Evaluation of two species, Cobia and Giant Grouper, as alternative species to farm in the WSSV affected areas of South East Queensland

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Abbreviations

BIRC	Bribie Island Research Centre
BW	Body weight
DAF	Queensland Department of Agriculture and Fisheries
FCR	Feed conversion ratio
LRFF	Live Reef Food Fish
RAS	Recirculating aquaculture system
RPPF	Rocky Point Prawn Farm
SGR	Specific growth rate
TCO	The Company One Pty Ltd
WSSV	White-spot syndrome virus

Executive Summary

What the report is about

In 2016/17, the Rocky Point Prawn Farm, along with other farms in the Logan River region of south-east Queensland, was severely affected by a white spot disease outbreak caused by the exotic white spot syndrome virus (WSSV). Measures enforced to eradicate WSSV resulted in a complete loss of stock and a ban on prawn production within the Logan River and wider Moreton Bay area until May 2018. As a result, Rocky Point Prawn Farms (RPPF) elected to investigate the feasibility of finfish aquaculture as an alternative to prawn farming. The current project was undertaken to assess the potential of two finfish species, Cobia (*Rachycentron canadum*) and Giant Grouper (*Epinephelus lanceolatus*) as alternative aquaculture candidates for the Rocky Point Prawn Farm and potentially other aquaculture enterprises. The study was developed and led by RPPF with assistance from The Company One (TCO) and the Department of Agriculture and Fisheries (DAF), with staff from the Bribie Island Research Centre (BIRC) and ran from March 2017 until June 2018. In the study, the commercial performance of each species was assessed when cultured in both indoor tank systems and outdoors in cages. Culture facilities at two of RPPF's production sites included a former prawn hatchery building which housed the indoor tank-based production, and an outdoor landlocked saline lake which contained cages. Cobia fingerlings were produced at BIRC and Giant Grouper fingerlings were supplied by TCO hatchery in Cairns. All fingerlings were initially grown in indoor tanks under controlled temperature conditions and later some were transferred to outdoor cages to assess their performance in both winter and spring/summer. Fish were fed once or twice per day and water quality data was collected daily. Weight and health checks were conducted monthly and any mortalities were removed from tanks or cages daily. The data were used to calculate key production parameters of feed conversion ratio, growth rate and survival throughout the production cycle. Both species were grown to harvest and sold into the domestic market. The production and market information generated by this project provided a framework to evaluate the relative costs and benefits of the two species within the range of production methods and strategies available to RPPF, and guidance towards future investment and optimising production in the future.

Background

The occurrence of WSSV in prawn farms in south-east Queensland in December 2016, resulted in the destruction of stock on the prawn farms in the Logan River area and a cessation of prawn production in ponds until 2018. Rocky Point Prawn Farms was one of the businesses affected by the WSSV outbreak and subsequently sought to consider alternative species to culture in its indoor prawn hatchery and/or outdoor pond farm facilities. Cobia (*Rachycentron canadum*) and Queensland Groper or Giant Grouper (*Epinephelus lanceolatus*) were considered as suitable alternative species for production in prawn farms in south-east Queensland. Both species are fast growing, occur naturally in south-east Queensland, and have been the focus of research and development by DAF in recent years. Research led to regular hatchery production of Cobia fingerlings at the DAF Bribie Island Research Centre and to the establishment of a commercial Giant Grouper hatchery, operated by The Company One, in Cairns. However, there was limited data available on the post-hatchery performance of these species in sub-tropical aquaculture facilities. The present study was undertaken to address this information gap and to inform RPPF on potential future directions for finfish production on their farms.

Aims/objectives

The project aimed to assess and compare the production performance and value of Cobia and Giant Grouper, two emerging aquaculture species for the Australian market. Two production systems were evaluated for both species: firstly, using the hatchery as an overwintering or production facility, and secondly, cage culture in a saline lake. Fish would be harvested and sold into the domestic market to assess suitability and market acceptance of these species.

The project had two objectives

1. Study tour of South East Asia to determine alternative farming methods for Cobia and Giant Grouper and investigate optimum market parameters.
2. Determine which method of grow out culture, indoor, pond or cage culture produces the optimum fish for the market.

Methodology

Giant Grouper (*Epinephelus lanceolatus*) juveniles were sourced from The Company One (TCO) hatchery in Cairns. In total, 39,928 Giant Grouper fingerlings were received in three batches and mean weight of fish varied between batches from 15.1 to 150.0 g. Cobia (*Rachycentron canadum*) fingerlings were sourced from the DAF Bribie Island Research Centre (BIRC). A total of 4,344 fingerlings were received in three batches with mean weights of fish from 28.0 to 250.0 g. Once received, fingerlings were stocked into tanks (designated LR tanks) located in the former RPPF prawn hatchery facility. Tanks were supplied with seawater filtered through a multimedia sand filter and 10 μm cartridge filtration unit. Over the course of the project, additional water treatment elements, including protein skimmers, sand filters and additional biofilters, were installed, which enabled groups of parabolic tanks to operate as a functional recirculating aquaculture system (RAS). Fish were initially maintained in tanks in the hatchery facility for a two-month overwintering period then either transferred to outdoor cages in the landlocked lake for grow-out, or on-grown indoors in tanks until reaching harvest size. A small number of fish were transferred to cages in the lake in June 2017, to assess winter performance. All fish were fed by hand to satiety with the commercial pelletised feed Pelagica (Ridley Aquafeeds), once or twice daily.

Feed consumption and mortalities were recorded daily in all tanks and cages. Water pH, dissolved oxygen, temperature and salinity were recorded daily, and alkalinity, total ammonia and nitrite were monitored weekly. In the saline lake, water quality parameters were measured at depths of both 1 m and 3 m. Weight and health checks were conducted monthly. Fish were sampled from tanks using hand nets and from cages using either hand, seine, or cast nets. A bulk weight of 10-30 fish was recorded, and fish were then examined externally for abnormalities, lesions or external parasites. Gill samples were taken from three fish per system and placed into a vial for further examination under a compound microscope at RPPF's laboratory. In the case of a suspected disease outbreak, samples of whole fish or fixed tissues were submitted to the DAF Biosecurity Sciences Laboratory for testing, diagnosis and advice. Data from feed intake, survival and growth was used to assess production performance by calculating specific growth rate (SGR) and feed conversion ratio (FCR).

Results/key findings

A study tour of South East Asia (See Appendix 4 for the report) was undertaken to investigate alternate farming methods of Cobia and Giant Grouper. Giant Grouper was seen to be grown either in tanks using RAS technology as seen in Hong Kong or in ponds as seen in Taiwan. Both of these methods were looked at to trial at RPPF as well as production in cages within the lake. No Cobia farming was seen on the tour due to some damage of seas cages from a typhoon off the coast of Taiwan.

In the tank systems, water quality parameters were generally maintained within the required range for these species. Mean water temperature was approximately 24 °C for Cobia and 25 °C for Giant Grouper, salinity was in the range of 23 g $L^{-1}$to 36 g L^{-1} for Cobia and 30 g L^{-1} to 37 g L^{-1} for Giant Grouper. Dissolved oxygen concentration was generally greater than 4 mg L^{-1} and in instances where water quality had started to decline, water flow to tanks and stocking density were adjusted to assist with the maintenance of appropriate water quality. In the lake, seasonal trends in water temperature were observed. During the 2017 winter trial, water temperatures varied between 16.5 and 19.2 °C, while salinity was stable at 27 g L^{-1}. Despite the reduced temperatures, and reduced feeding responses, survival was 100% in both cages of Cobia and Giant Grouper. In 2017/18 water temperatures consistently exceeded 25 °C from November to April and dropped to a minimum of 16 °C in July. Dissolved oxygen levels were greater than 5 mg L^{-1} and salinity ranged from 26 g L^{-1} to 29 g L^{-1}. The key water quality parameters of temperature, dissolved oxygen and salinity were very similar at the 1-m and 3-m depths.

Post-transfer growth rates of each batch of Giant Grouper were similar in tanks and cages, with juveniles achieving a size of 400 g within 140 days, and a specific growth rate of approximately 1.3 to 1.5% BW per day. Growth rates of Giant Grouper in tanks were markedly higher in the summer period (November to March) than those of similar size in the spring (September to December). Giant Grouper stocked into tanks in winter attained a harvest weight of 800 g within 9 months, which was similar to that attained by juveniles stocked into ponds following a nursery period in tanks. Feed conversion ratios of 1.3 were achieved for some Giant Grouper groups, however high mortality rates due to disease affected the overall FCR across the production cycle.

Post-transfer growth rates of Cobia in tanks were highly variable, with SGR ranging from 0.4 to 2.5% body weight per day. This generally reflected isolated incidents of poor water quality and/or health problems in tanks with low SGR. A single cohort of cage-reared Cobia had a SGR of 1.05% BW day^{-1} over 6 months. Feed conversion ratios of tank-reared Cobia ranged from 1.04 to 2.58. This high variation is likely to be a function of variations in the duration of growth, together with small populations under consideration, and as a direct result of frequent stock movements between tanks. For that reason the mean SGR of 1.61 is considered a more representative value. Similarly, there was variation in FCR in cage-reared Cobia, with a range of 1.08 to 1.76 and a mean of 1.51 for the three groups studied.

Mortalities arose from operational or equipment failures as well as pathogens and parasites, in both tank- and cage-reared fish. In some instances, the losses were catastrophic, affecting in excess of 50% of the tank or cage population. In some instances, water quality, in particularly elevated ammonia levels, occurred prior to mortality events such as an outbreak of Columnaris disease. Two tanks of Cobia fingerlings were lost during the post-transfer period due to an outbreak of the parasitic dinoflagellate *Amyloodinium ocellatum*. Nodavirus was responsible for mortality levels of 34% to 95% in cage populations of Giant Gouper. This disease is highly contagious, rapidly infecting individuals within a cage population and fish in adjacents cages. However, cage populations of Cobia housed adjacent to infected Giant Grouper were unaffected.

Implications for relevant stakeholders

Water quality was able to be maintained at suitable levels for production of both species, despite low water temperatures in the lake during winter. Both Cobia and Giant Grouper were grown to harvest size, at growth rates and with feed conversions that are within commercially acceptable levels. These parameters indicate the suitability of these species for production in south-east Queensland. However, production strategies will depend on the reliable supply of fingerlings. A commercial hatchery exists for giant grouper with production throughout the year but a risk will exist as it is a sole supplier. For cobia there is currently no commercial supplier of fingerlings and the continuation and expansion of the industry will will require one or two industry players to commit and invest in establishing a commercial hatchery.

Recommendations

A significant contribution to the economics of Cobia culture in south-east Queensland may be the establishment of reliable markets for fish of varying sizes, to further enhance year-round harvesting. More data on Cobia, such as fillet recovery for a range of sizes, is required to further develop these markets.

Infection by nodavirus caused large-scale mortality of juvenile and harvest-sized Giant Grouper in cages. This highlights the need to control stress events that may precede an infection and which increase the risks associated with cage culture. While on-farm management practices have been shown to mitigate some of the risk of nodavirus infection in tropical locations, the availability of an effective vaccine is a priority that has been identified and is now being addressed.

Although acceptable growth and feed conversion was achieved in this study, the development of improved diets for both species is recommended in order to control this major production cost.

Keywords

Cobia; *Rachycentron canadum*; Queensland Groper; *Epinephelus lanceolatus;* aquaculture; commercialisation; health; nursery; pond culture; diversification, FCR; growth; mortality

Introduction

The occurrence of WSSV in prawn farms in south-east Queensland in December 2016, resulted in the destruction of stock on the prawn farms in the Logan River area and a cessation of prawn production in ponds until 2018. Rocky Point Prawn farm (RPPF) was one of the businesses affected by the WSSV outbreak and subsequently considered alternative species to culture in its indoor hatchery and/or outdoor farm facilities.

Cobia (*Rachycentron canadum*) and Queensland grouper or Giant Grouper (*Epinephelus lanceolatus*) were considered as suitable alternative species for production in prawn farms in south-east Queensland. Both species are fast growing, occur naturally in south-east Queensland, and have been the focus of research and development by the Queensland Department of Agriculture and Fisheries (DAF) in recent years. However, there was limited data available on the performance of these species in sub-tropical aquaculture facilities. Available data on the performance of Cobia suggests that year-round growth in ponds is significantly lower in subtropical areas, in comparison to the tropics, probably as a result of lower water temperatures, particularly in winter (Dutney and Palmer, 2008; Dutney *et al.*, 2010). Therefore there is a need to develop alternative production strategies which optimise production efficiencies of these species by evaluating the performance of both species within heated indoor aquaculture systems, pond and lake systems or a combination of both systems.

Cobia is a large benthopelagic fish species, endemic to all tropical and subtropical waters across the globe with the exception of the eastern Pacific (Shaffer and Nakamura 1989). Cobia aquaculture is undertaken in several countries through the Asia-Pacific region, USA and South America (Liao *et al.*, 2007; Leano *et al.*, 2008; Liao *et al.*, 2004; Nhu *et al.*, 2011; Sampaio *et al.*, 2011; Benetti *et al.*, 2008) with approximately 43,000 T produced in 2015 (FAO, 2017). Cobia is considered a suitable candidate for aquaculture in Queensland based on several characteristics, including growth rates that exceed 5 kg per year, adaptability to commercially available Aquafeeds, excellent culinary qualities and suitability to water temperature and salinity of coastal locations (Holt *et al.*, 2007; Shiau, 2007; Weirich *et al.*, 2007; McLean *et al.*, 2008).

Research into Cobia aquaculture began in Australia in 2007, focusing on this species as a diversification option and off-season crop for prawn farms in Queensland (Dutney and Palmer, 2008). The feasibility of hatchery production of juvenile Cobia was demonstrated at the Bribie Island Research Centre (BIRC), using methods previously developed for other marine finfish species (Palmer, 2020). Subsequent studies proved the technical feasibility of Cobia grow-out in prawn ponds and demonstrated higher yields and growth rates in tropical localities (Dutney *et al.*, 2010). At the beginning of the present program of works, there was a fledgling industry of approximately 100 t per annum, with a single commercial producer, Pacific Reef Fisheries Ltd. (PRF), based in Ayr, North Queensland. Farmed Cobia was introduced to the Australian market in the late 2000's following the recognition of Cobia as a viable diversification option for pond farms in Queensland (Dutney and Palmer, 2008; Dutney *et al.*, 2010). Subsequent consumer panel studies indicated a high level of market acceptance for the product, with Cobia rating more favourably for several measures of consumer preference than either barramundi or yellowtail kingfish (Lee *et al.*, 2015).

Groupers and rock-cod include 159 species from 15 genera of Epinephelinae, a subfamily of Serranidae. They occur primarily in tropical reef systems and some species are cultured widely in the South East Asia (SE Asia) where they are highly valued when sold live, although fresh product also attracts good prices (McGilvray and Chan, 2003). Currently, global grouper production is in excess of 150,000 t per annum with more than 100,000 t produced annually in China (FAO, 2017). The Live Reef Food Fish (LRFF) trade is a billion dollar industry that is dominated by consumption in China and that sources LRFF from across SE Asia and now also Australia, and the Indo-Pacific region. The Australian contribution to the LRFF trade is almost exclusively live coral trout which is wild-caught from the tropical east coast and exported from Cairns, Queensland (Muldoon and Johnston, 2006). The Australian market for grouper has historically been as a wild-caught, chilled product of a variety of grouper species supplied to the market as by-catch from the coral trout fishery.

Research into grouper aquaculture in Australia commenced in the late 1990s at the Northern Fisheries Centre in Cairns and focussed on the hatchery production of several grouper species. Initially, high-value marine species such as barramundi cod (*Cromileptes altivelis*) were the research focus but this changed to estuarine grouper species such as giant grouper as they are better suited to aquaculture opportunities in Australia.

