



Negative effects of fish cages on coral reefs through nutrient enrichment and eutrophication in Nha Trang Bay, Viet Nam

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ABSTRACT

The potential impact of cage farming activities on nutrient enrichment of the coastal waters of Nha Trang bay, Viet Nam as investigated within a project financed by the Vietnam Academy of Science and Technology (VAST). Results show a very high level of nitrogen (N) in the studied area: the average content of dissolved inorganic nitrogen (DIN) was $177.4 \pm 6.0 \mu\text{g/l}$ (range from 169.9 to $188.9 \mu\text{g/l}$), in which $\text{NO}_3\text{-N}$ accounts for the major proportion (average $152.9 \pm 1.9 \mu\text{g/l}$). The Redfield ratio (N/P) also showed values larger than 16 in almost all studied sites, indicating that phosphorus may be the limiting nutritional factor in these coastal waters. The TRIX indexes recorded for both the surface and bottom waters are within a range of about 5–6 (at high nutrient level); especially at sites under the cages and near the cage farming area. Cross-transplantation experiments with corals showed significant differences at different sites, particularly in relation to distance to fish cages. In comparison, the zooxanthellae densities of *Acopora formosa* in coral polyps indicated a rapidly reduced value after 31 days of exposure in the polluted areas. Strong side effects such as increased sedimentation as a result of fish farm activities can be detected on nearby coral reef. It is concluded that fish cage farming is negatively impacting coral reefs by being a point source of surplus nutrients.

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1. Introduction

During the last 30 years, marine fish cage culture has rapidly expanded in the world and environmental impacts of cage aquaculture activities are still poorly known in developing countries (Nils et al., 2015). At present, sea-cage aquaculture plays an increasingly important role in fish production, also involving many small-scale farmers in Vietnam. However, marine cage farms cause deterioration of marine environments by a high amount of faeces and un-eaten feed (Du et al., 2006; Hung and Tuan, 2009). Long-term organic waste input from cage farms can modify the physicochemical characteristics of the bottom sediment. Therefore, the amount of unconsumed feed accumulating in the sediment results in increasing negative environmental impacts. Decay of organic matter in the sediment decreases the amount of dissolved oxygen, releases toxic compounds, especially nitrogenous compounds, as well as enhances the growth of algae.

Previous studies have indicated that marine cage culture introduces massive amounts of un-consumed food and faecal materials into the environment (Hargrave et al., 1993; De Silva, 2012).

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The impacts of cage culture are fairly well understood in coastal temperate regions (Holmer et al., 2005), but little literature is available from tropical regions. Environmental pollution is frequently reported from coastal areas with aquaculture farming operations, with fairly high contents of nutrients and organic matter from un-consumed feed and excretion of raised animals directly discharged into the environment (Sowles et al., 1994; Casabianca et al., 1997); Nordvang and Johnson, 2002; (Du et al., 2006). Increased nutrients contents through aquaculture farming activities are highly likely a trigger of negative effects such as eutrophication and algal blooms, adversely affecting coastal waters and reducing the water quality, hence affecting the rates of survival and growth of aquatic life (Beveridge, 1984). However, little is known about the exact distribution of nutrients and whether fish cages have potential negative impacts on the already threatened coral reefs (Nils et al., 2015). Several studies have considered direct effects of elevated dissolved inorganic nitrogen (DIN) and phosphate (DIP) on coral calcification, tissue growth and zooxanthellae (Marubini, 1996; Nordemar et al., 2003). They found that high levels of DIN and DIP both reduce calcification up to 50%. Most of the studies indicated that increased DIN increases both zooxanthellae density and the contents of nitrogen and chlorophyll a per zooxanthellae. Results also showed that short-term exposure to high levels of DIN and DIP does not kill or greatly harm individual coral colonies, however chronically

increased levels of inorganic dissolved nutrients may alter reef metabolism and reef calcification to cause noticeable changes in coral communities (Fabricius, 2005).

