway and Chile.

1-2. Genetic Research Initiatives for Sustainable Aquaculture Production in the Philippines

Maria Rowena R. ROMANA-EGUIA[1,2], Ma. Carmen Ablan LAGMAN[2], Zubaida U. BASIAO[3] and Minoru IKEDA[4]

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The Philippines is one of several countries in Southeast Asia that has, for several decades, made steady contributions to world aquaculture production both from inland and marine waters. In recent years, fish production has been on the decline mainly because of the lack of quality seedstock, limited stocks of captive breeders or spawners of major aquaculture commodities, adverse effects of climate change and other environmental factors on fish breeding and rearing, fish diseases caused by pathogenic organisms and prohibitive cost of aquaculture inputs such as feeds, etc. Genetic researches have been conducted mostly through local grants with the aim of addressing the aforementioned constraints. Such initiatives focused on developing and applying methods in (a) selective breeding; (b) marker-assisted genetic strain assessment for broodstock development and for monitoring inbreeding in farmed stocks and (c) genomics to understand and enhance on-farm stock performance through the identification of genes that are responsible for nutrition, stress and immune responses, among others. This paper highlights examples of local genetics applications in tilapia, mangrove crab, shrimp, milkfish and abalone aquaculture. The significance of implementing genetic interventions to boost and sustain aquaculture production in the Philippines is likewise discussed.

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Scientist and Associate Professor. Population genetics as applied to the breeding and farming of tropical aquaculture species such as tilapia, freshwater prawn, milkfish, abalone and mangrove crab has been among her major research interests apart from addressing concerns related to aquatic biodiversity. Her current research involves DNA marker-based identification of Philippine eel species for purposes of conservation, management and sustainable utilization.

1-3. The 2011 Tohoku Tsunami, Marine Ecosystem Dynamics, and the Re-establishment of Coastal Aquaculture Facilities in Onagawa Bay, Japan

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For many towns and villages along the Pacific coast of northern Japan, fishing and aquaculture had been the primary industries. For example, there were over 1200 long-lines for culturing scallops, oysters and edible ascidians as well as around 120 salmon farm cages in Onagawa Bay. However, the 2011 Great East Japan Earthquake and tsunami devastated entire aquaculture installations and severely damaged the associated ecosystem. To assess the change in the state of the marine ecosystem, multi-seasonal surveys were conducted to characterise spatio-temporal dynamics in a range of physical, biological and aquaculture-related parameters across Onagawa Bay between 2012 and 2018. Benthic macrofaunal abundance, biomass and species diversity were examined as indicators of environmental health and trends. These metrics increased steadily from the lowest values at the beginning to the highest over time. During the same period, the spatial extent of aquaculture facilities recovered steadily up to ~75 % of the original state. The multivariate analysis revealed the observed spatio-temporal variability in benthic macrofaunal community was significantly explained, primarily, by proximity to the nearest aquaculture facilities, fetch length, sediment grain size, and the total area of the aquaculture facilities. This study shows the importance of coastal aquaculture re-building in determining the occurrence and distribution of benthic macrofaunal communities and thereby influencing recovery of seafloor biota at ecosystem scales following even a catastrophic natural disaster.

Toyonobu FUJII (E-mail: toyonobu.fujii.a8@tohoku.ac.jp)

My research interest centres on identifying both natural and anthropogenic factors affecting changes in the distribution of marine fauna and flora across a range of spatial and temporal scales. Currently I investigate the impacts of the 2011 Tohoku earthquake and tsunami on the dynamics of marine coastal ecosystem in Onagawa Bay, Japan, to better understand the potential role of coastal anthropogenic activities in the ecology of marine biological populations around the disaster-affected region. I would like to make a significant contribution in developing a unifying multiple-stressors approach for the study of marine socio-ecological system dynamics in order to efficiently understand, predict and manage marine environments and resources.

1-4. Possible Use of Blue Light in Aquaculture and Kelp Forest Ecology

Masakazu AOKI

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Latest studies have shown that blue light promotes the growth of both gametophytes and sporophytes of laminarian kelps. On the contrary, insects and some other animals are negatively affected by the blue light emission. Therefore, we aimed to promote the growth of cultured *Undaria pinnatifida* and also to deter the herbivorous grazing isopod *Cymodoce japonica* by the emission of blue light. *Cymodoce japonica* grazes on the young sporophytes of cultured *U. pinnatifida* and often causes great loss of its production. A water-proof blue LED light capable of emitting in every night time for more than two months was developed and employed underwater for the growth experiment of *U. pinnatifida* in the field from January to April in 2018. In the laboratory, alternative selection experiments from four conditions: red, green and blue LED lights and dark were conducted in a container for 30 individuals of *C. japonica*. The nocturnal blue light emission in the field promoted the growth of *U. pinnatifida*. In the laboratory choice experiments, *Cymodoce japonica* apparently avoided blue light. Therefore, the blue light emission to young sporophytes will largely contribute to the rise of *U. pinnatifida* production through the promotion of growth and the exclusion of grazers.

Masakazu AOKI (E-mail: masakazu.aoki.e6@tohoku.ac.jp)

Associate Professor. Major interest is in the ecology and life history strategies of the temperate reef marine benthos. Main study materials: peracarid crustaceans (such as caprellids, gammarids and isopods), herbivorous gastropods, *Undaria pinnatifida*, *Ecklonia cava*, *Eisenia bicyclis*, *Sargassum* spp.