Following the Queensland government divestment in northern aquaculture R&D in 2013, a private company Finfish Enterprise Pty Ltd was established to commercialise the R&D and a grouper hatchery has been operating in Cairns since 2014. This hatchery has been owned and operated by The Company One Pty Ltd (TCO) (http://www.thecompanyone.com) since 2017 and is currently producing up to one million Giant Grouper fingerlings per year, primarily for export to Hong Kong and Taiwan (Courtney, 2018). TCO also provides giant grouper fingerlings to Australian growers who supply live grouper to Asian restaurants and whole-chilled product to restaurants and to the Sydney Fish Market. Domestic supply of aquaculture produced giant grouper is now ~100 T pa (2019).

At the commencement of the project, RPPF had considerable infrastructure suited to finfish aquaculture, including indoor aquaculture facilities that previously comprised a prawn hatchery. Housed within the hatchery was a series of 10,000 L and 20,000 L parabolic tanks together with 6,000 L round tanks, which could be retrofitted to function as sand filters. On a separate site were earthen ponds previously used for prawn grow-out, and a large landlocked saline lake created by sand mining. Water supply to the hatchery was from two dams and the water in these could be batch disinfected prior to entering the hatchery. The hatchery was also fitted with cartridge water filtration and water heating equipment.

The Taiwan study tour provided an opportunity to look at different grow out systems and how they could be incorporated into RPPF. See Appendix 4. The use of RAS indoors to over winter fish before moving into cages or ponds was crucial in achieving market size for both species. Indoor RAS was also seen as a way to grow fish, mainly grouper, out of season to meet market demand. Floating raft cages in a 9m deep pond in Taiwan formed the idea of the floating cage systems used for Giant Grouper and Cobia in the lake.

The company had also planned for the purchase of additional equipment for the stepwise installation and operation of a recirculating aquaculture system (RAS) within the hatchery over the course of the project. Due to regulatory restrictions associated with management of the WSSV outbreak, the earthen ponds were not available for use during the course of the current project, but the landlocked lake was available. As previous studies of pond culture of Cobia in the Logan region had demonstrated low growth during winter, RPPF's production strategy involved utilisation of the prawn hatchery as a nursery and overwintering facility for Cobia and Giant Grouper, prior to transfer of juvenile fish to ponds or lake-based cages on the farm. This strategy has the potential to offset some disadvantages of cooler winter water temperatures, as well as allowing farms to dry out ponds through the winter for disease control. This two-phase production would also be applicable to Cobia or Giant Groper production on other prawn farms in south-east Queensland and elsewhere. A small sample of Cobia and Giant Grouper were be kept in cages over winter in the lake to determine whether they can survive the colder temperatures of winter in south east Queensland. The project was a collaboration between RPPF, TCO and DAF, with DAF staff involved in monthly sampling as well as data analysis.

Project aim

The project aimed to assess and compare the production performance and value of Cobia and Giant Grouper, two emerging aquaculture species for the Australian market. Two production systems were evaluated for both species: firstly, using the hatchery as an overwintering or production facility, and secondly, cage culture in a saline lake.

Objectives

Study tour of South East Asia to determine alternative farming methods for Cobia and Giant Grouper and investigate optimum market parameters.

Determine which method of grow out culture, indoor, pond or cage culture produces the optimum fish for the market.

Methods

General husbandry

Three batches of Giant Grouper juveniles were supplied by TCO (formerly Finfish Enterprise) hatchery in Cairns. In total, 39,928 Giant Grouper fingerlings were received and designated Batches 1, 3 and 4. Mean weight of fish in the batches varied from 15.1 to 150.0 g (Table 1).

Cobia fingerlings were sourced from BIRC. A total of 4,344 fingerlings were received in three batches, designated Batches 1, 2 and 3 that varied in mean batch weight from 28.0 to 250.0 g (Table 1).

Once received at the RPPF hatchery facility, fingerlings/juveniles were stocked into either 10,000 L or 20,000 L parabolic tanks (designated LR tanks) located in the former larval rearing area (Figure 1A), or 6,000 L round tanks (designated BT tanks) located in the former prawn broodstock area (Figure 1B). Several BT tanks also had a layer of sand in the base to function as a biofilter, a remnant of their previous use for prawn broodstock. All tanks were supplied with seawater filtered through a multimedia sand filter and 10 μm cartridge filtration unit (Figure 1C), initially operating on a partial exchange basis (10-50%) each day. Over the course of the project, additional water treatment elements, including protein skimmers, sand filters and additional biofilters, were installed, which enabled groups of two to four parabolic tanks to operate as a functional recirculating aquaculture system (RAS).

Fish were initially maintained in tanks in the hatchery facility for a two-month overwintering period then either transferred to outdoor cages in the landlocked lake (Figure 1D) for grow-out and harvest, or retained indoors in tanks until reaching harvest size. To assess survival over winter, 100 Cobia and 12 Giant Groper were stocked in separate cages in the lake from 01/06/17 to 31/08/2017. Following survival of all fish during this period, additional fish were stocked in the cages in September 2017 (Table 2).

Fish were fed to satiety with a formulated pelletised feed, Pelagica (Ridley Aquafeeds) by hand once or twice daily.

Table 1. Details of fish received and monitored in the project.

Species and batch	Stocking date	Number of fish	Average weight (g)
Grouper - Batch 1 2017	12/4/2017	2,000	150.0
Grouper - Batch 3 2017	30/6/2017	4,562	15.1
Grouper - Batch 3 2017	30/6/2017	9,756	20.4
Grouper - Batch 4 2017	17/10/2017	7,291	93.0
Grouper - Batch 4 2017	25/10/2017	9,319	97.0
Cobia - Batch 1 2017	18/05/17	1,847	28.0
Cobia - Batch 2 2017	23/05/17	2,197	34.0
Cobia - Batch 3 2017	15/11/17	300	250.0

Table 2. Details of fish stocked into production systems.

Species and batch	System	Number of fish	Average weight (g)
Grouper - Batch 1 2017	Cage 2 Lake	1,100	423
Grouper - Batch 1 2017	BT8 Tank	50	423
Grouper - Batch 3 2017	Cage 3A/3B Lake	3,000	64/73
Grouper - Batch 3 2017	Cage 4A/4B Lake	7,000	117/120
Grouper - Batch 3 2017	2 x 20,000 L Tank	2 x 1,000 fish	73/120
Grouper - Batch 4 2017	Cage 4 Lake	16,610	95
Cobia - Batch 2 2017	2 x 10,000 L Tank	50 / tank	193
Cobia - Batch 2 2017	Cage 5 Lake	1,738	193

Figure 1. Facilities at RPPF used during the project. A. Parabolic tanks (10,000 L, 20,000 L). B. Round tanks (6,000 L). C. Hatchery water filtration system. D. Cages in landlocked saline lake.

Sampling and data collection

Feed consumption and mortalities were recorded daily in all tanks and cages. Details of any fish transferred to other tanks or cages, additional fish added or harvested from tanks and cages were also recorded by RPPF staff. The following water quality parameters in tanks were monitored and recorded on a daily basis: pH, dissolved oxygen, temperature and salinity. Alkalinity, total ammonia and nitrite were monitored weekly. Un-ionised ammonia levels were calculated from values for total ammonia pH, temperature and salinity (USEPA, 1989). During the 2017 winter-survival trial in the lake, temperature was recorded daily and salinity, pH and dissolved oxygen were measured weekly. In the 2017/18 growing season in the lake, temperature at 1 m was recorded daily, and temperature at 3 m, pH at 1 m and 3 m, dissolved oxygen at 1 m and 3 m, salinity at 1 m and 3 m, nitrate at 1 m and total ammonia at 1 m were all recorded weekly.

BIRC staff visited RPPF on a monthly basis, assessing grow-out performance of both species through weight and health checks of fish in tanks and cages.

Fish were sampled from tanks using hand nets and from cages using either hand, seine, or cast nets. A bulk weight of 10-30 fish was recorded, and fish were then examined externally for any abnormalities, lesions or external parasites. Gill samples were taken from three fish per system and placed into a vial for further examination under a compound microscope at RPPF's laboratory. Fish were then counted and returned into their culture system.

In addition to monthly visits, BIRC project staff were on-call to provide advice for any technical issues that arose. In case of suspected disease outbreaks, samples of whole fish or fixed tissues were submitted to the DAF Biosecurity Sciences Laboratory for testing, diagnosis and advice.

Data from feed intake, survival and growth was used to assess production performance by calculating specific growth rate (SGR) and feed conversion ratio (FCR). The calculation of these parameters was restricted to populations that were maintained for periods of greater than 30 days, in an attempt to avoid non-representative data arising from short durations. In addition, the calculation of production performance parameters was restricted to fixed populations, that is, where possible separate parameters were calculated following the mixing of populations.

SGR was calculated as:

$$\text{SGR (\% body weight day}^{-1}\text{)} = ((\ln \text{(final weight)} - \ln \text{(initial weight)}) / \text{number of days}) * 100$$

Feed conversion ratio was primarily calculated as economic FCR (eFCR), which provides a robust measure of production costs:

$$\text{eFCR} = \text{feed consumed} / \text{economic weight gain}$$

In the case of tank or cage populations where stock were moved in or out, or harvested, these movements were also taken into account in calculations by:

$$\text{Economic weight gain} = \text{final biomass} + \text{biomass removed}^{*} - \text{initial biomass} - \text{biomass received}$$

In some instances, the eFCR was substantially skewed by large-scale mortality events, skewing values to greater than 10, which, while strictly still a measure of production costs, can bias FCR as a performance measure. In this case, the biological FCR (bFCR) was also calculated, which includes the biomass of fish which subsequently died and is a better indicator of the biological potential of the species:

$$\text{bFCR} = \text{feed consumed} / \text{biological weight gain}$$

$$\text{Biological weight gain} = \text{final biomass} + \text{mortality biomass} + \text{biomass transferred out or harvested} - \text{biomass transferred in} - \text{initial biomass}$$

Results

Water Quality

Tanks

Water quality for Batch 1 of Giant Grouper showed some variability, reflecting the development and stabilisation of water treatment systems as additional water treatment elements were installed. In general, water temperatures were maintained at greater than 21.7 °C, with an average of 24.0 – 25.7 °C during the production period for the six batches cultured during this project. pH was maintained between 6.83 and 7.94 and salinity between 23.0 g L^{-1} and 37.0 g L^{-1} that are within suitable limits based on studies of these or similar species (Cheng *et al.*, 2013; Muhammadar *et al.*, 2014; Resley *et al.*, 2006; Atwood *et al.*, 2004; Rodrigues *et al.*, 2015) (Table 2). In general, total ammonia and nitrate were kept below levels known to impact the health and survival of these species (Atwood *et al.*, 2004; Rodrigues *et al.*, 2007; Barbieri and Doi, 2012; Ip *et al.*, 2001) (Table 3). Toxic free ammonia (NH_3-N) levels were very low at the levels of total ammonia recorded primarily due to the reduced pH maintained within the RAS used to culture these fish.

Table 3. Water quality parameters of rearing tanks during the initial rearing of Batch 1 Giant Grouper. Values are mean (max, min) for the duration of rearing.

Tank #	Days post-transfer	Temperature (°C)	pH	DO (mg L^{-1})	Salinity (g L^{-1})	Nitrite (ppm)	Total Ammonia (ppm)	Un-ionised ammonia[1] (ppm)
BT4	87	25.6 (27.0-22.0)	7.29 (7.93-6.83)	5.2 (6.8-4.0)	30.01 (35.00-23.00)	0.1 (1.0-0.0)	0.1 (0.5-0.0)	0.002 (0.019,0.000)
BT5	163	25.0 (27.0-22.0)	7.31 (7.94-6.89)	5.3 (6.8-4.1)	32.16 (36.00-23.00)	0.1 (2.0-0.0)	0.0 (0.5-0.0)	0.001 (0.014,0.000)
BT6	251	25.7 (28.1-21.7)	7.01 (7.32-6.93)	5.7 (7.5-3.8)	32.88 (37.00-23.00)	0.2 (2.0-0.0)	0.1 (4.0-0.0)	0.001 (0.035,0.000)
BT7	148	25.0 (27.0-21.9)	7.28 (7.80-6.93)	5.4 (7.0-3.4)	31.89 (36.00-23.00)	0.1 (1.0-0.0)	0.1 (1.0-0.0)	0.001 (0.011,0.000)
BT8	41	25.5 (27.0-22.0)	7.42 (7.70-7.18)	6.1 (7.1-5.2)	27.26 (32.00-23.00)	0.6 (2.0-0.0)	0.1 (1.0-0.0)	0.002 (0.016,0.000)
BT11	142	24.0 (25.1-23.0)	7.33 (7.51-7.17)	5.7 (6.4-5.0)	35.42 (36.00-35.00)	0.1 (1.0-0.0)	0.1 (1.0-0.0)	0.000 (0.008,0.000)

[1] Calculated, using formula in USEPA (1989)

Some major water quality issues were experienced with Batch 3 Giant Grouper during the post-transfer period. Elevated ammonia (TAN and unionised ammonia) and nitrite levels were recorded (Table 4) and these were associated with significant mortality events in tanks LR3 and LR4 (refer to "Health and Survival" below). The resultant need to increase water exchange caused a reduction in water temperature, seen in the minimum temperatures for these tanks. Aside from this period, water quality parameters were generally in the target range (Table 4).

Table 4. Water quality parameters of rearing tanks during the initial rearing of Batch 3 Giant Grouper. Values are mean (max, min) for the duration of rearing.

Tank #	Days post-transfer	Temperature (°C)	pH	DO (mg L^{-1})	Salinity (g L^{-1})	Nitrite (ppm)	Total Ammonia (ppm)	Un-ionised ammonia[1] (ppm)
LR1/ BT10	87	24.0 (26.0-20.0)	7.4 (8.0-7.19)	5.8 (8.2-3.7)	34.31 (37.00-32.00)	0.8 (5.0-0.0)	0.5 (4.0-0.0)	0.007 (0.068,0.000)
LR2/ BT 8	127	24.4 (26.5-20.0)	7.42 (7.89-7.22)	5.8 (8.3-3.3)	34.95 (37.00-30.00)	0.4 (5.0-0.0)	0.2 (4.0-0.0)	0.003 (0.064,0.000)
LR3	137	24.0 (35.5-20.9)	7.51 (7.85-7.21)	6.2 (8.3-3.9)	34.90 (37.00-30.00)	1.4 (5.0-0.0)	0.9 (4.0-0.0)	0.013 (0.094,0.000)
LR4	137	23.8 (28.0-20.5)	7.50 (7.87-7.10)	6.2 (8.4-3.8)	34.92 (37.00-30.00)	1.4 (5.0-0.0)	1.0 (4.0-0.0)	0.014 (0.096,0.000)
BT4	103	24.54 (26.1-22.1)	7.38 (7.94-7.14)	5.2 (6.4-0.8)	34.97 (37.00-32.00)	0.1 (1.0-0.0)	0.1 (4.0-0.0)	0.001 (0.3800,0.000)

Cobia Batches 1 and 2 were received seven days apart. Water temperature was variable for these batches, occasionally declining below 22 °C, mostly in the post-transfer period in May/June (Table 5). Dissolved oxygen levels declined below 4 mg L^{-1} as biomass increased in the 6,000 L BT tanks. Once juveniles were transferred to the 20,000 L LR tanks, dissolved oxygen levels were maintained above 5 mg L^{-1}. Elevated biomass was also associated with a reduction in pH below 7 (Table 5), driven by increased CO_2 production.

Graphs of water quality data from representative cohorts (Giant Grouper, Batch 1 BT7; Giant Grouper, Batch 3 LR2/BT8; Cobia, Batch 2 BT11/LR25) demonstrating these trends, are shown in Appendix 3.

Table 5. Water quality parameters of rearing tanks during the initial rearing of Cobia Batches 1 and 2. Values are mean (max, min) for the duration of rearing.