Nowadays, cage farming has been developed too fast in coastal waters of Vietnam, without clear-cut planning and without compliance with regulations. As a result the environment of farming areas has been adversely affected, particularly natural aquatic ecosystems such as corals, sea-grass meadows and mangroves (Tuan et al., 2005). Most marine cage farms are directly connected to coral reef areas, evenly distributed along the coastal lines. The lack of information and professionalism among provincial coastal managers, about Vietnam's coastal and marine resources has already led to serious environmental problems. Therefore, the main challenge is to provide supporting information about direct and indirect effects of cage farming, in order to enable local managers to limit the uncontrolled expansion of cage farming businesses.

In Nha Trang bay, coastal cage farming activities are expanding in scale with different farming methods, unfortunately mostly unplanned and without being part of coastal management. Therefore, the study will focus on the environmental water quality and sediment bottom as well as the nutrient enrichments in nearby waters of primarily lobster farming and other influences on the ecological condition of reef waters.

2. Materials and methods

2.1. Study area and aquaculture activities in Khanh Hoa province

Khanh Hoa is a coastal province in Southern Central Vietnam with a total land area of more than 5200 km² and a coastal line of 520 km, with a high potential for developing marine aquaculture. Aquaculture production in the province reached more than 17,117 tons by 2014. In recent years, the cage culture of spiny lobster (*Panulirus* spp.) has developed very rapidly. There were more than 40,000 cages which mainly farmed lobster and also produced marine fish in Khanh Hoa Province and nearby provinces in central and southern Viet Nam (Hung and Tuan, 2009). Nha Trang bay is located in Khanh Hoa province with an area of about 507 km², including 19 islands (Hon Tre with 3250ha is the biggest island). The weather of Nha Trang bay is characterized by two distinct seasons: the dry season lasting from January until August and the rainy season from September to December. Nha Trang bay (NTB) is under the seasonal influence of the South West (SW) and North East (NE) monsoons. They have effects on the oceanography, particularly water temperatures, and circulation patterns. The Nha Trang bay is characterized by diurnal tidal regime with a tidal range from about 40 cm during neap tide to more than 2 m during spring tides. Ocean currents of low/moderate velocity (< 1 knot) flow between the islands driven by coastal winds, tides and regional oceanography (Appendix A). Sea surface temperatures usually peak at ca. 30 °C (SW), falling to 24 °C during NE monsoon (Vo et al., 2002).

At present cage aquaculture areas comprise a total area of about 263 ha, mainly around the islands of: Tri Nguyen, Hon Mot, Bich Dam, Dam Bay and Hon Mieu. The study site is located southwest of Tre Island, thus it avoids strong wind and wave actions (Appendix A). The depth at the cage-farming area is about 10 to 20 m. The farms use cages of 16–20 m² (surface area) and consist of frames, nets, floating buoys and anchor systems. The cages are often assembled into “rafts” of four or more cages. The main cage-farming species is lobster as well as many other species such as grouper, red snapper and rabbit-fish. Lobster and fishes are fed trash fish, crabs, molluscs twice a day in the morning and in the afternoon. As of 2014, there are about 9,347 cages concentrating mainly at Vung Ngan, Bich Dam, Dam Bay and Hon Mot.

In Nha Trang bay, coastal cage farming activities are expanding in scale and diverse farming methods, unfortunately mostly unplanned and without being part of coastal management. As a result, the coastal zones are under strong pressure and threaten the environment with an increased ecological risk to aquatic organisms. The main cage aquaculture types are Lobsters (*Panulirus ornatus*, *P. hormarus*, *P. timpsoni*, and *P. longipes*), Groupers (*Epinephelus bleekeri*, *E. akaara*, *sexfasciatus*, *E. malabaricus*, *E. coioides*, *E. merra* and *Cephalopholis miniata*), and ornamental fishes (Tuan and Mao, 2004).

2.2. Sampling strategies

This study was conducted at different marine cage culture facilities in Nha Trang bay. Water and sediment samples were collected at 7 sites with different distances off shore from the cage areas: sites within the farming area (NT1, NT2, NT3), intermediate sites 1.2 km from the cages (NT4 and NT6), and sites about 3 km from the cages (NT5 and NT7) (Fig. 1).