1-5. Potency of Barnacles as Aquaculture Organisms

Takefumi YORISUE

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Thoracican barnacles (hereafter referred as barnacles) are crustaceans which dominate many intertidal to subtidal environments. Today, more than ten species of barnacles are distributed in the market worldwide. They are divided into stalked (barnacles having a stalk) and acorn barnacles (barnacles lacking a stalk). The world production of stalked barnacles is 300 to 500 tonnes / year in recent years and resources are decreasing in the Iberian Peninsula. In addition, it is dangerous to harvest stalked barnacles because they inhabit the rocky intertidal zone exposed to the wave. Hence, the interest to the aquaculture of stalked barnacles is increasing in terms of resource conservation and safety. The aquaculture method, however, has not yet been established. In contract, some acorn barnacles are cultured using suspended method although there are tasks to be solved for the stable supply of high-quality ones. In the presentation, I will introduce recent approaches for the establishment of barnacle aquaculture in Japan.

Takefumi YORISUE (E-mail: takefumi.yorisue.d5@tohoku.ac.jp)

Assistant Professor. Barnacles inhabit wide variety of marine environments. To understand how barnacle larvae disperse and select settlement sites, I am currently conducting molecular and field-based experiments.

Selected publications

Yorisue *et al*. (2018) Evaluating the occurrence of cryptic invasions of a rocky shore barnacle, *Semibalanus cariosus*, between the northeastern Pacific and Japan. *Biofouling*, 34: 183-189.

Yorisue *et al*. (2019) Mechanisms underlying predator-driven biotic resistance against introduced barnacles on the Pacific coast of Hokkaido, Japan. *Biological Invasions*. (accepted).

1-6. New Technology to Facilitate the Aquaculture of Marine Invertebrates – Using Embryology, Genetics and Hydrodynamics –

Yoshihisa KURITA

Fishery Research Laboratory, Kyushu University, Fukutsu, 811-3304, Japan

In the fisheries of Japan, the importance of aquaculture of marine invertebrates such as oysters, sea cucumbers and sea urchins, has increased for establishing stable productions. For improving productivity, several new techniques to control maturation, spawning, growth and taste, are developed. Here, I introduce new techniques for aquaculture using embryology, genetics and hydrodynamics.

1) In the genomic era, we can easily access to the spatio-temporal gene expression pattern using NGS RNA-seq regardless of model/non-model organisms. On the other hand, gene functional itself is still poorly understood due to lack of gene functional analysis. I showed some cases of gene knockdown experiments in shellfish embryogenesis using microinjection of dsRNA(RNAi) and Morpholino oligo.

2) Small planktonic crustaceans, which contaminated from supplying sea water, cause serious problems in invertebrate aquaculture tanks through predatory damage or competition for food resources with the aquaculture species. To solve the problem, our team developed a novel method for eradicating small planktonic crustaceans using a ‘cavitation’ shock wave. Cavitation treatment killed more than 90% of planktonic crustaceans contained in sea water. The result suggests that cavitation treatment is an effective method for controlling planktonic crustaceans without using chemicals.

Yoshihisa KURITA (E-mail: kurita.yoshihisa.070@m.kyushu-u.ac.jp)

Assistant Professor. My research field is mainly embryology of marine invertebrates (mainly bivalves, gastropods and sometimes echinoderms). I’m interested in the mechanisms for generating the morphological diversity including life-history traits, body color and taste. To approach the question in this research area, I’m also developing new methods in microinjection, spawning induction, DNA extraction, etc. of the marine invertebrates.

1-7. Fisheries-based Evaluation of Carrying Capacity for Scallops in Ogatsu Bay

Makoto OSADA and Kazue NAGAWASA

Graduate School of Agricultural Science, Tohoku University, Sendai 980-8572, Japan

Scallop farming is one of major aquaculture industries in the Sanriku coast of northern Japan. The earthquake and tsunami on March 11 in 2011 brought devastating losses in the scallop culture as well as oyster, sea squirt and marine alga etc. In the process of recovering and reconstructing the aquaculture farm lost by the natural disasters, evaluation of environmental carrying capacity in each farming site is an essential task to guarantee a sustainable production of filter feeders like a scallop in the future. We focused on a transition of scallop farming after the disaster in Ogatsu Bay where scallops are predominantly produced and recovering began first in the coast of Miyagi prefecture. We investigated productivity based on the number of facility and annual production in the bay, and growth state compared to pre-quake state with annual food availability. The decrease in productivity of scallop resulting from a low growth of scallops in deeper layer was observed in Ogatsu Bay in 2014, suggesting that a food availability reducing with depth was not sufficient for the increasing scallops farmed in deeper layer in Ogatsu Bay in 2014. It may be a time that the farmers need to reconsider and regulate the amount of production to accomplish a sustainable and efficient production of scallop as a filter feeder on the basis of environmental carrying capacity estimated in Ogatsu Bay.

Makoto OSADA (E-mail: makoto.osada.a8@tohoku.ac.jp)

Professor, Laboratory of Aquacultural Biology. Bivalve mollusks is commercially important as an aquaculture organism in the world. The artificial seed production of bivalves based on reproductive control is required for improvement of productiveity in aquaculture. I focus on gonial cell multiplication, oocyte growth, and spawning (oocyte and sperm release) in bivalve mollusks, in which these processes are precisely regulated by endocrine systems. Some of endocrine regulatory molecules are shared among animals with some homology to vertebrates and others possess unique molecules to regulate reproduction.

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