Tank #	Days post-transfer	Temperature (°C)	pH	DO (mg L^{-1})	Salinity (g L^{-1})	Nitrite (ppm)	Total Ammonia (ppm)
BT10/LR24	154	23.8 (35.7-20.0)	7.33 (7.80-6.92)	5.8 (23.1-2.7)	34.36 (37.00-30.00)	1.1 (2.0-0.0)	0.5 (2.0-0.0)
BT11/LR25	154	23.7 (28.5-20.0)	7.34 (7.72-6.94)	5.6 (7.6-2.7)	34.35 (37.00-30.00)	1.3 (2.0-0.0)	0.5 (2.0-0.0)
BT8/LR23	147	23.8 (28.5-20.0)	7.33 (7.80-6.83)	5.7 (7.5-3.7)	34.48 (37.00-30.00)	0.8 (2.0-0.0)	0.3 (2.0-0.0)
BT12/LR22	147	23.8 (29.0-20.0)	7.37 (7.98-6.96)	5.6 (7.6-3.0)	34.44 (37.00-30.00)	1.0 (2.0-0.0)	0.4 (2.0-0.0)

Cages

During the winter trial, water temperatures in the saline lake where the cages were located varied between 16.5 and 19.2 °C, while salinity was stable at 27 g L^{-1} (Figure 2A). Dissolved oxygen was consistently greater than 7.3 mg L^{-1} and pH was steady at approximately 7.6 (Figure 2B). Despite the reduced temperatures, and reduced feeding responses, survival was 100% in both cages of Cobia and Giant Grouper.

During the 2017/18 production season, water temperature in the lake was relatively consistent for 1 m and 3 m depth samples (Figure 3A). Water temperatures consistently exceeded 25 °C from mid- November 2017 until April 2018. A maximum water temperature of 29.8 °C was recorded in February and the minimum temperature of 16 °C was reached in July, consistent with trends in 2017 (Figure 3A). Dissolved oxygen levels were essentially the same between samples collected at 1 and 3 m depth. During the period from December to April, dissolved oxygen levels were regularly at or below 5 mg L^{-1} (Figure 3B). Lake water pH peaked at 8.55 during a short period in late November but in general pH remained between 7.3 and 8.0 (Figure 3C). Salinity increased from 27.0 to 28.8 g L^{-1} in February 2018, before dropping to 26.0 g L^{-1} following a rain event in the same month (Figure 3D). Nitrite and ammonia were not detected throughout sampling (data not shown).

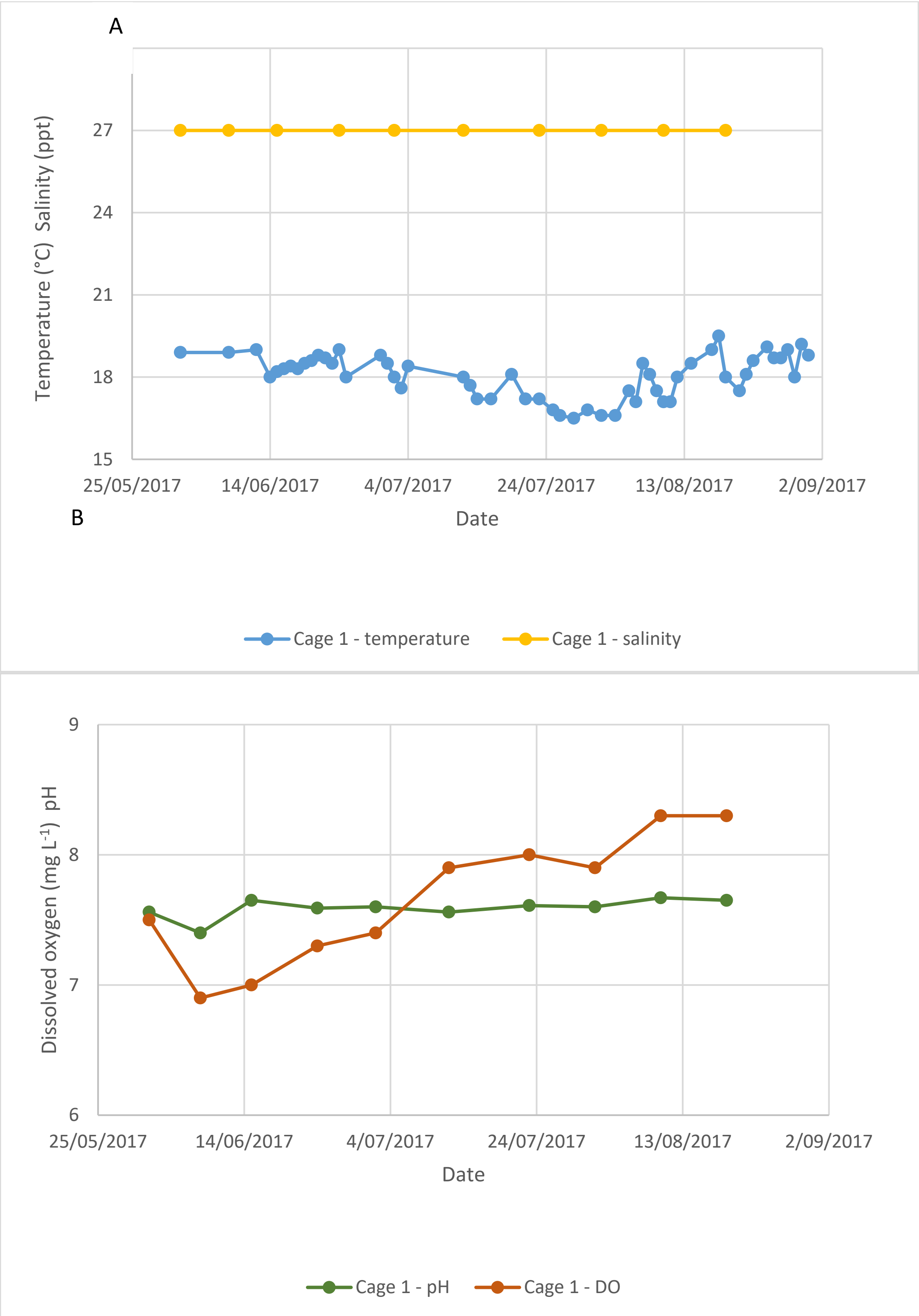

Figure 2. Water quality parameters during the winter cage trial (Cage 1). A. Water temperature and salinity. B. Dissolved oxygen (DO) and pH.

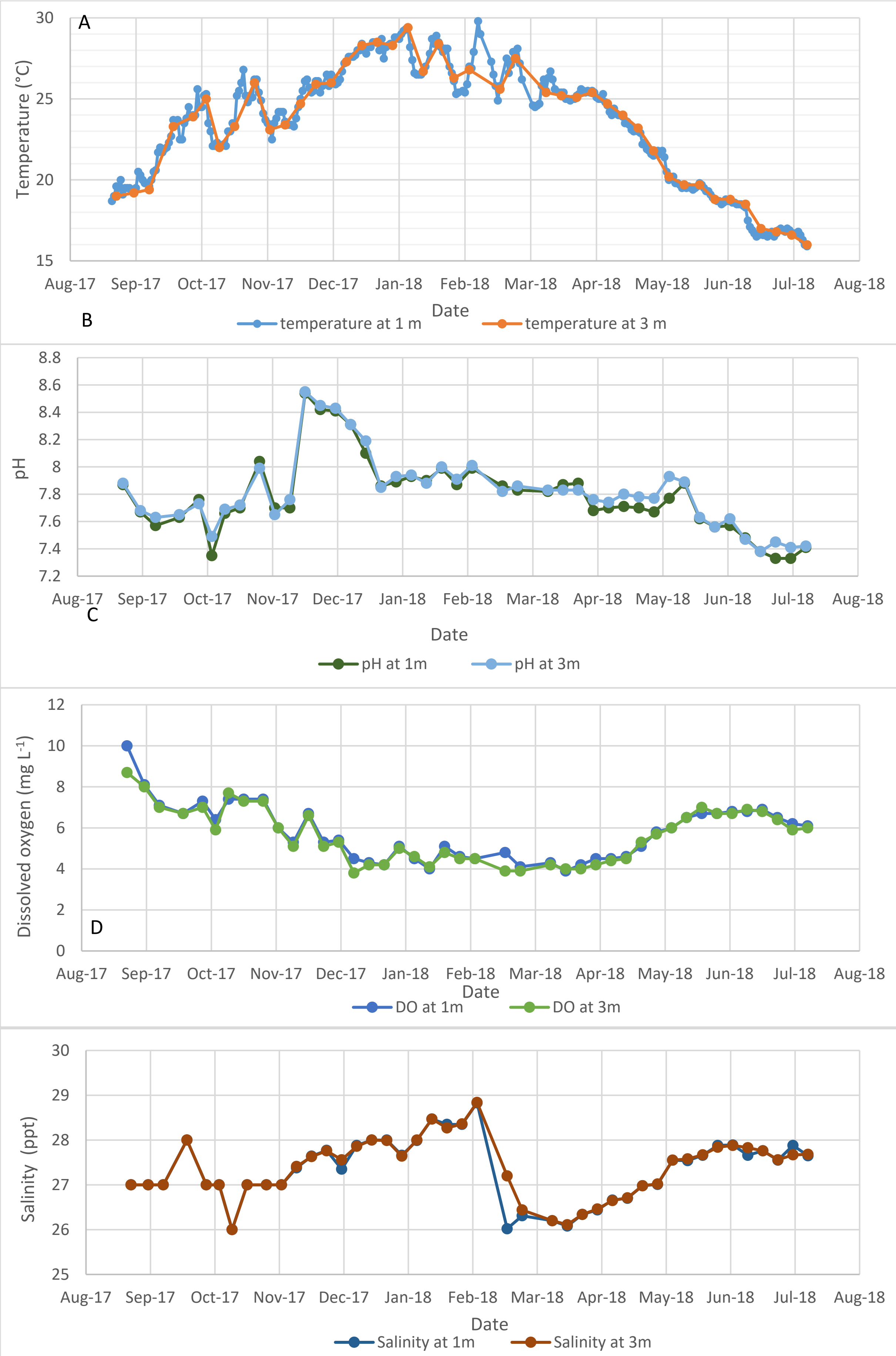

Figure 3. Lake water quality parameters at 1 m and 3 m depths during 2017/18.
A. Temperature. B. pH. C. Dissolved oxygen (DO). D. Salinity.

Production

Giant Grouper

Post-transfer growth rates of Giant Grouper were similar in tanks and cages, with juveniles achieving a size of 400 g within 140 days, at a SGR of approximately 1.3 to 1.5% BW per day (Figures 4 and 5, Tables 6 and 7). Although achieving a similar rate of growth, larger individuals had lower SGR (e.g. Batch 1 Cage 2) reflecting the dependence of this measure on body weight. Growth rates of Giant Grouper in tanks were markedly higher in the mostly-Summer period (November to March) (Figure 4B) than those of similar size in spring (September to December) (Figure 4A), which was not evident in pond-based populations (Figure 5). Giant Grouper stocked into tanks in winter attained a harvest weight of 800 g within 9 months (Figure 4), which was similar to that attained by juveniles stocked into pond-cages following a nursery period in tanks (Figure 5).

Table 6. Growth of cage-reared populations of Giant Grouper.

Batch	Cage	Duration (days)	Initial weight (g)	Final weight (g)	SGR (% body weight day^{-1})	Average growth rate (g day^{-1})
1	2	121	423	1,183	0.85	6.28
3	1	172	64	723	1.41	3.83
3	4	48	97	193	1.44	2.01
3	6	140	149	1,000	1.36	6.08
4	7	154	97	892	1.44	5.16

Table 7. Growth of tank-reared populations of Giant Grouper.

Batch	Tank(s)	Duration (days)	Initial weight (g)	Final weight (g)	SGR (% body weight day^{-1})	Average growth rate (g day^{-1})
1	BT5	163	150	455	0.68	1.87
1	BT6	245	150	791	0.91	2.62
1	BT7	106	150	359	0.82	1.97
1	BT8	41	150	248	1.23	2.39
3	LR3-LR13	333	20	1,214	1.23	3.55
3	LR2-LR14	333	15	1,146	1.30	3.37
3	BT8-LR16	333	15	931	1.24	2.75

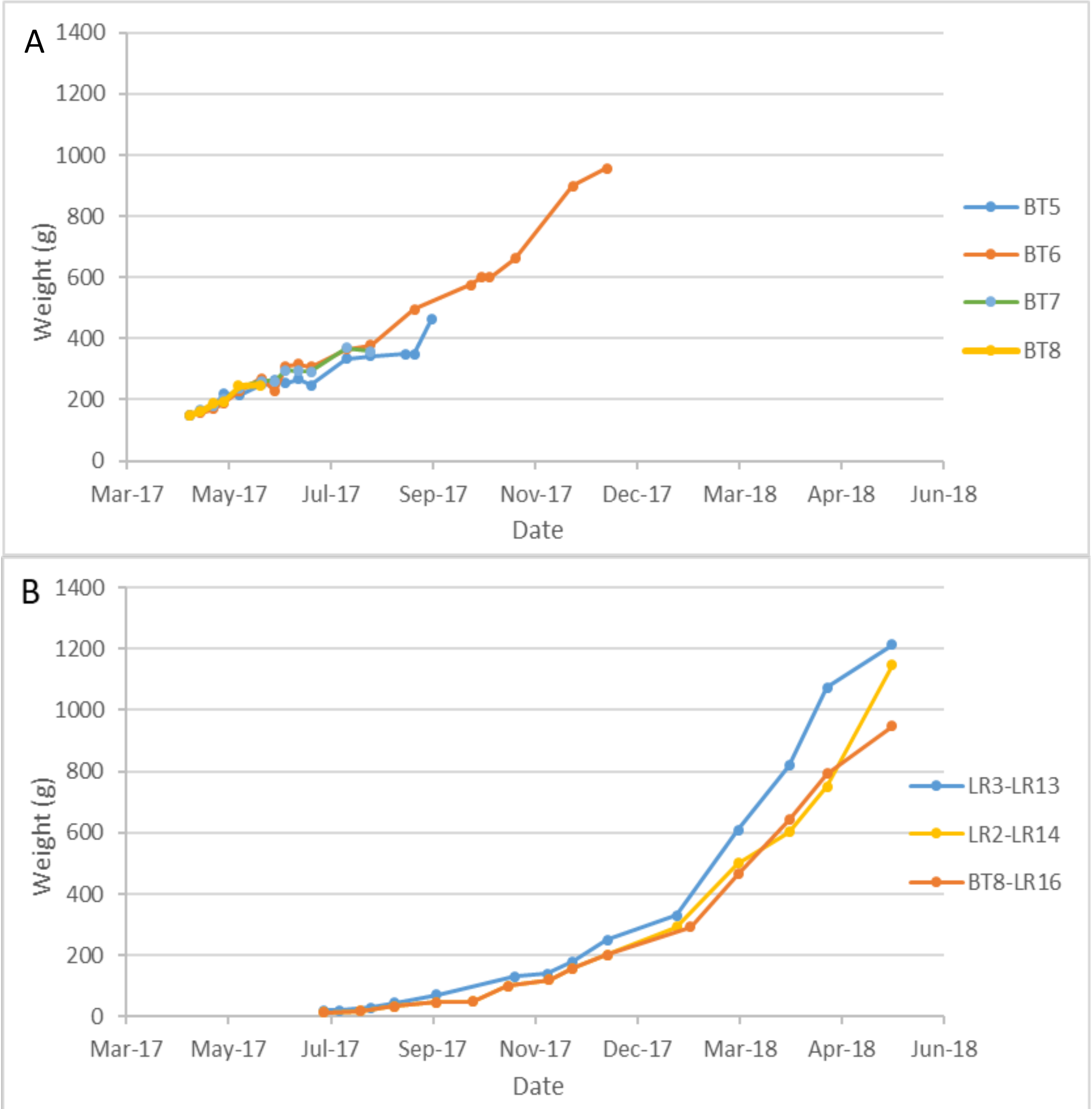

Figure 4. Growth curves of populations of Giant Grouper reared in tanks. A. Batch 1. B. Batch 3.