The results are from surveys in the dry seasons of two years. Water samples and suspended matter were collected at several stations with different distances from the cage farms: nearby and within the cages – about 3 sites, intermediate distance (1.2 km) from the cages – 2 sites, and about 3 km from the cages – 2 sites.

Water samples were collected from the surface and the bottom layer using a 5L-Niskin sampling bottle (USA). The following water quality parameters were analyzed: dissolved oxygen (DO), pH, salinity, temperature with ALEC multiprobes (JPE Advantech – Japan) and dissolved inorganic nutrients (DIN), chlorophyll-*a*, and total suspended matter (TSM). Sediment traps were deployed under the cage, at intermediate (1.2 km) and far distance (3 km) from the cage with sampling periods of 48 h. These sediment traps (with three replicates) were cylinders with a 1:5 proportion (cylindrical diameter: 90 cm; length: 450 cm) (Gardner, 1980; U.S. GOFS Planning, 1989).

Experimental design: A set of *Acropora formosa* corals was simultaneously cross-transplanted between the west (Hon Mot - 1) and the east side of Hon Mot island (Hon Mot -2) according to the common-garden method of reciprocal transplantation. Polyps ($n = 12$) of corals were transplanted from the east side to the west and finger – long (5 cm) polyps of the *Acropora* coral were cut off from the healthiest – looking corals branches at ca 3 m depth and brought up to the boat in plastic Falcon[®] tubes (1polyp/tube). All 12 tubes were put in the shade during transplant so that sunlight would not stress the coral-polyps. Therefore, the coral polyps were transported in the falcon tubes, hidden in a cooler-box that was filled up with water from the ocean. When brought to the final destination, the corals were bought down in falcon tubes, and attached to the concrete rods that were pre-attached to the plastic boxes (Appendix A). After 31 days of experimental time, the coral specimens were brought up and counted for live and dead corals (bleaching), measured for their zooxanthellae were counted. The reference site was set up in a coral reef of Hon Mun island –3 (MPA – Marine Protected Areas) for comparison.

2.3. Analysis methods

For analysis of total suspended matter (TSM) the samples were filtered through Whatman GF/F filters (pore size: 0.7 μm; diameter: 47 mm). The paper was then dried and its weight defined (lost and retained weights) with high precision analytical scales ($d = 0.0001$ g).

Dissolved inorganic nutrients were analyzed for dissolved inorganic nitrogen-DIN (NH₄-N, NO₂-N, NO₃-N) and phosphate (PO₄-P) by UV-visible spectrophotometer (Parson et al., 1984).

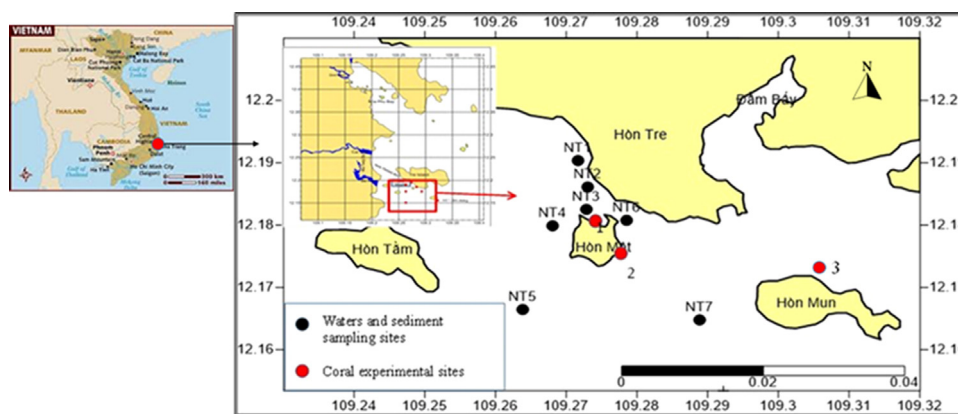


Fig. 1. Map of Vietnam with detailed map showing sampling stations in Nha Trang bay, Viet Nam.

