

# Cobia cage culture distribution mapping and carrying capacity assessment in Phu Quoc, Kien Giang province

Vị trí phân bố và tính toán sức chịu tải môi trường khu vực nuôi cá bớp lồng bè (Cobia or Back King fish) tại Phú Quốc, Kiên Giang

Research article

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Cobia fish cage is the most popular marine culture species raised in Phu Quoc Island, Vietnam. For its sustainable development, there is a need to determine the carrying capacity to avoid negative marine environmental impact in the future. This study was carried out to collect water samples each two months at the lowest and highest tides at four points around the farming area in Rach Vem, Phu Quoc Island, Kien Giang Province from February to October 2011. Water quality in cobia cage culture was surveyed to assess the environmental status of coastal aquaculture areas including seven parameters such as DO, COD, BOD, TSS, TN, TP and Chlorophyll-a. These parameters are suitable to rear cobia fish cage in this area. Nitrogen and phosphorus are considered as the principal nutrients produced by the cobia fish farm and affecting water environment. This study found that the carrying capacity for fish cage farming in the area is 290.96 to 727.81 tons (based on total nitrogen) and 428.64 to 1,383.88 tons (based on total phosphorus) from February to August 2011. The maximum number of cobia cages should be, based on total nitrogen, from 64 to 266 and, based on total phosphorus, from 94 to 253. Moreover, this study examined the possibility of remote sensing and geographic information system (GIS) technique based on Object-based Image Analysis (OBIA) method by THEOS imagery for mapping of cage culture facilities and detect the location for cobia cage culture in study area.

Cá bớp nuôi lồng bè là một trong những loài cá nuôi phổ biến khu vực ven biến Phú Quốc, Việt nam. Nhằm phát triển bền vững vùng ven biển, đề tài thực hiện đã xác định và đánh giá hiện trạng môi trường nước và sức tải môi trường của nghề nuôi cá bớp lồng bè ở đảo Phú Quốc. Nghiên cứu này được thực hiện thông qua việc thu mẫu môi trường nước mỗi 2 tháng theo mức nước triều cao nhất và thấp nhất tại 4 điểm quanh khu vực nuôi tại ấp Rạch Vẹm, huyện Phú Quốc, tỉnh Kiên Giang từ tháng 02-10/2011. Chất lượng nước khu vực nuôi thủy sản cũng được khảo sát với 7 chỉ tiêu gồm DO, COD, BOD, TSS, TN, TP, Chlorophyll-a. Các thông số chất lượng môi trường này phù hợp nuôi cá bớp tại khu vực nghiên cứu dựa trên tiêu chuẩn chất lượng môi trường. Trong nghiên cứu này, đạm và lân là 2 thông số được sử dụng để tính toán sức tải môi trường. Sức tải môi trường được tính toán cho khu vực nuôi cá bớp dao động khoảng từ 290.96 tấn đến 727.81 tấn (tính trên hàm lượng đạm tổng số) và từ 428,64 tấn đến 1.383,88 tấn (tính trên hàm lượng lân tổng số) trong thời gian từ tháng 2 đến tháng 10 năm 2011. Số lượng tối đa lồng bè nuôi cá bớp khoảng từ 64 đến 266 (đạm tổng số) và từ 94 đến 253 (lân tổng số) dựa vào phân tích hồi quy tương quan. Bên canh đó, công nghê viễn thám và hê thống thông tin đia lý (GIS) đã được ứng dung bằng cách sử dung ảnh THEOS để xác đinh vi trí và phân bố không gian khu vực nuôi cá lồng bè dựa trên phương pháp phân tích đối tượng theo hướng (OBIA).

**Keywords:** cobia farming, carrying capacity, environmental quality, remote sensing, Geographic Information System (GIS)

# 1. Introduction

In recent years, coastal aquaculture has received wide popularity across many countries and further growth is expected in the coming decades (FAO, 1992). However, increasing aquaculture production leads to nutrient release into the standing waters leading to eutrophication. In addition, release from domestic, industrial, agriculture, deforestation and livestock production also adds to the water nutrient load and this has an adverse effect on aquaculture and carrying capacity of the water body. The concept of environmental carrying capacity is not only important for species cultivation but also for other concerns such as water quality and tourism (Duarte et al., 2003). Carrying capacity is defined as the maximum biomass of a farmed species that can be supported without violating the maximum acceptable impacts to the farmed stock and its environment. Maximum acceptable impacts on the farmed stock and the environment are expressed by standards for water quality in the farm and the surrounding environment (Anders, 2011).

Compared with inland areas, the coastal zone has more complex ground objects and greatly temporal and spatial distribution. Although in particular, pixel-based classification has been fully developed and widely applied in coastal research, it is hard to be used in automatic extraction of information in high-spatial resolution image (Sun et al. 2008). The object-oriented technique is a new technology that appeared over the recent years. Rather that classifying the remote sensing images in pixel-level, it classifies the images in patch-level. According to the spectral heterogeneity of an image, the object-based image classification segments the image into small homogeneous objects with particular geometric features and spatial information that serve as building blocks for subsequent classification (Zhou et al., 2008). Object characteristics such as textural features, shape, spatial relations and reflectance statistics can be used for classification (Im et al., 2008). The object-based image classification is coincident with human thinking pattern and has distinct advantages in classifying high spatial resolution images, such as Quick bird, Ikonos and Spot5, without salt-pepper noise (Cao et al., 2006; Cheng et al., 2006).