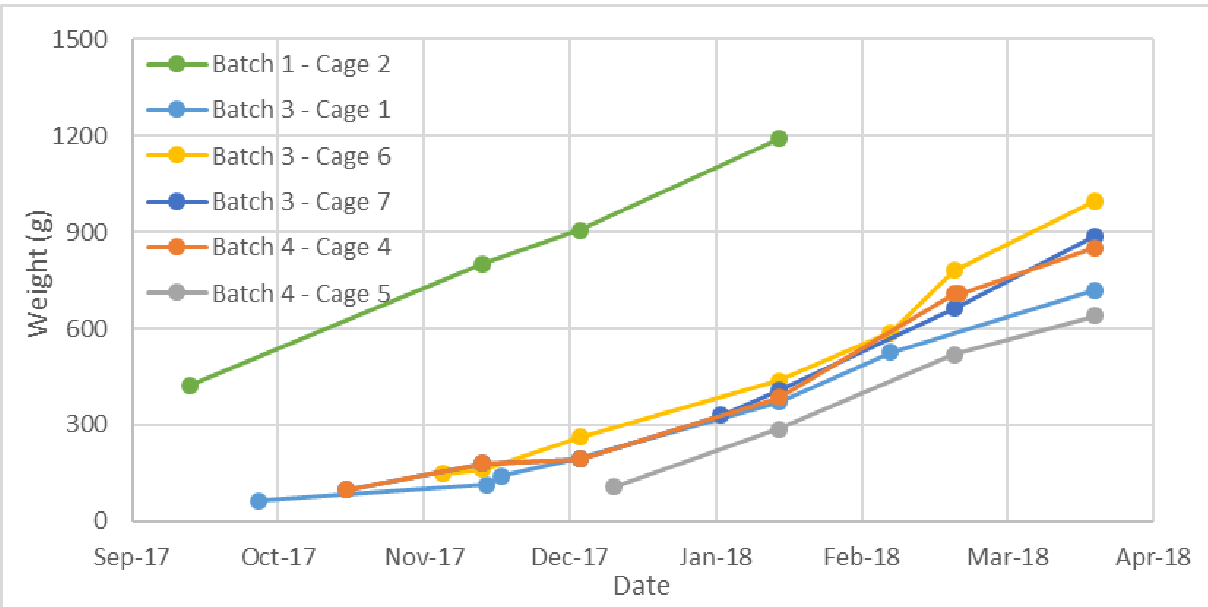

Figure 5. Growth curves of cage populations of Giant Grouper.

Feed conversion ratios of tank- and pond-reared populations of Giant Grouper are shown in Tables 8 and 9. The FCR in both tanks and cages was affected by high levels of mortalities in some populations. In some instances a meaningful estimate of FCR (eFCR) was not able to be calculated due to large scale mortalities, while biological FCR (bFCR) was applied when there was sufficient data for an estimate of potential performance.

Table 8. Feed conversion ratio (FCR) of tank-reared populations of Giant Grouper.

Batch 1			Batch 3		
Tank #	**duration (days)**	**FCR**	**Tank #**	**duration (days)**	**FCR**
BT5	163	1.06*	LR3	137	1.19
BT6	252	1.48	LR4	137	1.18
BT7	149	0.87	LR13	215	0.85
BT8	42	0.83	LR14	234	1.38
			BT4	119	0.92
			BT8	107	0.94
Mean ± SE		**1.06 ± 0.18**			**1.07 ± 0.08**

* bFCR used as eFCR was skewed (>10) due to high mortality levels

Table 9. Feed conversion ratio (FCR) of cage-reared populations of Giant Grouper. (NC - not calculated as insufficient data).

Batch 1			Batch 3			Batch 4		
Cage #	**Duration (days)**	**FCR**	**Cage #**	**Duration (days)**	**FCR**	**Cage #**	**Duration (days)**	**FCR**
2	59	1.17	3B	46	1.07	4	43	1.48
2	452	NC	3C	49	0.77	5	130	NC
			6	172	1.30			
Mean ± SE		**1.17**			**1.04 ± 0.15**			**1.48**

Cobia

Post-transfer growth rates of Cobia in tanks were highly variable, with SGR ranging from 0.4 to 2.5% body weight per day (Table 10). This generally reflected problems with water quality and/or health problems in tanks with low SGR (see Health and Survival). Only a single cohort of cage-reared Cobia were followed and SGR was relatively constant throughout the production cycle, but daily growth increment (g day^{-1}) increased substantially with size (Table 11, Figure 7), with growth best represented by an exponential curve (R^2=0.9702) (Figure 7). Feed conversion ratios (FCR) for tank-reared Cobia were highly variable, ranging from 1.04 to 2.58 (Table 12). The variation is likely to be a function of variation in the duration of growth, together with small populations under consideration, both a result of frequent stock movements between tanks. For that reason the mean value of 1.61 is considered a more representative value. Similarly, there was variation in FCR in cage-reared Cobia, with a range of 1.08 to 1.76 and a mean of 1.51 for the three groups studied.

Table 10. Specific growth rate (SGR) of tank-reared populations of Cobia.

Batch	Tank	Duration (days)	Start weight (g)	Final Weight (g)	SGR (% body weight day^{-1})	Average growth rate (g day^{-1})
2	BT 8	55	32	100	1.67%	0.83
2	BT10	49	28	97	2.51%	1.40
2	BT11	49	28	96	2.49%	1.38
2	BT 12	44	28	96	2.29%	1.39
2	LR22	104	97	163	0.37%	1.39
2	LR23	104	97	141	0.49%	0.43
2	LR24	78	80	172	0.98%	1.18
2	LR25	78	80	177	1.02%	1.24

Table 11. Specific growth rate (SGR) of cage-reared populations of Cobia.

Batch	Cage	Duration (days)	Start weight (g)	Final Weight (g)	SGR (% body weight day^{-1})	Average growth rate (g day^{-1})
2	3A	47	175	300	1.15%	2.66
2	3/5	268	175	3,400	1.05%	12.03

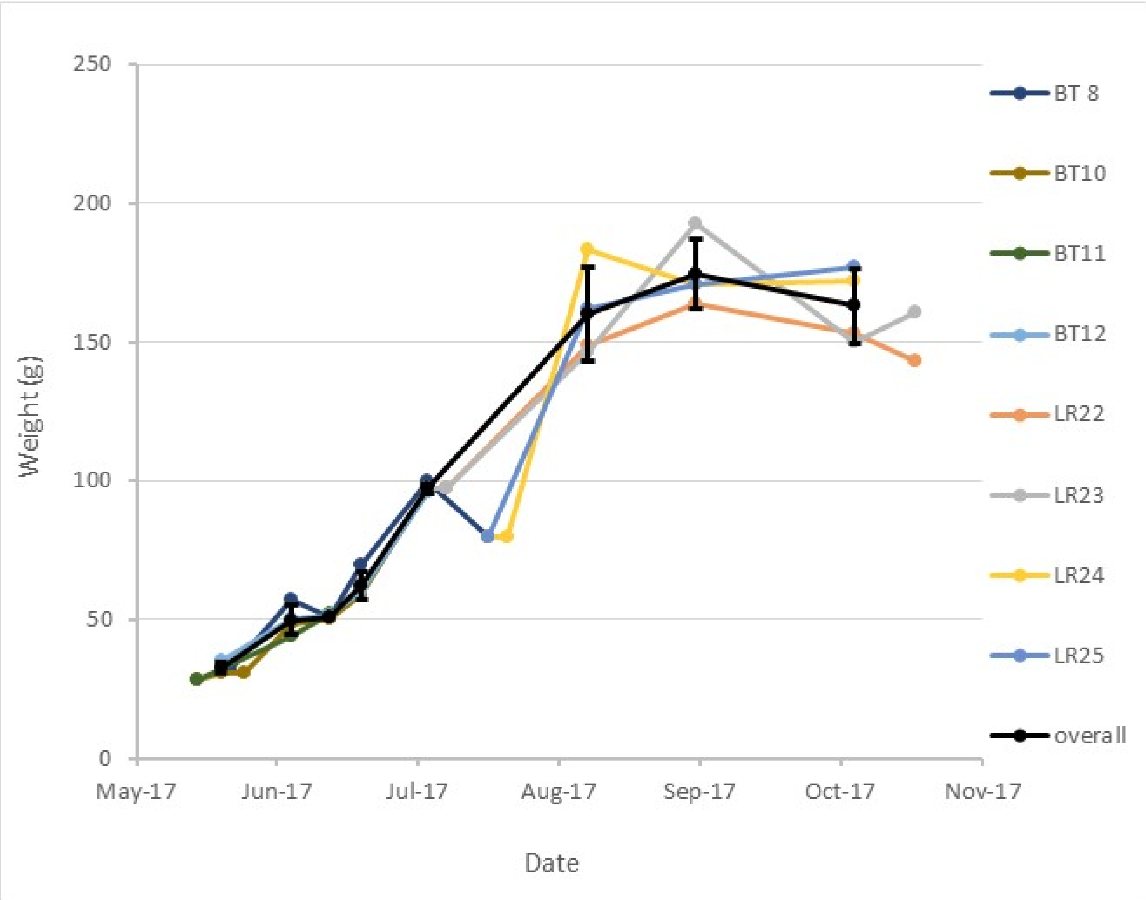

Figure 6. Growth of Cobia in tanks showing individual tank populations in 6,000 L (BT) or 20,000 L (LR) tanks and an average weight (g) curve (mean ± S.E.).

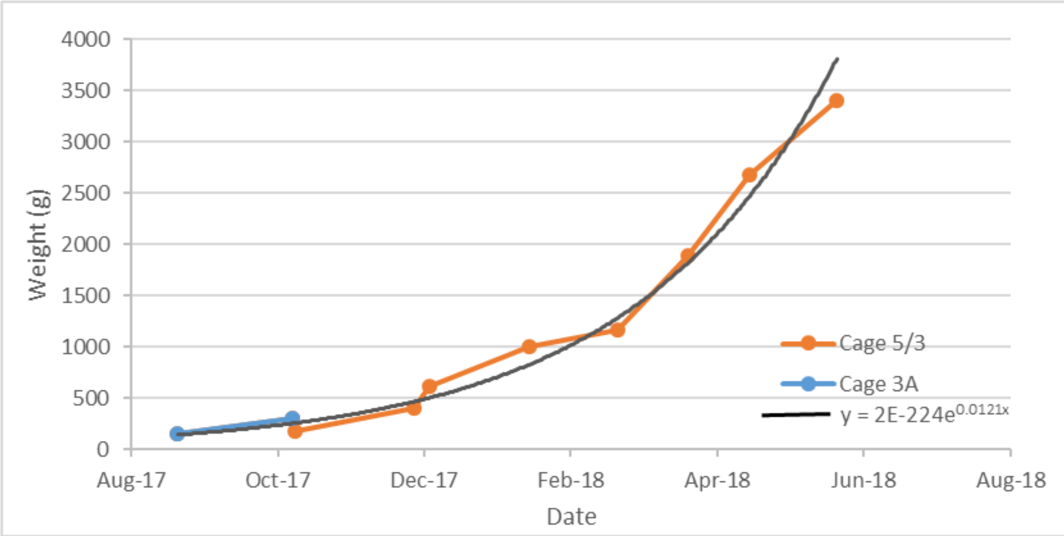

Figure 7. Growth of Cobia juveniles, transferred to cages in August 2017. Cages 5 & 3, Cage 3A and best-fit exponential curve.

Table 12. Feed conversion ratio (FCR) of tank- and cage-reared populations of Cobia.

Tank #	Duration (days)	FCR
BT8	55	1.04
LR22	104	1.69
BT10	49	2.58
LR23	104	1.60
BT11	49	1.12
LR24	78	1.60
BT12	42	1.46
LR25	78	1.75
Mean ± SE		**1.61±0.17**
Cage #	**Duration (days)**	**FCR**
3a	48	1.70
5	42	1.08
3	270	1.76
Mean ± SE		**1.51±0.22**

Health and Survival

Mortalities arose from operational or equipment failures as well as pathogens and parasites, in both tank- and cage-reared fish. In some instances, the losses were catastrophic, affecting in excess of 50% of the tank or cage population. Individual events are listed in Table 13 together with comments on likely impacting factors and any mitigating actions undertaken. In some instances, water quality issues, in particular elevated ammonia levels, occurred prior to mortality events, such as Columnaris disease (*Flavobacterium sp*) (Figure 8). Total ammonia levels reached 4.0 ppm, while un-ionised ammomnia reached 0.94 ppm and 0.96 ppm in affected tanks (Table 4).

Some populations of Cobia fingerlings were lost in the first few months post-transfer. Two tanks of fingerlings had ceased feeding and infection by the dinoflagellate *Amyloodinium ocellatum* was identified. Unfortunately, the infection was well advanced prior to treatment and all stock were lost.

Nodavirus was responsible for mortality levels of 34 to 95% in cage populations of Giant Gouper (Table 13). The disease is higly contagious, rapidly infecting indiduals within a cage population and populations in adjacent cages. Figure 9 shows the rapid impact of nodavirus on cage populations, and demonstrates the limted capacity of emergency harvesting to substantially reduce losses.

Table 13. Significant mortality events and causes.

Species/Batch	Tank/ Cage #	Incident Mortality	Comments
Grouper - Batch 1	BT5	58%	Possible *Amyloodimium ocellatum* infection noted on fresh gill preparations but the diagnosis was not confirmed. Mortality rates reduced substantially following freshwater bath treatment.-
Grouper - Batch 1	BT6	4%	Air blower failure
Grouper - Batch 3	LR3	14%	Columnaris disease, a bacterial infection caused by *Flavobacterium columnare*. The losses coincided with declining water quality, primarily increased ammonia levels, and reduced appetite (see also Figure 8). Increased water exchange and reduced stocking density were used to reduce the impact of disease prior to diagnosis and the application of antibiotics .
Grouper - Batch 3	Cage 2	95%	Nodavirus outbreak. Stocks lost within 10 days of first mortality
Grouper - Batch 3b	Cage 6	38%	Nodavirus outbreak. Stocks lost within 10 days of first mortality. Emergency harvest undertaken to reduce losses.
Grouper - batch 4	Cage 5	87%	Nodavirus outbreak. Stocks lost within 10 days of first mortality. Emergency harvest undertaken to reduce losses.
Grouper - Batch 4	Cage 4	34%	Nodavirus outbreak. Stocks lost within 10 days of first mortality. Emergency harvest undertaken to reduce losses.
Grouper - Batch 4	Cage 8	56%	Nodavirus outbreak. Stocks lost within 10 days of first mortality. Emergency harvest undertaken to reduce losses.
Cobia - Batch 1	LR1, LR2	100%	*Amyloodinium ocellatum* infection

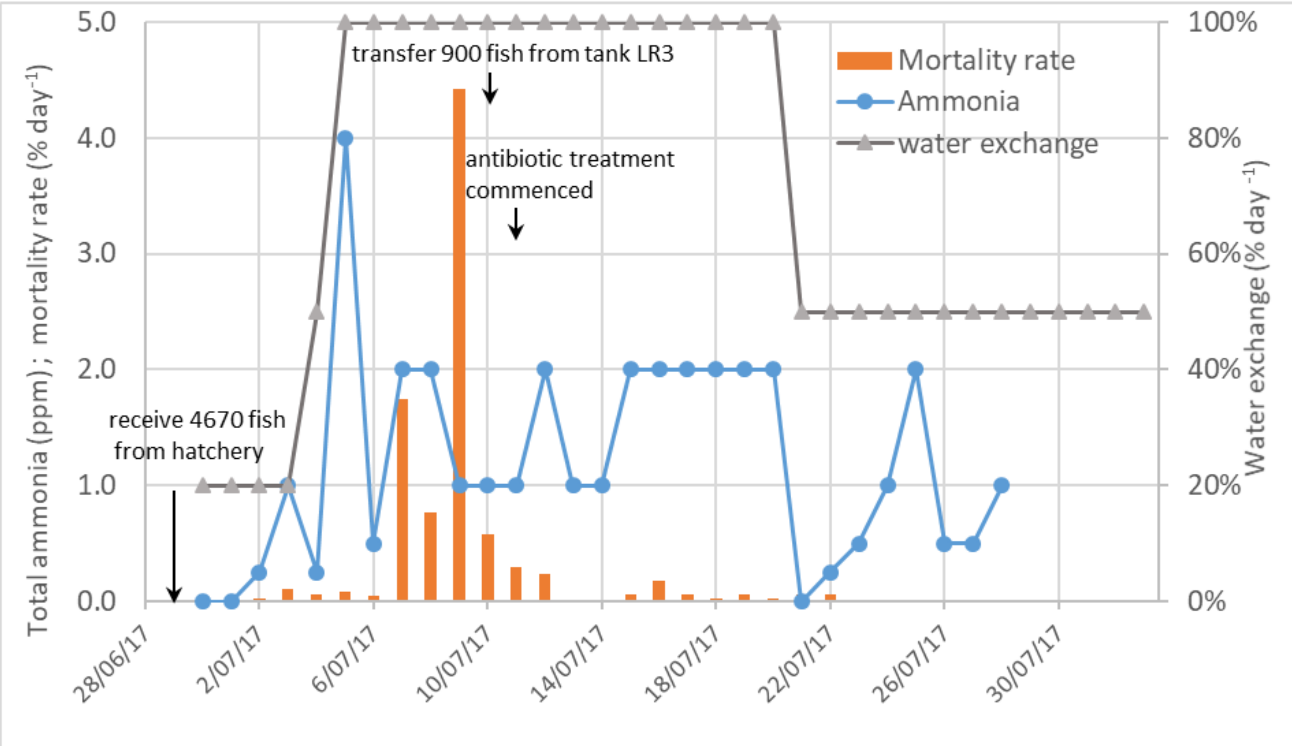

Figure 8. Outbreak and management of Columnaris disease, following transfer of Giant Grouper fingerlings and elevated ammonia in tank.