Table 1
Water quality parameters (average ± SD) at different sites.

| Sampling areas | Survey in 2015 | | | Survey in 2016 | | |
|------------------------|--------------------------|---------------------------|-----------------------------|--------------------------|---------------------------|-----------------------------|
| | DO (mg L ⁻¹) | TSM (mg L ⁻¹) | Chl-a (mg m ⁻³) | DO (mg L ⁻¹) | TSM (mg L ⁻¹) | Chl-a (mg m ⁻³) |
| Near the cages (n = 6) | 6.71 ± 0.11 | 1.92 ± 1.02 | 0.82 ± 0.28 | 6.32 ± 0.10 | 2.09 ± 1.38 | 0.85 ± 0.34 |
| Mid-distance (n = 4) | 6.81 ± 0.04 | 1.52 ± 0.83 | 0.73 ± 0.25 | 6.40 ± 0.15 | 2.19 ± 0.43 | 0.73 ± 0.24 |
| Far-distance (n = 4) | 6.80 ± 0.05 | 1.42 ± 0.10 | 0.63 ± 0.17 | 6.24 ± 0.21 | 1.69 ± 0.63 | 0.86 ± 0.22 |

Total nitrogen (TN) and total organic carbon (Corg) from particulate matters samples were measured with an elemental analyzer CHNO-S (EA 1120) described by Grasshoff (1999). Chlorophyll-a concentration was analyzed by spectrophotometric method after seawater filtration through the Whatman GF/F and extraction in 90% acetone (Parson et al., 1984). Nutrient levels were assessed with the help of the TRIX index (Vollenweider et al., 1998; Giovanardi and Vollenweider, 2004), with the following equation:

$$TRIX = (\log_{10} [Chl - a \times \%O_2 \times DIN \times TP] + k) / m$$

Where: Chl-a is chlorophyll-a concentration (mg m⁻³)
 %O₂ is oxygen as absolute % deviation from saturation
 DIN – Dissolved inorganic nitrogen (NH₄-N + NO₂-N + NO₃-N) (mg L⁻¹)
 TP – Total Phosphorus (PO₄-P) (mg L⁻¹).

The parameters *k* = 1.5 and *m* = 1.2 are scale coefficient, introduced to fix the lower limit value of the Index and the extension of the related Trophic Scale, from 0 to 10 TRIX units.

3. Results and discussion

3.1. Influence of cage farm activities on eutrophication level of the coastal waters

The salinity and temperature in the studied area was comparatively consistent among sites. Salinity varied between 33.6 and 33.7 PSU at the surface layer, and from 33.7 to 33.9 PSU at the bottom layer. The temperatures were between 26.4 and 27.1 °C at the surface, and 24.4 to 25.5 °C at the bottom layers. The average of DO, TSM and chlorophyll-a are showed that the contents are no significantly different between near the cage, mid-distances and far-distance of the sites (Table 1). There is no clear relationship between chlorophyll-a and the contents of nutrients (except for NO₂-N with R² = 0.36). This proves to be fairly consistent independent from the variation of nutrients. The average values of the two surveys in May 2015 and 2016 show that the content of NO₃-N increased about 3.6 times and the NH₄-N increased about 5.1 times (Table 2) as compared to the same period in 2011. The distribution of nutrients in the study area shows that NO₃-N

Table 2
Statistical data of nutrient concentration in coastal waters of Nha Trang bay. (During dry seasons of 2015 and 2016)

| Values | NH ₄ -N (μg L ⁻¹) | NO ₂ -N (μg L ⁻¹) | NO ₃ -N (μg L ⁻¹) | DIN (μg L ⁻¹) | P-PO ₄ (μg L ⁻¹) |
|--------|--|--|--|---------------------------|---|
| Min | 10.9 | 3.1 | 148.2 | 169.9 | 6.2 |
| Max | 30.4 | 4.9 | 155.3 | 188.9 | 21.9 |
| Mean | 20.5 | 3.9 | 152.9 | 177.4 | 11.7 |
| Stand | 6.8 | 0.5 | 1.9 | 6.0 | 4.0 |
| n | 14 | 14 | 14 | 14 | 14 |

Table 3
The variation of nutrients in coastal waters of Nha Trang.

| Year | NO ₂ -N (μg L ⁻¹) | NO ₃ -N (μg L ⁻¹) | NH ₄ -N (μg L ⁻¹) | PO ₄ -P (μg L ⁻¹) | DIN (μg L ⁻¹) | DIP (μg L ⁻¹) |
|-------------|--|--|--|--|---------------------------|---------------------------|
| 2005(a) | 0.6 | 47.0 | 0.0 | 10.9 | 47.6 | 10.9 |
| 2006(b) | 0.6 | 33.0 | 38.3 | 10.4 | 71.9 | 10.4 |
| 2007(b) | 0.9 | 36.0 | 9.8 | 11.4 | 46.6 | 11.4 |
| 2008(b) | 0.0 | 35.0 | 6.0 | 13.7 | 41.0 | 13.7 |
| 2009(b) | 41.5 | 212.0 | 17.3 | 13.5 | 270.7 | 13.5 |
| 2010(c) | 0.0 | 31.0 | 6.5 | 11.3 | 37.5 | 11.3 |
| 2011(c) | 3.1 | 28.0 | 17.8 | 16.6 | 48.9 | 16.6 |
| Apr 2011(c) | 0.4 | 30.0 | 11.3 | 10.2 | 41.7 | 10.2 |
| Jun 2011(c) | 0.0 | 31.0 | 8.0 | 11.5 | 39.0 | 11.5 |
| May 2015(d) | 3.9 | 153.0 | 20.5 | 11.7 | 177.4 | 11.7 |
| May 2016(d) | 1.9 | 65.7 | 77.8 | 16.8 | 145.4 | 16.8 |

Notes: (a) – the sources from the references of Vinh et al. (2005); (b); Data sources of the monitoring site in Nha Trang bay; (c) from references of Huong et al. (2015); (d): In this study.

and PO₄-P concentrations are mainly concentrated in aquaculture areas (Appendix A). There was little variation in nutrient contents Nha Trang Bay coastal waters until about 2005 (Vinh et al., 2005), while the levels of NO₃-N and NH₄-N in the period 2005 to 2011 have slightly changed (Table 3). However, from 2011 to 2016 strong changes in the concentrations could be observed.

Our findings that phosphorus might probably be the limitation factor in these waters, are contrary to those obtained in cage farm areas in Dam Bay, where nitrogen was identified as the limiting nutrient factor (Huong et al., 2015). A previous study by Vinh et al. (2005) also concluded that phosphorus has always played the role

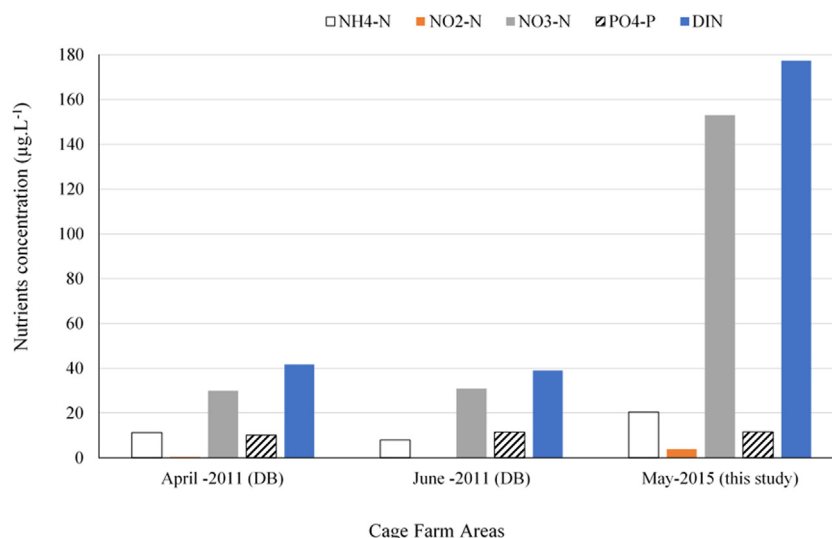


Fig. 2. Comparison of mean nutrient values between the cage farm areas in Đam Bay areas (ĐB)- (based on the data of [Huong et al., 2015](#)) and in this study.