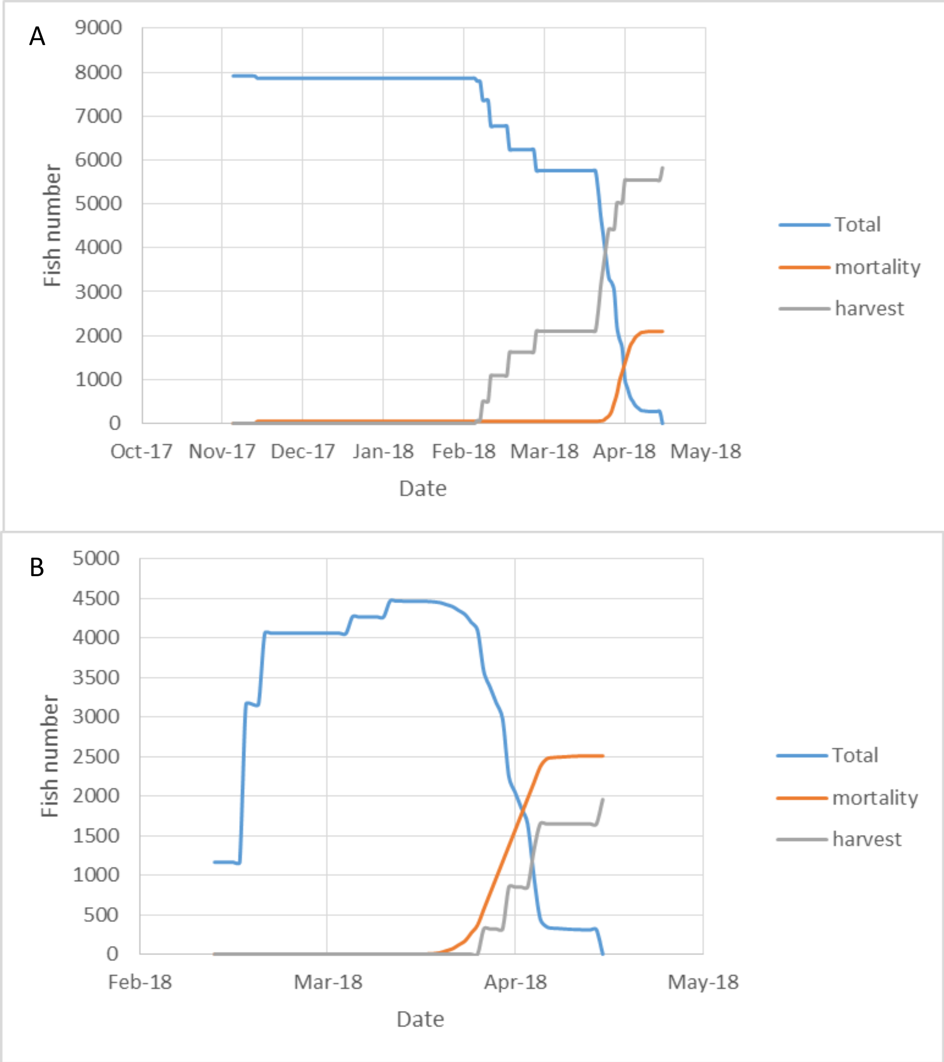

Figure 9. Mortality curves for two representative cages of Giant Grouper during an outbreak of nodavirus. A. Cage 6. B. Cage 8.

Discussion

Water Quality

Water temperature is a major factor influencing fish growth, health and performance, both via direct impacts on physiology, and through interactions with factors such as dissolved oxygen levels and pathogen viability (Boyd and Tucker, 1998). The temperature range for optimum growth and performance is generally species specific, and reflected in the natural distribution of the species in question. Cobia perform better at temperatures greater than 25 °C (Benetti *et al.*, 2010; Sun and Chen, 2014), but less than 33 °C (Sun and Chen, 2014). Feed intake by Cobia declines within the temperature range 31 °C to 23 °C (Sun and Chen, 2014) and ceases below 18 °C (Nhu *et al.*, 2011; McLean *et al.*, 2008; Shaffer and Nakamura 1989). Similarly, various *Epinephelus* species perform better at higher water temperatures (Pierre *et al.*, 2008; Lin *et al.*, 2008; De *et al.*, 2016; Tsuji *et al.*, 2014; Lopez and Castello-Orvay, 1995). Cobia can tolerate temperatures less than 15 °C but studies by Atwood *et al.* (2004) determined the minimum critical thermal limit (50% CT_{MIN}) for Cobia as 12.1 °C. The 50% CT_{MAX} and 50% CT_{MIN} for brown marbled grouper (*E. fuscoguttatus*) were in the range 35.0 to 38.3 °C and 9.8-12.2 °C respectively, depending on salinity and initial temperature (Cheng *et al.*, 2013). In cage culture of Cobia, prolonged periods of temperatures below 16 °C have been associated with high mortality events, either directly, or via disease outbreaks (Liao *et al.*, 2004; Nhu *et al.*, 2011). Declining water temperatures have also been associated with the onset of several bacterial diseases in Cobia (Leano *et al.*, 2008).

In contrast to Cobia, temperature-related mortality due to microbial pathogens in grouper typically occurs during periods of increased water temperature (Fukuda *et al.*, 1996; Albert and Ransangan, 2013). There is also evidence for high rearing temperatures causing developmental abnormalities in grouper, including swim bladder syndrome (Erazo-Pagador and Cruz-Lacierda, 2004) and spinal deformities (Tsuji *et al.*, 2014). Water temperatures experienced by both species in the current study were generally within preferred ranges of 20 °C to 28 °C while in tanks. In cages, fish did experience several weeks of water temperatures in the range 16 °C to 18 °C during winter; however, no significant mortality events or disease outbreaks were noted during this period. In this project, outbreaks of nodavirus in caged grouper occurred in February to April, during which there were occasional spikes in surface water temperature; however, the data are not sufficient to correlate these factors or discriminate temperature from other potential factors such as increased biomass. Outbreaks of nodavirus are frequently the result of a stress event five to seven days prior to first mortality and it is very likely that localised stress events occurred that initiated the disease outbreaks. Similar nodavirus outbreaks were common at a pond farm in Cairns and modifications to nursery and farm practices to minimise stress events led to greatly improved outcomes.

Maintenance of dissolved oxygen levels greater than 5 mg L^{-1} is a general recommendation for aquaculture (Boyd and Tucker, 1998). Cobia are a species with a high growth rate, and a requirement to actively maintain buoyancy by swimming due to the lack of a swim bladder (Fraser and Davies, 2009; Benetti *et al.*, 2010; Benetti *et al.*, 2007). This results in high energy demands (Fraser and Davies, 2009), and metabolic energy requirement (Sun and Chen, 2014; Feeley *et al.*, 2007). As such Cobia have a low tolerance of reduced dissolved oxygen levels. Although aquaculture operations prioritise dissolved oxygen levels where possible, mortalities of juvenile Cobia during transport have been ascribed to low dissolved oxygen levels (Liao *et al.*, 2004). Similarly, low dissolved oxygen levels of 2.8 mg L^{-1} were responsible for a mortality event in tank-reared red grouper (*E. morio*) in Mexico (Brulé *et al.*, 1996) and have also been implicated in the development of swim bladder syndrome in several cage-reared *Epinephelus* species in Taiwan (Erazo-Pagador and Cruz-Lacierda, 2004). Although in the current study, dissolved oxygen levels did decline below 3 mg L^{-1} for both species, no mortalities could be ascribed directly to the effects of this. In general, when oxygen levels did decline, this was stabilised by either increasing water flow and/or aeration or by reducing stocking density, through transfer of stock to other tanks.

Cobia and grouper species have been shown to be tolerant of a range of salinity levels, but this tolerance is dependent on other water quality variables such as temperature, as well as the duration of exposure. Cobia can tolerate acute exposure to salinity of 8 g L^{-1} but exposure to 2 g L^{-1} resulted in 80% mortality within 24 hr (Atwood *et al.*, 2004). Brown marbled grouper (*E. fuscoguttatus*) exposed to gradual changes in salinity had a critical salinity maximum (50% CS_{MAX}) of 67 g L^{-1} to 75 g L^{-1}, depending on initial salinity and water temperature, and all survived at gradual salinity reduction to 0 g L^{-1} (Cheng *et al* 2013). Upper and lower limits for acute changes to salinity were less broad, with 50% CS_{MAX} less than 65 and 100% mortality of fish at 0 g L^{-1}. Similarly Goliath grouper (*E. itajara*) could survive a 96 hr acclimation to 0 g L^{-1}, but had a 60% mortality following sudden transfer to 0 g L^{-1}. Growth and FCR of Cobia grown at 5 g L^{-1} was not different to those reared at 30 g L^{-1}; however, mortality rates were higher when reared over an 8-week period at 5 g L^{-1} (Resley 2006). Growth of brown marbled grouper (Cheng *et al.*, 2013) and dusky grouper (*E. marginatus*) (López and Orvay, 2003) was greatest at salinities greater than 32 g L^{-1}, in comparison to salinities of 28 g L^{-1} or less. In the present study Cobia and Giant Grouper experienced relatively stable salinity in tank and pond environments. In tanks, water was maintained between 23 g L^{-1} and 37 g L^{-1}, while in the brackish lake water, salinity ranged from 26 g L^{-1} to 29 g L^{-1}, with the most abrupt change of 3 g L^{-1} occurring over a two-week period. At no time did fish exhibit behaviour, poor feeding, or declining performance that could be linked to salinity.

As a result of its specific ionic composition seawater has an inherent buffering capacity and rarely ranges outside 7.5 to 9.0 (Boyd and Tucker, 1998). In the present study, pH was maintained between 6.9 and 8.0 in tanks, and remained between 7.3 and 8.6 in the lake. This is well outside the range that has been shown to cause damage at a cellular (pH<6.5) and tissue (pH<6.0) level in Cobia (Rodrigues *et al.*, 2015), but would be cause for concern should pH become elevated, for example, as the result of a strong algal bloom.

In this project elevated levels of ammonia within RAS tanks was attributed to subsequent mortality of grouper. Ammonia, the primary nitrogenous waste product produced by fish, is toxic at low concentrations for most species, particularly in the un-ionised form, NH_3. It is recommended to be maintained at less than 1-2 mg L^{-1} in recognition of the 50% lethal concentration (LC_{50}), determined across a range of species, of 0.2-3.0 mg L^{-1} for 24 to 96 hours exposure (Boyd and Tucker, 1998; Ip *et al.*, 2001). The microbial breakdown compounds produced by the oxidation of ammonia, nitrite (NO_2^-) and nitrate (NO_3^-) are substantially less toxic than ammonia, by two or three orders of magnitude respectively (Boyd and Tucker, 1998; Ip *et al.*, 2001). In addition to lethal effects, all compounds may also have significant sub-lethal effects at a cellular level (Ip *et al.*, 2001). The 24-h LC_{50} for unionised ammonia (NH_3) for juvenile Cobia in 35 g L^{-1} seawater was determined to be 1.8 mg L^{-1}, and this sensitivity increased with reduced salinity (Barbieri and Doi, 2012). Estimates of a 96-hour LC_{50} for unionised ammonia ranged from 0.7 mg L^{-1} (Rodrigues *et al.*, 2007) to 1.13 mg L^{-1} (Barbieri and Doi, 2012). Juvenile gold-spotted cod (*E. coioides*) also exhibited high mortalities in response to unionised ammonia, with a 24-hour LD_{50} calculated as 2.4 mg L^{-1} and a 96-hour LD_{50} of 0.2 mg L^{-1} (Leyun, 2012). Levels of un-ionised ammonia in the current study, associated with subsequent mortality events were approaching this, at 0.094 mg L^{-1}. In culture, gold-spotted cod had reduced growth and suppressed feeding behaviour in response to elevated ammonia concentrations (Zheng *et al.*, 2013). Exposure of Cobia to a nitrite concentration of 32 mg L^{-1} had no discernible behavioural or physiological effect (Atwood *et al.*, 2004), and Rodrigues *et al.* (2007) estimated the 96-hour LC_{50} to be greater than 210 mg L^{-1}. Similarly, a 96-hour LC_{50} for exposure of Cobia to nitrate was calculated as 1,829 mg L^{-1} although the study did also detect gill and oesophageal hyperplasia as well as changes to brain tissues following exposure to lower concentrations of nitrate (Rodrigues *et al.*, 2011). Similar to Cobia, gold-spotted cod had significantly higher tolerance to nitrite with a 24-hour LD_{50} of 354.8 mg L^{-1} and a 96-hour LD_{50} of 20.8 mg L^{-1} (Leyun, 2012).

Production

Giant Grouper

In the current study, approximately 400 kg of Giant Grouper were harvested, ranging in size from 0.5 to 1.5 kg. Harvested fish were sent live and chilled to markets. In some instances, harvests were scheduled to target specific sizes, while several emergency harvests were also conducted, in which all fish were harvested, regardless of size. The fish produced are within the desired size range for export products, and this market retains significant potential for cultured Giant Grouper now and in the future. Fish grown in either tanks or ponds reached a market size after nine months, based around the spring to autumn (September to May) period. Similarly, production of orange–spotted grouper (*E.coioides*) and Malabar grouper *(E. malabaricus*) in small-scale farms in the Philippines took 10-11 months from receipt of fingerlings (Pomeroy *et al.*, 2004).

Economic studies of pond- and cage-based grouper production have indicated that feed costs represent up to 60% of grouper production costs (Petersen *et al.*, 2013; Afero *et al.*, 2010). Feed conversion has, been shown to have a significant impact on the economics of finfish aquaculture, including grouper production (Afero *et al.*, 2010). Although variable, FCR's were generally less than 1.3 utilising a diet not specifically formulated for Giant Grouper. Improvements in efficiency and economic performance may be possible with new dietary formulations, but this will likely require elevated production levels to encourage the local aquafeed industry to invest in the development of new feeds for Giant Grouper.

Reliable fingerling supply is essential for the development of any aquaculture sector. Grouper production in Asia typically involves a number of producers, each focussing on a specific portion of the production cycle (Afero *et al.*, 2010; Petersen *et al.*, 2013; Pierre *et al.*, 2008). The model used by RPPF is more basic, with both nursery and grow-out phases undertaken by the company. However, the company is still dependent on a third party supply of fingerlings, currently TCO, based in Cairns. Any large-scale expansion of Giant Grouper aquaculture by RPPF will necessitate either the reliable contracted supply of fingerlings by an agency such as TCO or the development of hatchery facilities operated by RPPF.

Cobia

In the current study it was not possible to distinguish any impacts of fingerling size, in comparison to seasonal effects relating to the time of fingerling introduction, on overall growth rates or fingerling performance. However, overall performance of fingerlings in terms of growth rate and survival, was comparable to other studies (Benetti *et al.*, 2008; Kilduff, 2001; Sampaio *et al.*, 2011) and the present study demonstrated the commercial feasibility of cobia production at RPPF using a combination of tank- and pond-growth phases, applying similar principles to those used in Vietnam and Taiwan (Liao *et al.*, 2004; Nhu *et al.*, 2011), albeit at a single farm. The indoor tank system maintains good growth and therefore provides an ideal nursery and/or overwintering facility, and grow-out to harvest size may most efficiently be achieved in outdoor ponds or within cages in the lake. A number of production strategies utilising the facilities at RPPF are therefore possible to enable year round supply of harvest sized Cobia for market. Fingerling intake could be undertaken over an extended period from November to April, with fingerling supplier(s) utilising methods developed at BIRC based on photothermal manipulation (Dutney, 2016; Lee *et al.*, 2015). Alternatively, or in addition to this, maintenance of a proportion of tanks at higher temperatures may be used to advance some populations over others, providing an extended period for juveniles of a sufficient size, to be stocked into ponds or cages.

The overall SGR of 0.4 to 2.5% BW day^{-1} achieved in the present study compares favourably with an SGR of 1.30% BW day^{-1}; for tank-reared fish (Kilduff, 2001). Higher SGR of 4.6 to 4.7%BW day^{-1} were obtained for cobia reared in RAS (Webb *et al.*, 2007); however, that study was based on the growth of small fingerlings from 6.7 g to approximately 180 g, when SGR will be higher. Studies of Cobia growth in the USA (Kilduff, 2001) and Brazil (Sampaio *et al.*, 2011) both demonstrated a reduction in incremental SGR with increasing fish size, which was also the case in the present study. Incremental FCR of 1.2-1.3 for fish in the size range 0.1-2.0 kg and 0.8-0.9 for fish approaching 4 kg are similar to values recorded in Brazil in cage–reared Cobia (Sampaio *et al.*, 2011) but higher than for tank-reared Cobia in the USA (Kilduff, 2001; Webb *et al.*, 2007). Studies in Vietnam of pellet-fed, cage-reared Cobia showed FCR increasing from 1.2 to 2.0 as size increased from 0.2 to 6.8 kg (Nhu *et al.*, 2011); and FCR increased for tank-reared Cobia from 0.8 to 1.5 with a size increase from 0.1 to 1.5 kg (Kilduff, 2001). In the current study, FCR ranged from 1.0 to 2.6 but variation was often a result of other factors affecting performance, such as mortality events. Mean FCR were 1.5 and 1.6 for cage-reared and tank-reared populations respectively, with cage-reared fish raised to a >3 kg. The importance of FCR as a significant factor affecting Cobia aquaculture profitability is well recognised (de Bezerra *et al.*, 2016; Huang *et al.*, 2011; Miao *et al.*, 2009), and although FCR in the present study are comparable to other systems, improvements to FCR, through improved diets potentially offers scope to significantly reduce production costs, particularly for larger fish.

Internationally, farmed Cobia are marketed fresh, chilled or frozen as whole fish or fillets, with fresh or chilled product typically attracting a price premium (Freeman, 2010), with fish >6 kg preferred by several Asian markets (Benetti *et al.*, 2007; Freeman, 2010). The bulk of farmed Cobia in Australia are provided to the market at >4 kg (unpublished data); however, in the present study, fish from 2 to 6 kg were harvested and successfully marketed. There is limited data on the recovery of Cobia, expressed as fillet weight as a proportion of body weight. Values of 52% (Flores *et al.*, 2016) and 46% (Kilduff, 2001) have been reported for 3 kg fish, but there is no comparative data for fish of different sizes. There is a similar paucity of information on fillet yield in grouper, with one study reporting a recovery of 29% for red grouper (*E. morio*), but also noting very little variation due to fish size, which varied from 0.8 to 3.6 kg (Gall *et al.*, 1983). A significant contribution to the economics of Cobia culture in south-east Queensland may be the establishment of reliable markets for fish of varying sizes, to further enhance year-round harvesting. Data on recovery for a range of sizes of cultured Cobia could contribute to the establishment of such markets.

Health and Survival

Cultured Cobia and Giant Grouper are susceptible to a wide variety of pathogens, parasites, nutritional and environmental factors (see overviews Nagasawa and Cruz-Lacierda, 2004; Harikrishnan *et al.*, 2011; Leano *et al.*, 2008; McLean *et al.*, 2008). In general, when grown under appropriate water quality conditions, notable organisms causing significant losses in Cobia and grouper species are protozoan parasites (McLean *et al.*, 2008) and viruses (Harikrishnan *et al.*, 2011; Nagasawa and Cruz-Lacierda, 2004), respectively. Environmental conditions also significantly affect Cobia health and survival, and water temperatures, below 15 °C have caused large-scale mortalities in sea-cage reared Cobia (Nhu *et al.*, 2011).

Infection by the parasitic dinoflagellate *Amyloodinium ocellatum* has been the cause of large-scale mortality events in fish hatcheries involving a range of species worldwide including: juvenile milkfish (*Chanos chanos*) and mangrove red snapper (*Lutjanus argentimaculatus*) in the Philippines (Cruz-Lacierda *et al.*, 2004); sea bream (*Sparus aurata*) in Israel (Paperna, 1980); European sea bass (*Dicentrarchus labrax*) in Egypt (Bessat and Fadel, 2018) and yellowtail (*Seriola dumerili*) in Italy (Aiello and D'Alba, 1986). Amylodiniosis is also known to affect Cobia in the hatchery (Benetti *et al.*, 2008), nursey and grow-out phases (Liao *et al.*, 2004). High mortality of pond-reared Cobia due to *Amyloodinium* has also been an issue in Australia (Lee *et al.*, 2015). In the present study, catastrophic mortality of two tanks of Cobia juveniles, less than 100 g, occurred. The rapid onset of this disease following reduced feeding activity demonstrates the need for detailed observations of juveniles, including gill examinations, in the event of any changes to feeding or other behaviour. Importantly, mortalities were restricted to two of eight tanks, highlighting the importance of good hygiene practices, particularly for a pathogen such as *Amyloodinium* which can readily spread between tanks (Roberts-Thomson *et al.*, 2006).

Viral encephalopathy and retinopathy (VER) or viral nervous necrosis (VNN) is caused by viruses in the family Nodaviridae, in the genus Betanodavirus (OIE, 2018). Nodavirus outbreaks have been associated with high levels of mortality in over 50 marine and freshwater fish species (OIE, 2018). Mortality is typically highest in larval or juvenile stages, but high levels of mortality have also been reported in older animals (OIE, 2018). The Australian aquaculture sector has been significantly impacted by nodavirus with the barramundi hatchery industry experiencing high mortalities in the early 1990s (Anderson and Oakey, 2008). Although altered hatchery practices such as the implementation of green-water culture practices reduced the incidence of disease, outbreaks continued for the ensuing 15 years (Anderson and Oakey, 2008). Similar issues have also been experienced in barramundi hatcheries elsewhere (Parameswaran *et al.*, 2008; John *et al.*, 2014; Banerjee *et al.*, 2014).

In Australia, disinfection and biosecurity controls have enabled the hatchery production of grouper fingerlings without nodavirus infections and all fingerlings supplied by TCO are health certified free of nodavirus at dispatch. However, fingerlings will remain susceptible to infection without vaccination. Worldwide, several Grouper species including seven band grouper, *E. septemfasciatus* (Fukuda *et al.*, 1996; Kokawa *et al.*, 2008), orange-spotted grouper *E. coioides* (Maeno *et al.*, 2002), brown-marbled grouper, *E. fuscogutatus*, Hong Kong grouper (Chi *et al.*, 1997), dusky grouper, *E. marginatus* and golden grouper *E. costae* (Vendramin *et al.,* 2013) have all been shown to be highly susceptible to nodavirus, particularly in the hatchery phase. The results of the present study contrast somewhat with these observations, in that cage populations of larger fish (greater than 500 g) also experienced high levels of mortality and that the onset of mortality events was rapid. However, it is in agreement with the on-farm experience with several grouper species across multiple farms in northern Queensland. Environmental conditions can impact on susceptibility to disease, and in some European sea bass cage farms increased water temperatures have been associated with increased mortality rates (Le Breton *et al.*, 1997). In the current study, mortalities coincided with declining water temperatures and this may be a factor for Giant Grouper when grown in cooler conditions such as in outdoor facilities in southern Queensland. More data will be needed on the performance of Giant Grouper in southern Queensland before any mitigating factors can be identified. A number of studies have demonstrated the efficacy of vaccines to improve survival in cultured grouper species exposed to nodavirus (Kai and Chi, 2008; Lin *et al.*, 2007; Nishizawa *et al.*, 2012; Yamashita *et al.*, 2009), and the development of a vaccine to provide protection against local strain(s) of nodavirus is a priority for the industry. Finfish Enterprise has funded a PhD position at James Cook University to characterise local isolates of nodavirus and develop and test a vaccine for nodavirus on giant grouper. The thesis will be submitted in 2019. Cobia have been shown to be susceptible to nodavirus (Chu *et al.*, 2013; McLean *et al.*, 2008), with significant mortality levels in both larvae and harvest-sized individuals (Chu *et al.*, 2013). However, in the present study, there was no evidence of Cobia being affected by nodavirus, despite being held in close proximity to heavily infected cages of Giant Grouper for extended periods. As Cobia were not tested for the presence of nodavirus, it remains unclear whether this is a result of resistance or tolerance to the virus. As all giant grouper cohorts are tested free of nodavirus at supply to RPPF it is recommended that future cohorts of pond-grown Cobia be tested, for the presence of nodavirus to confirm a lack of carrier status.

In all aquaculture production systems, water quality, particularly as it relates to system operation, impacts directly and indirectly on fish health and survival. In the present study, production systems were being modified and improved in response to production needs (discussed above). As a result, in some instances, water quality declined to a sufficient point to impact on fish health, and some losses were incurred. Mortalities resulted either directly from poor water quality, as occurred following an air blower failure, or from a secondary infection, following a poor water quality stressor, as occurred with *Flavobacterium* infection, following elevated ammonia levels. It is important to put such losses in the context of a dynamic system which was undergoing constant development, as new equipment was purchased and system operations were streamlined. As such the mortalities resulting from these causes need not reflect on the suitability of the system as is was at the end of the experimental period, nor the suitability of Cobia and Giant Grouper for tank culture.

Conclusion

Both species exhibited commercially relevant performance within the production systems at RPPF. Cobia achieved a harvest size within the 12 months duration of the project, achieved through a combination of post-transfer tank rearing and later, cage production. Harvest weights were variable over the course of the project ranging from 2 to 6 kg. This may necessitate the development of new markets for smaller fish if this continues as hatchery supplies of larger numbers of fingerlings are expanded. Growth rates were higher in tanks than cages, but this is typically the case for smaller fish. Feed conversion ratio of 1.5 to 1.6 was within commercial expectations. Survival rates were generally high, with mortality or other poor performance events being a function of system operational problems or equipment failure.

Giant Grouper reached a plate-sized harvest weight of 0.8-1.0 kg within 9 months in the tank-based culture system. Feed conversion ratios of less than 1.31 were achieved within tank systems, and less than 1.3 for cage culture when unaffected by nodavirus. Infection by nodavirus caused large scale mortality, predominantly of Giant Grouper in cages, including large fish highlighting the need to better understand the stress events that precede VNN outbreaks and to modify farm practices to mitigate against them. This has been demonstrated as possible in a prawn farm in Cairns. However, a vaccine against nodavirus is a priority to be able to protect against infection or stress events that will occur and are beyond a farm's control. Of note is that Cobia in cages showed no evidence of susceptibility to nodavirus infection, despite being housed in close proximity to infected populations of Giant Grouper.

Water quality within the tank-based system was affected by stocking density and water treatment system performance. This was compromised to some extent by the need to develop water treatment systems during the course of the study. The system in place at the conclusion of the study consistently allowed for the maintenance of good water quality. Pond water temperature impacted on growth of both species, particularly during the cooler months; however, conditions were otherwise good for culture. Handling stock in the cages was difficult due to the use of a rigid containment system. This necessitated any sampling or examination of stock to be undertaken with dip or seine nets, which was both inefficient and stressful for the stock. The inclusion of a soft netting system could effectively alleviate these issues.

Implications

This study has identified benefits and pitfalls of two growing systems and two potential species which will enable the proponent of this study to make more informed business decisions in moving into finfish aquaculture with either or both of these species. The study has demonstrated the feasibility of Cobia in culture in south-east Queensland, which, while different to production strategies applicable to north Queensland, still provides capacity to produce Cobia to market size.

Production of Giant Grouper was achieved in tanks; however the severe impact of VNN on Giant Grouper production highlighted the need to develop an effective vaccine for this disease as soon as possible. It is highly likely that an effective vaccine will enable efficient pond-based production of this and other grouper species in south-east Queensland.

Although production was achieved, efficiency could be improved through reduced feed conversion ratios, which may be attained through improved feed formulations in association with the development of optimised feed delivery for these species.

Ultimately it is hoped the study will lead to increased production of finfish in Queensland and an increased variety of species available to consumers, in addition to the provision of more diversification options for the Queensland pond-farming sector.

Recommendations

The study has demonstrated the feasibility of Cobia as a viable species for production in south-east Queensland. Similarly, Giant Grouper demonstrated production characteristics suited to aquaculture in south-east Queensland, provided viable solutions to nodavirus infection can be developed and deployed.

It is recommended that Rocky Point Prawn Farm use the results of the study to improve elements of existing production systems in order to improve the performance and profitability of both species. Enhancement of land-based production facilities to better control water quality and maintain water parameters within optimum ranges will improve production efficiency. Pond culture can be improved through improved cage systems that enable more efficient access to stock and easier maintenance of the system. Operational practices based around best practices for health management will need to be adhered to in order to minimise the impact of parasites and pathogens.

Further development

The need for a functional vaccine against VNN has been highlighted, and will need to occur to reduce the risks with pond culture of Giant Grouper. The development of a nodavirus vaccine for grouper and other finfish species is now being progressed through FRDC Project "2018-098 Vaccination for emergency and long-term control of nodavirus in Australian marine aquaculture".

The identification of FCR of >1.8 in some populations has demonstrated the need for improvements to feeds or feeding approaches for these species. This will also be important to minimise the impacts of effluent arising from the production of Cobia or Giant Grouper.

The study demonstrated a viable approach production, more suited to the more temperate climate of south-east Queensland for the two species under consideration. The use of an extended post-transfer nursery period in heated water over Winter, utilising a RAS provides sufficiently large fish in Spring to enable good Summer growth, as well as providing plate-sized fish for cash flow and market continuity.

The study was based on the premise of reliable fingerling availability for RPPF. The ongoing need for the cost-effective and reliable supply of commercial quantities of high quality fingerlings, over a sufficiently broad window to enable a variety of production strategies to be implemented, will be essential for the ongoing viability of this sector. While grouper fingerlings are currently relatively expensive, a commercial hatchery exists that meets these requirements. However, there remains no commercial hatchery for cobia and continued culture of cobia will necessitate RPPF and/or another commercial operator investing in a hatchery operation.

Extension and Adoption

The project was led by the end user and research activities were undertaken in close collaboration with the research provider.