of a limiting factor in the coastal waters of Nha Trang Bay in the dry seasons. A comparison with the results of nutrient levels obtained from [Huong et al. \(2015\)](#) in the lobster cage area at Dam Bay, Nha Trang Bay shows that the average values of inorganic nutrients such as $\text{NH}_4\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{PO}_4\text{-P}$ were relatively similar. However, the contents of $\text{NO}_3\text{-N}$ and DIN in the water column of the study area were significantly higher than those in Dam Bay at the same time period of the year (about 3–4 times) (Fig. 2). The N:P ratios at almost all surveyed sites were greater than the Redfield ratio of 16:1, except for the surface layer at site-NT2, with about 15.62 (in 2015) and for the bottom layer at sites NT4, NT6 with about 11.09 and 15.07, respectively (in 2016). This shows that during the time of the study, phosphorus might probably be the limiting factor in these waters.

The TRIX index suggested by [Vollenweider et al. \(1998\)](#) for assessing the nutrient levels, is a combination of variables such as Chlorophyll-*a*, DIN, $\text{PO}_4\text{-P}$, and dissolved oxygen. There are four scaling levels: 0–4: excellent water quality and low nutrient level; 4–5: good water quality and moderate nutrient level; 5–6: water of average quality and high nutrient level; and: 6–10: degraded water quality and very high nutrient level ([Giovanardi and Vollenweider, 2004](#)). From the TRIX indexes calculated with data from this research, it is noticeable that most TRIX indexes in both surface and bottom layers are within a scale of 5–6, i.e. a high nutrient level and seawater of an average quality. It can also be noticed that at such sites as NT1, NT2, and NT3 close the cage farm area, the TRIX indexes are higher than those in sites more distant from the cage farm area (NT4, NT5, NT6, and NT7) (Figs. 3a and 3b). This may show that these waters have been directly impacted by cage farm activities, which have triggered the rise of nutrient contents in the coastal waters.

The increase of dissolved inorganic nutrients in the waters of the cage farm area is closely linked to the eutrophication of coastal waters, especially with a substantial amount of disintegrated and mineralized organic matter from sediments, which enter the water column ([Alongi et al., 2009](#); [Nils et al., 2015](#)). The results of calculating N and P emissions from aquaculture areas show that lobster cage farming is the most polluting source of nutrients (N) for the environmental waters of Nha Trang bay. Lobster cage farming strongly emits nitrogen and phosphorus into the marine environment, about 28917 tons of nitrogen and 7740 tons of phosphorus per year, respectively. Expressed in produced tons of commercial lobsters, the amount of nitrogen and phosphorus released into the environment is 261.47 kg and

69.98 kg per day, respectively. This fits well to data from [Hung and Tuan \(2009\)](#), where the nitrogen load from lobster cages is 257 kg per ton of commercial lobster in Khanh Hoa province in 2009. From the results of cage farming it can be seen that lobster cages have a significant impacts, higher than other sources, due to the fact that the lobster feed conversion ratio is so high, leading to nitrogen and phosphorus deposits in Nha Trang bay (Table 4). Due to large differences in feed conversion ratios (FCR) and N/P contents in the feed used, the total N and P loads are highly variable in the calculations (Table 5).