Project coverage

16/07/2019 Queensland gropers sent to south-east to help prawn farmers battling white spot disease - ABC News (Australian Broadcasting Corporation)…

ABC NEWS

Queensland gropers sent to south-east to help prawn farmers battling white spot disease

By Casey Briggs and Renee Cluff

Updated Wed 12 Apr 2017, 8:33am

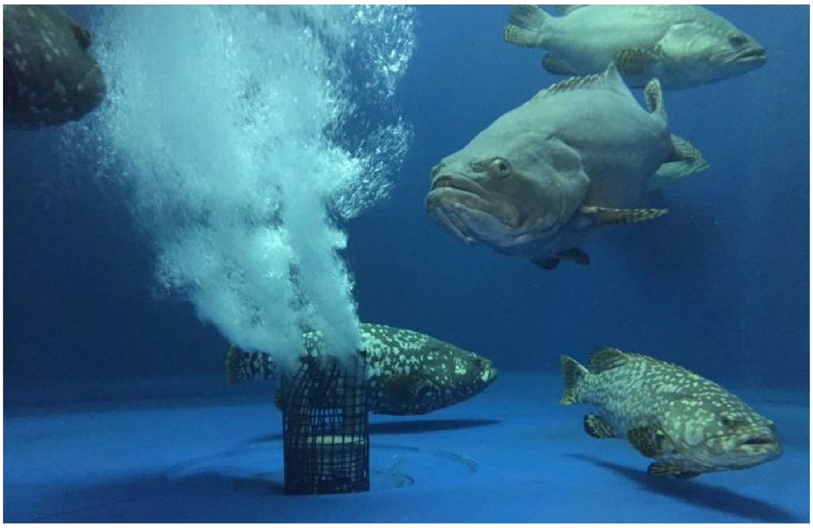

PHOTO: Prawn farms on the Logan River are about to receive 2,500 Queensland groper fingerlings. (ABC News: Casey Briggs)

An aquaculture hatchery in far north Queensland has sent 2,500 free fish to farms affected by the outbreak of white spot disease, in what has been described as a "small ray of sunshine" for prawn farmers.

RELATED STORY: Fisherman for top restaurants calls for public to pay more for sustainably farmed fish

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The Queensland groper fingerlings will arrive today to be farmed on the Logan River, with more to come in the weeks and months ahead.

Queensland groper, also known as giant groper, are a protected species and can only be sold when produced in hatcheries and farms.

The fish have been available for sale in Australia for less than two years.

The fingerlings are a few months old and weigh about 150 grams.

Gropers weigh 15 kilograms when three years old, and can weigh up to 300kg when fully grown.

For the farmers it is a chance to diversify, as many face financial devastation while the prawn industry is in limbo due to last year's outbreak of white spot disease.

Prawn farms on the Logan River in south-east Queensland have been further affected by flooding in recent weeks.

The manager of the Cairns hatchery supplying the fish, Richard Knuckey, said the company was not trying to displace prawn farming, but wanted to grow the market for groper.

"[When the industry recovers] we're hopeful we would've demonstrated the value of doing groper there, and that those farms would come back into doing prawns but would also maintain a level of groper production," Dr Knuckey said.

"The farmers that we've engaged with have been very positive and excited about the opportunity of trying something different."

Dr Knuckey said it was the first time they have sent the fish as far south as Logan.

"They do occur naturally as far south as New South Wales but the warmer waters are where they tend to grow faster ... they'll probably grow a little more slowly down there," he said.

Plans to break into Asian market

Hong Kong-based company The Company One bought the hatchery in Cairns in February after it went into voluntary administration, and its owners want to establish an export market into China and Hong Kong.

"We've been marketing the fish into the high end restaurants into Sydney and Melbourne ... it's a high end, high quality market," Dr Knuckey said.

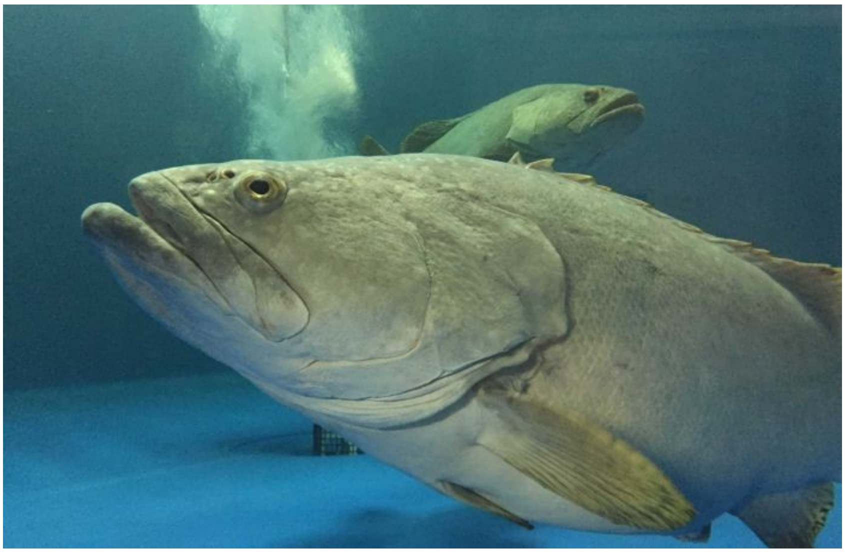

PHOTO: A fully grown groper can be as heavy as 300kg. (ABC News: Casey Briggs)

"The main thing that separates them from the other species is their skin ... when it's cooked you can do a lot with the skin, crisping it up really nicely and then it's got a lovely moist layer underneath."

Farmers 'very appreciative'

Queensland Agriculture Minister Bill Byrne said he had been doing what he could behind the scenes to enable the partnership.

"This is an innovative way of using an existing hatchery in a different fashion and it gives a lifeline to one operator to return a cash flow," Mr Byrne said.

"Speaking to the hatchery owners down on the Logan, they're very appreciative and they're very happy ... it's a small ray of sunshine in somewhat difficult circumstances."

The Company One said while the first deliveries of Queensland groper have been free, they were in talks to start selling or leasing the fish if the trial is a success.

Topics: fishing-aquaculture, regional, government-and-politics, rural, cairns-4870, logan-central-4114, alberton-4207, qld, australia

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https://www.abc.net.au/news/2017-04-12/queensland-groper-sent-logan-river-white-spot-disease-prawns/84353602/2

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Appendices

Appendix 1: List of researchers and project staff

Department of Agriculture and Fisheries (Bribie Island Research Centre)	
Trevor Borchert	Fisheries Technician
Dr Jose Domingos	Co-Investigator (to Feb 2018)
Tom Gallagher	Casual Hatchery Technician
Dr Peter Lee	Co-Investigator (from February 2018)
David Nixon	Fisheries Technician (to June 2018)
Rocky Point Prawn Farm	
Brad Cherrie	Principal Investigator
Tony Dickson	Hatchery Technician
Murray Zipf	Owner
Serena Zipf	Owner
The Company One	
Richard Knuckey	Co-Investigator

Appendix 2: Tank water quality and production

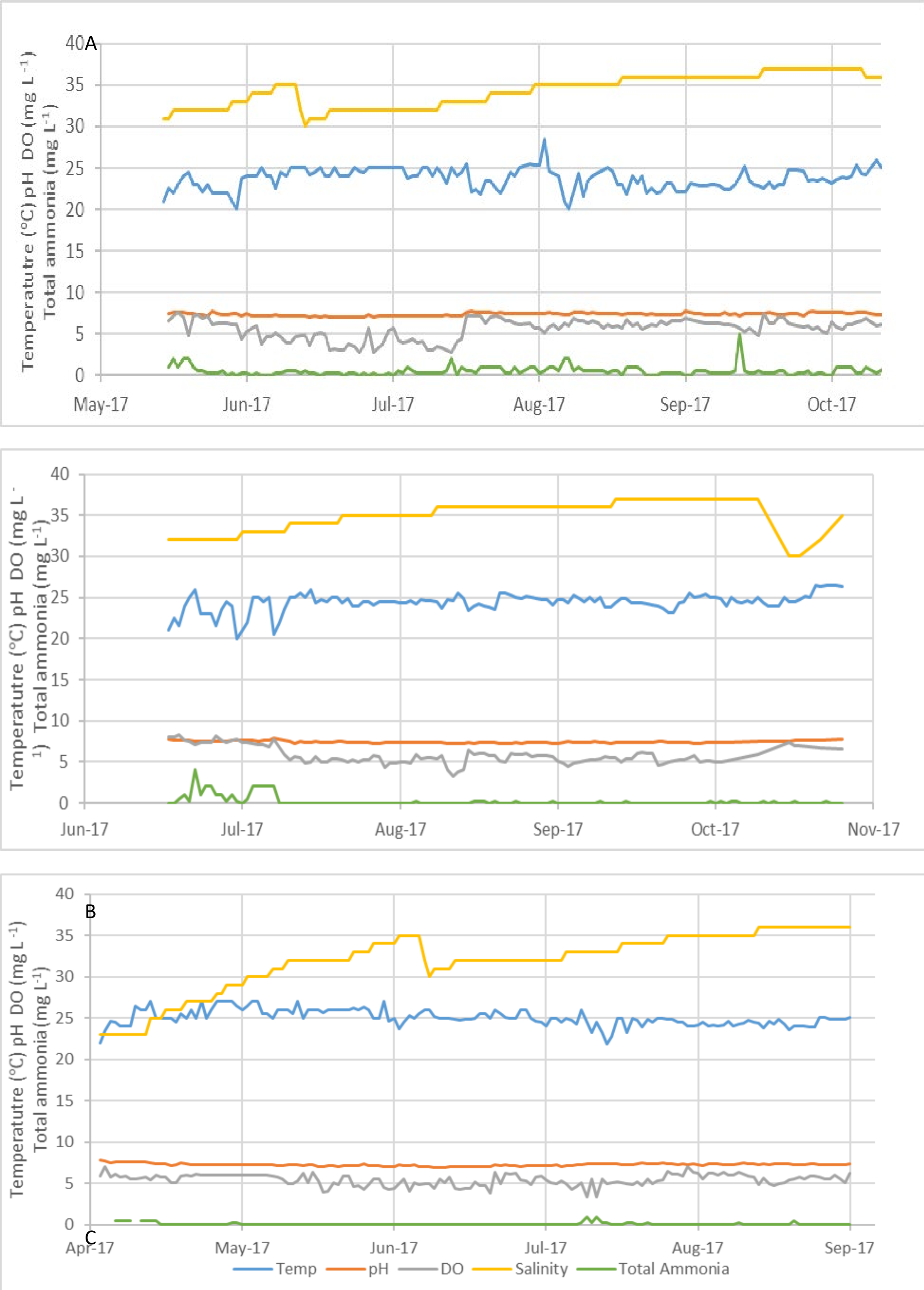

Figure A3.1 Representative tank water quality parameters for A. Cobia, Batch 2 Tanks BT11/LR25 Giant Grouper, B. Batch 1 Tank BT7, C. Giant Grouper, Batch 3 Tanks LR2/BT8.

Appendix 3: Study Tour of Hong Kong and Taiwan, Cobia and Grouper Facilities.

A tour of Hong Kong and Taiwan was undertaken in late September 2017 to review grow out design and procedures and determine market parameters such as fish quality, price and any counter seasonality advantage for both species. Four representatives from Rocky Point Aquaculture spent time in Taiwan looking at Giant Grouper pond production, cage production and tank production. Due to damage from a typhoon no production of Cobia could be reviewed. In Hong Kong a review of an indoor Grouper facility was undertaken as well as various markets and restaurants for grouper. Figure 1a and 1b show the areas visited in both countries.

Grouper and Cobia production in Taiwan

Grouper farms and nursery farms were visited near the small city of Tainan. No Cobia was farmed in this area and we were told that Cobia was not produced in ponds in Taiwan. There was Cobia cage production on a small island, Little Okinawa, but most cages were damaged in a recent typhoon.

Most of the farms visited in the Tainan area were polyculture farms. The area was predominantly prawn farms but had been forced to change species due to WSSV and EMS. Farms went to growing two species in the same ponds Clams, Giant Grouper, hybrids of Grouper, Black Tiger prawns, Vannamei prawns, Pompano and Milkfish were all grown in this area.

All farms in the area had their salt water supplied by a government supply canal. All farms used the tidal flow for their water exchange. Ponds were of all sizes and shapes and each farm varied from 1 or 2 ponds up to 40 ponds (Figure 2).

The water temperature varied from 18 degrees in Winter to 32 degrees in Summer although cold fronts in Winter have resulted in fish kills in various years. One farm reported 6 degrees for 8 days which caused severe mortality.

Taiwan **Hong Kong**

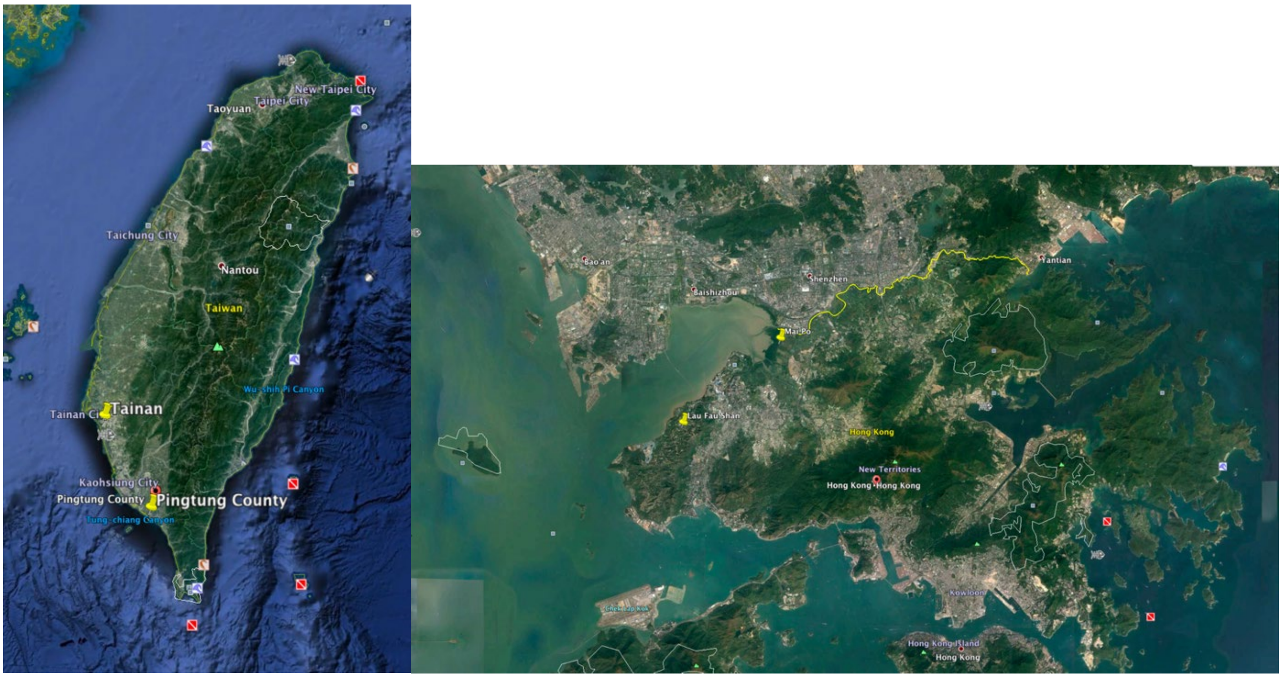

Figure 1: Areas visited in Taiwan and Hong Kong (The yellow pins indicate the areas visited).

The Giant Grouper farm visited consisted of 6 ponds each about 100m long and 30m wide. A single weir structure allowed water to flow in or out depending on the tide. The ponds were shallow for 4m around the edge (less than 1m deep) reaching 2m in the middle of the pond (Figure 2). Three single paddlewheels were located in each pond. Clams were stocked into the shallow part of the pond as well as the Grouper. The stocking rate on this farm was between 6000 and 10000 fish per pond and they harvest the fish starting at 600g to 4kg. On some farms fish are on grown for three years and reach 10kg in size. In Taiwan there is several steps in the farming process. Brood stock farms will produce eggs, hatcheries will produce fry, nurseries will produce fingerlings and farms will grow fish out. Sometimes farms will on sell different size fish up to 4 times.