From the above results, the cage aquaculture in Nha Trang bay has contributed to the increase of organic and nutrient contents in water column and bottom sediment in cage farming areas (Table 6). In addition, in semi-closed bays such as Nha Trang bay, especially in the southern part of the bay, where most of the lobster cages are located, the area is surrounded by islands. This makes the wastes from the sea-cage farming was difficultly for diffusion, its easy accumulate in the bottom layers. [Chen et al. \(2003\)](#) found that about 15% of C and N in faeces leached after a few minutes in water. The waste production of fish farms depends upon the individual aquaculture facilities, which may differ from province to province. Due to an additional waste component from uneaten feed, nutrients release rates can only be estimated from case to case. The nutrient loadings from cage farms represent a concentrated point source, strongly influencing surrounding waters ([Du et al., 2006](#); [Alongi et al., 2009](#)). Depending on the hydrodynamic conditions and depth of the sites, different currents will contribute to water exchange in the cage farms.

3.2. The influenced of aquaculture activities on coral reefs

In reef ecosystems, *Acropora* spp. corals are highly dependent on the photosynthetically fixated carbon derived from the endo-symbiotic algae ([Grottoli et al., 2004](#)). The adaptation to the nutrient poor environments has made the symbiosis rather important, providing the coral with excessive carbon. An increase of the DIN supply, the main effluent source from fish farming, leads to i) proliferation of zooxanthellae and thereby an increase in phosphate demand and in turn an “altered composition of thylakoid membranes and a reduced threshold for light- and heat-induced bleaching” ([Ferrier-Pagès et al., 2000](#)). Excessive nutrient loads, often combined with elevated levels of sedimentation, turbidity and lack of grazers due to overfishing, affect the mucus production of corals in two general ways: i) The mucus

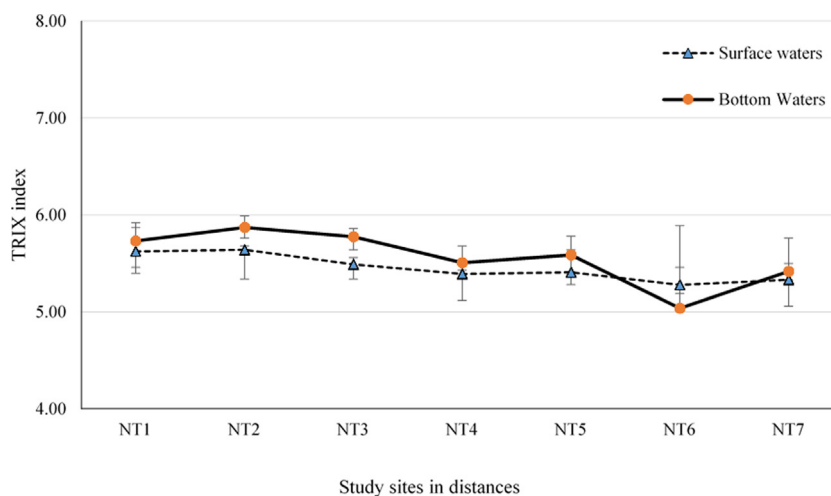


Fig. 3a. The TRIX index in studied sites (surface and bottom waters) – the survey in May, 2015.

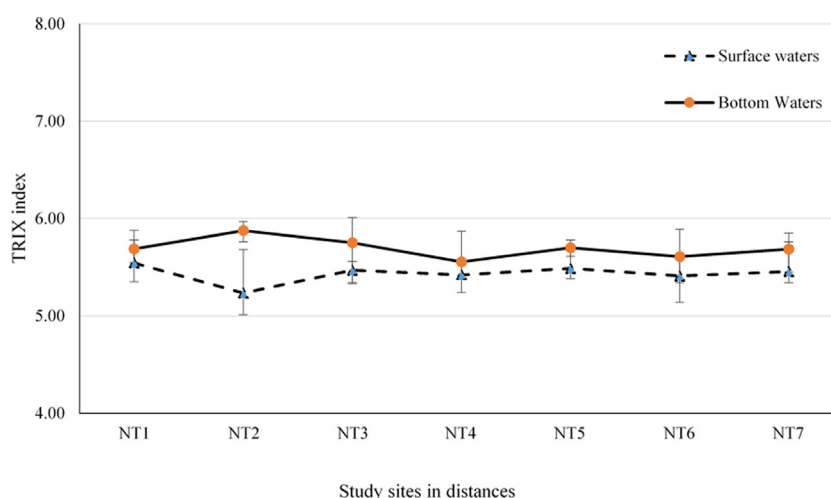


Fig. 3b. The TRIX index in studied sites (surface and bottom waters) – the survey in May, 2016.

Table 4

The numbers of cages and FCR (food conversion ratio) for different species in cages.

| Aquaculture species | | Number of cages in 2015 | Quantity in 2015 (tons) | FCR (trash fish) |
|---------------------|--------------|-------------------------|-------------------------|------------------|
| Crustacean Fish | Lobster | 2743 | 187 | 27.7 |
| | Cobia | 495 | 120 | |
| | Grouper | 183 | 15 | |
| | Seabass | 144 | 7 | |
| | Other fishes | 80 | 4 | |

Table 5

Calculated nitrogen and phosphorus releases from cage farm areas in Nha Trang bay.

| Aquaculture in cages | N | P | N | P |
|--|--------------|--------------|-----------|-----------|
| | Lobster cage | Lobster cage | Fish cage | Fish cage |
| Calculated N and P release from cages (tons) | 17.91 | 4.79 | 3.33 | 0.97 |
| Calculate for N and P (kg of N or P per ton of production) | 95.75 | 25.63 | 22.82 | 6.63 |

excretion increases due to exposure to the nutrient loading, but decreases in time to initial levels probably due to adaptation mechanisms; ii) The quality of the mucus decreases over time (Brown and Bythell, 2005; D’Angelo and Wiedenmann, 2014).

The cage farm location has all the typical attributes of a fish farm site: lower coral density, less visibility and higher levels of

Chlorophyll- a. There are no corals deeper than 5.2 m, which is almost 2 m less than at the reference site (Table 7). Earlier laboratory studies have shown similar results that elevated amounts of nitrogen and phosphorous in the ambient water caused a decrease in coral tissue growth (Ferrier-Pagès et al., 2000). When exposed to nutrient-rich waters, the coral mucus excretion rate

Table 6
Rate of sediment deposition in the study area.

| Sites | Deployment time (days) | Sedimentation rate (mg.cm ⁻² .d ⁻¹) | TOM (%) |
|--------------------------------------|------------------------|--|---------|
| Under cage farm (NT2) | 2 | 6.81 | 16.0 |
| Near-cage farm (coral reef area)-NT3 | 2 | 2.84 | 19.9 |
| Far from cage farm | 2 | 1.86 | 11.3 |

Table 7
Mortality of coral specimens from field-experiments after one month at the study sites.

| Sites | Number of specimens | Percent of dead corals (%) |
|-----------------------------------|---------------------|----------------------------|
| Hon Mot -1 (west side of island) | 12 | 83.3 |
| Hon Mot -2 (east side of island) | 12 | 16.7 |
| Hon Mun -3 (MPA) - reference site | 12 | 8.3 |

increased (as a short term response), although there was no difference in the mucus excretion in established colonies exposed to different levels of nutrient loads. When affected by nutrient loads, zooxanthellae accumulate nutrients and proliferate, resulting in lower amounts of mucus produced per coral, but a higher amount of total algae biomass producing DOM (D'Angelo and Wiedenmann, 2014).

4. Conclusion

This study confirms the negative impacts that nutrient loads have upon the coastal environment in general and the coral itself, with lowered growth-and calcification rates, finally resulting in a lowered contribution to ecosystem goods and services. This suggests that cage farm activities should be closely monitored and threshold densities should be defined by coastal managers, based on scientific results, considering N and P releases and flux calculations, in order to prevent long-lasting damage to coral reefs.

CRediT authorship contribution statement

Hoang T. Du: Conceptualization, Methodology, Investigation, Formal analysis, Writing – original draft. **Nguyen M. Hieu:** Methodology, Formal analysis, Data curation. **Andreas Kunzmann:** Investigation, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary material related to this article can be found online at <https://doi.org/10.1016/j.rsma.2022.102639>.

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