Figure 2: Ponds in the Tainan area of Taiwan. Note paddlewheels for aeration in ponds.

Depending on the size of the fish the farms stock, fingerlings up to 50 grams need to be graded once per week using a fish grading basket. They are usually kept in cages (Figure 3). At 100 grams fish are sorted into 2 grades. At this stage most farms will free range into there ponds.

Figure 3: floating cages where fish are grown to 50 to 100 grams

To grow the fish a secchi disk depth of 70/80cm is maintained. Feeding is carried out once a day, usually early morning, using feed trays or feed baskets on which all the feed for the pond is placed (Figure 4).

Figure 4: Feed trays and baskets used in grow out ponds.

Twelve trays per pond are used with up to 4kg of feed on each tray. Each tray is checked after one hour. Feed is produced by several different Taiwanese feed companies specific for Grouper and it was noted since farms changed from using trash fish production increased. Some automatic blower feeders were noted to be used on other farms but were used on milkfish and Pompano (Figure 5).

Figure 5: Automatic blower feeder.

Harvesting of the Giant Grouper was undertaken by using a drag net with a heavy lead line (Figure 6). Fish were condensed and selected for harvest.

Figure 6: Drag net used for harvesting.

Depending on what the market requires, unacceptable fish are returned to the pond. Sometimes larger fish are caught using a fishing rod. All fish going to market are kept live and purged. In Winter fish are purged for three days while in Summer fish are purged for at least one day, sometimes two as their metabolism is slower in Winter.

An important part of the Giant Grouper production cycle in Taiwan is the nursery phase. This is usually carried out by specific operators. Upon arrival at one farm a "stockbroker" arrived with a sample of fish for the nursery farm to try. The farm consisted of three ponds which contained cage systems.

The first stage system was where the just weaned fry (10mm in length) were put into small floating cages and fed 4 times per day. Grading occurred 3 times per week using different sized grading baskets. The cages were shaded to prevent excessive algae growth (Figure 7).

Figure 7: Shaded cages where new fry are held.

The second stage of the nursery farm was in ponds which were 9m deep and consisted of cages within floating drum rafts (Figure 8). The cages were about 1m x 1m x 80cm. Grading occurred once per week and fish were on sold at 30 grams to 50 grams. All cages are cleaned at least once per week with a high pressure cleaner to prevent fouling.

Figure 8: Floating raft cages showing the cages within the raft.

Escapees occurred in all ponds and as the farmer had no way of draining ponds the escapees have survived for a number of years. Fish as large as 20kg were seen feeding on pellets the size of golf balls (Figure 9).

Figure 9: Feed size for the 20kg Grouper

These fish are occasionally harvested for restaurants for special orders. It was noted that during a cold spell last year all farms except this one lost their fish due to extreme cold temperatures (down to 6 degrees for 8 days in ponds). The farmer believes his fish survived due to the deep ponds. According to the farmer the Giant Grouper will feed at 18 degrees and stop feeding at 16 degrees but will still survive. The farmer quoted that the addition of extra vitamin C before Winter is a way of conditioning the fish for winter.

A visit was then undertaken to review the aquaculture area of Ping Tung County in the southern part of Taiwan. This area consisted of straight walled concrete ponds of all different sizes, shapes and depths with different farms often sharing pond walls (Figure 10). The water supply was direct from the ocean via pumps and pipes leading to each farm.

Figure 10: Concrete walled ponds in Ping Tung County

Figure 11: Crazy network of water supply pipes in Ping Tung County

A small Cobia hatchery was reviewed with brood stock being held in concrete tanks 10m x 5mx 2m deep (Figure 12). Fingerlings were produced from this facility (Figure 13) and due to the destruction of sea cages on Little Okinawa due to a typhoon were being sent to Vietnam. It was noted that copper sulphate was used in the brood stock tanks.

Figure 12: Cobia brood stock in pond.

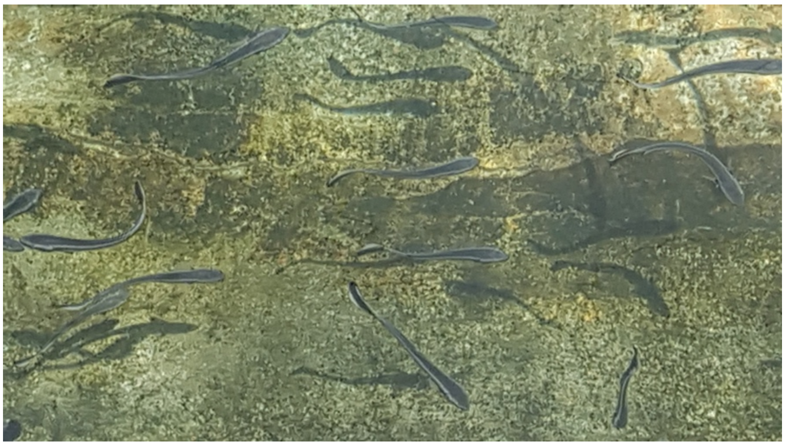

Figure 13: Cobia fingerlings.

A Grouper nursery recirculating aquaculture system (RAS) was then reviewed. This facility was by far the most advanced and bio-secure facility reviewed. The facility was split into three sections and each section consisted of 64000L of water with 32000L of growing tanks (Figure 14). This facility was designed to receive batches of 30000 fingerlings which would be taken up to 100 grams before stocking out into ponds. Fish were also being trialled with a vaccine against Nodavirus which involves injecting each fish with the vaccine.

Figure 14: Grouper nursery recirculating system.

The RAS system was set up as follows:

Culture Tank > Sedimentation Tank > Drum Filter > Sump > Pump > Foam Fractionation with Ozone > Trickling Filter incorporated into Bio-filter > pumps return water to Culture tanks via UV sterilizers.

The culture tanks (Figure 14) had both inlets at the bottom of the tank and at the water level of the tank. Bottom outlets were not necessary as the grouper do not produce solid faeces for long. Each culture tank had four air diffusers and one oxygen diffuser plate.

Figure 14: Culture tank with air diffusers

The bio-filter incorporated a trickling filter (Figure 15) which served two purposes. Firstly, it allowed degassing of ozone produced in the foam fractionator and secondly, it may produce a different type of nitrifying bacteria according to the manager of the facility. According to the manager, a working bio-filter should result in a 30% to 70% reduction of Total Ammonia before and after the bio-filter. The bio-filter should be set up so that any waste that it produces can be flushed from the system.

Figure 15: Bio-filter with trickling filter incorporated.

Water turnover was 100% and oxygen was added to tanks via oxygen diffuser plates direct into culture tanks (Figure 16).

Figure 16: Oxygen diffuser plate.

Oxygen should be kept at 6.5ppm before feeding and should only reduce to 5ppm after feeding. Aeration was also used in the culture tanks and in the bio-filter. Ozone was monitored by ORP and was measured in the sump with a level of 250mV maintained. The level was not to exceed 350 mV as fish mortality will occur. The design of the system should be such that if the system stops it should restart without any of the water levels changing.

Regular grading up to three times per week was conducted using grading baskets (Figure 17). Fish were moved out into ponds or sent to other recirculating systems at 100 grams. More success has been had stocking fish into ponds at 100 grams rather than 10 grams. It was noted that leaving the Ping Tung County Aquaculture area that most farms in the area were again using multiple species in polyculture.

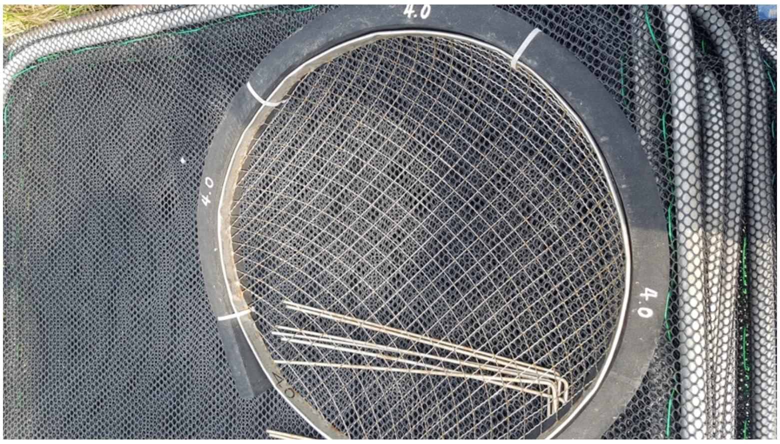

Figure 17: Grading baskets.

Grouper Production in Hong Kong

Giant Grouper production in Hong Kong consisted mainly of indoor recirculating systems and a very small amount of pond culture. Two facilities were reviewed. Both facilities were owned by Aquaculture Technologies Asia (ATA). An older site at Mei Po and a newer facility at Lau Fan Shen.

The site at Mei Po is an older facility which relies solely on recirculation of its water. All the saltwater is made from fresh water and chemical salt. It consists of tanks for saltwater preparation, small tanks to rear fingerlings up to 50 grams and large grow out tanks about 130 000 L with each grow out tank on its own recirculating system.

Each system consisted of a drum filter, foam fractionator with ozone injected into it and a bio-filter. The water turnover was around 100% per hour and staff there stated that ozone was not always used. Aeration was added to each tank but oxygen was used only as back up. The bio-filter was a two stage process with a trickling filter incorporated with a moving bed filter. The media was quite large and staff stated that this was so the media could be cleaned easily when needed.

We arrived at the Mei Po site around midnight to coincide with the arrival of some fingerlings from Australia. A shipment of 100 polystyrene boxes containing 120 fish each were being unloaded when we arrived. Fish were placed into mesh cages in a tank for acclimatization and quarantine (Figure 18).

Figure 18: Acclimatization tanks with newly arrived Giant Grouper fingerlings.

The water quality was checked every 5 bags to make sure oxygen and pH were within their parameters. Limited mortalities occurred and fish looked to settle in well.

The site at Lau Fan Shen was visited the next day. Again this system was fully recirculated with all salt water made from fresh water and chemical salt. The system design was similar to the Mei Po site and consisted of 130,000 L grow out tanks each on there own recirculating system (Figure 19). Waste water was taken from both the top of the tank and the bottom of the tank and went into a drum filter., foam fractionator with ozone injected into it, moving bed bio-filter incorporated with a trickling filter and finally some UV sterilization before being returned to the grow out tank.

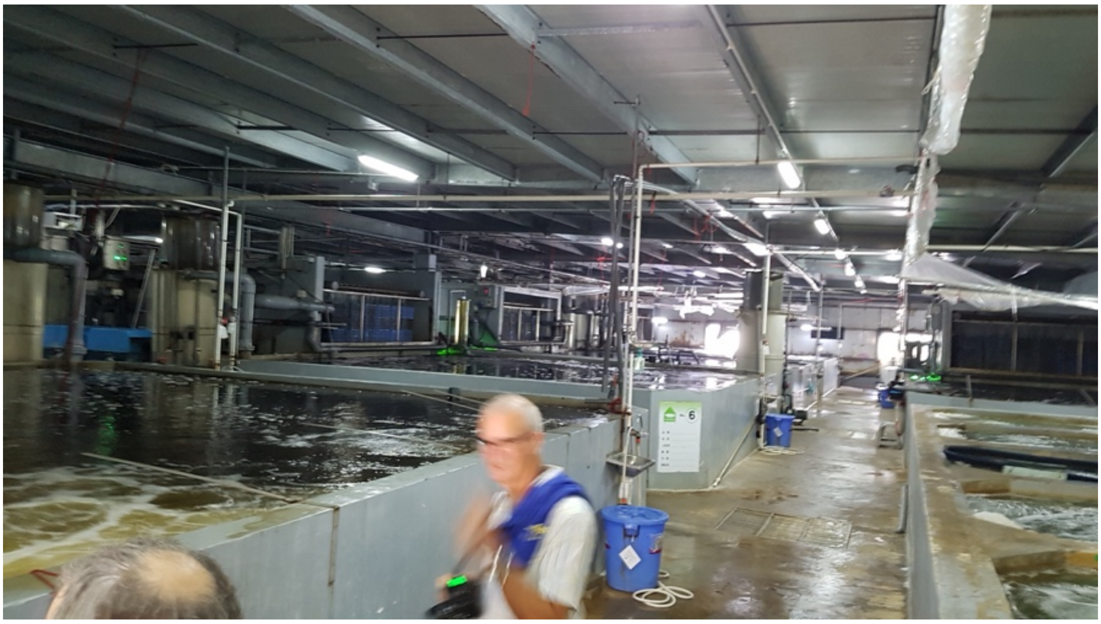

Figure 19: The Lau Fan Shen indoor recirculating system.

This site consisted of approximately 16 of these grow out tanks and a purging tank system (Figure 20) to allow for holding and grading of fish before being sold to market. Each grow out tank was stocked with 4000-5000 fingerlings with fish being grown to 1.8kg with the majority of fish were sold locally in Hong Kong.

Figure 20: Purging tanks where fish are held before sale.

Market Parameters of the Giant Grouper in Taiwan and Hong Kong.

No Cobia was seen in any market in Hong Kong or Taiwan most likely due to production issues.

Taiwan

There was a market for every sized grouper in Taiwan whether for on growing of fish or for eatable product. One farmer reported that it was not uncommon for a fish to be sold up to four times through the course of its grow out from farm to farm.

The eatable market for Giant Grouper in Taiwan ranged from fish of 600 grams through to banquet fish 2-3kg in size (Figure 21) through to fish up to 20kg. The plate sized fish were in direct competition with hybrid grouper species which were believed to grow faster but not have the same flavour and texture as the giant grouper. It also fetched a higher price than other cod species such as the gold spot.

Figure 21: Steamed Giant Grouper.

A hybrid grouper was tested for taste and found to be of a muddy taste and softer texture than the giant grouper of the same size.

Prices in Taiwan ranged from $190-$300 Taiwan dollars per 600grams (1 caty) which equates to $13-$21 AUD per kg. Due to the competition of the hybrid species the best market in Taiwan was for large fish (10kg or more) which fetched a similar price per kg but took 2/3 years in growing time. A large proportion of the plate and banquet size giant grouper was exported from Taiwan to Hong Kong and China.

Hong Kong

The market in Hong Kong was mainly for the plate size and banquet sized fish although larger fish cut into pieces was seen in some Hong Kong supermarkets (Figure 22). Prices for live fish ranged from $21-$54 per kilo in various retail outlets. The size range was mainly 600 grams to 1.8 kg. Some larger fish were seen in restaurants but were mainly for display.

Figure 22: Fresh Giant Grouper pieces for sale in Hong Kong supermarket.

Upon viewing the sale of a live fish in a Hong Kong supermarket it was caught and then killed and gutted within view of the customer. The giant grouper was in competition with many other species but the majority of the time commanded a higher price. It was noted that the fish must be in good and healthy condition to survive staying alive in supermarket or restaurant tanks (Figure 23).

Figure 23: Live Giant Grouper for sale in Hong Kong supermarkets.

Recommendations

The Hong Kong and Taiwanese Giant Grouper farming industry is continuing to grow as people become more accustomed to this fish as a food source. Although a smaller market in Australia, a ready made market is available to take good quality plate sized fish while assessing whether it is viable to on-grow fish to a larger size. The market however will require regular supply. There is potential to export excess fish overseas but further investigation will be required to assess this potential.

Production indoors and outdoors can be utilized to grow the fish. Due to the seasonal constraints in South East Queensland overwintering fish in a recirculating system as well as production of market sized fish will need to be achieved. Production cages outdoors will be used to grow the fish out over the summer months while the indoor system is being constructed.

The giant grouper can be a viable species to grow in South East Queensland if we utilize indoor and outdoor facilities correctly. The Cobia viability and market parameters may require further investigation due to the lack of production in the areas visited.