In this paper, the authors attempt to apply object-oriented technique into the aquaculture extraction from remote sensing data by using THEOS image and estimate carrying capacity for fish cage culture to control nutrients release and limit cage culture production in study site.

# 2. Methods

# 2.1. Study area

Phu Quoc Island is part of Kien Giang province and is the largest island in Vietnam covering a total of 589.23 km<sup>2</sup>. This study focuses on the northern part of the island stretching from  $10^{\circ}14'$ N in the south to  $10^{\circ}27'$ N in the north and between  $103^{\circ}50'$ E and  $104^{\circ}05'$ E longitude. This region includes the communes Cua Can, Ganh Dau, Bai Thom and more than half area of Cua Duong commune.

The study area is both seaward and landward sites at five km away from seashore.



Figure 1. Fish cage culture in the Northern part of Phu Quoc Island, Kien Giang Province, Vietnam

# 2.2. Field survey and sampling

Water samples were collected from April to August 2011. The samples were collected in three campaigns from stocking to harvest of snail life cycle. Each time, four samples were collected twice at high and low tide of a day above the seabed from each net at a distance of 50 m from the both sides of the net (Figure 1). The samples were kept in 1 litre bottle, stored at 4-15  $^{\circ}$ C (with ice) and transported to the laboratory within 12-15 hours after sampling.

The chemical parameters were analysed in laboratory, including total ammonia-nitrogen  $NH_3-N$  (TAN: mgL<sup>-1</sup>), total nitrite nitrogen  $NO^{-3}-N$  (mgL<sup>-1</sup>) and total phosphate (P-PO<sub>4</sub><sup>-3</sup>). The physical parameters measured on field were temperature (T<sup>0</sup>C), pH, depth (m) at peak high and low tides, flow velocity, dissolved oxygen (DO) and salinity. The hydrographical and technical properties such as total surface area (m<sup>2</sup>), average depth (m), average volume (m<sup>3</sup>), snail stocking, feed and feeding were collected by the interviews with farmers living in study area.

## 2.3. Remote sensing and GIS analysis

This study used remote sensing, GPS and GIS techniques to allocate and classify cobia fish cage location. THEOS satellite image (Thailand Earth Observation Satellite) combined to GPS was used to define cobia fish cage sites.

## 2.3.1. Image registration

Image registration is a crucial step in all image analysis tasks in which the final information is obtained from the combination of various data sources like in image fusion, change detection and multichannel image restoration (Zitova and Flusser, 2003). In this study, image-to-image registration was used and Ground Control Points (GCPs) were collected and located on all satellite images. THEOS images from 2011 were georeferenced by UTM zone 48 North and WGS 84 were applied to all satellite images as map projection and reference ellipsoid, respectively.

### 2.3.2. Image fusion

Image fusion was adopted to enhance the marine habitats. This is one of the techniques applied to geometrically integrate the details of two images, one high resolution of panchromatic (PAN) image and one low resolution of multispectral (MS) image, to produce the MS image with high resolution. In this study, the fusion technique is applied for THEOS image for producing the THEOS MS image with two meters resolution, which was fused from one band of THEOS PAN (2 m) and four bands of THEOS MS (15 m).

## 2.3.3. Feature selection

For high-resolution satellite images, aquaculture is found to follow a regular grid-pattern and has similar spectral features with other water bodies. So by building rule based on the spatial, spectral and texture attributes, aquaculture information can be extracted accurately (Xue et al., 2010).

In this study, the image was georeferenced, so the areas of objects are the true area in square meter. By building the rules based on object attributes including area, compactness, elongation, band ratio and T-entropy, some unwanted small objects, land objects and other water bodies objects are eliminated. The analysis of THEOS image in this study were used by applying the object-oriented classification method for obtaining aquaculture distribution.

#### 2.3.4. Raster to vector conversion

All classes of images available in ERDAS IMAGINE 9.2 software in form of raster data type were converted to vector data type. This data format is followed in GIS software for further analysis. The maps of fish cage culture facilities were thus created.

## 2.4. Statistical analysis

Water quality parameters (Table 1) were analysed by using several methods such as Winker method for DO concentration, Kjeldahl method for total nitrogen and total phosphorus, colour spectrum for  $NO_2^-$ , cadmium reduction method for  $NO_3^-$  and Phenate method for TAN (APHA, 1995). Further data analysis was made using Excel 2003 and SPSS version 16.0 Inc.

## 2.5. Estimation of carrying capacity

The methodology has been developed from earlier methods (Gowen, 1994; Ward et al., 1999) and theoretical concepts (Anon 2001a; Anon 2001b; GESAMP 1996; Bartholomew et al., 2000). Carrying capacity was computed based on total nitrogen (TN) input, total phosphorus (TP) input, flushing rate and current flow. The assessment was done in consideration of nitrogen and phosphorus as the limiting factors for primary productivity and the consequent biological impacts.

## 2.5.1. Estimation of nutrient effluent loadings

There are several methods for nutrient input calculation and many researchers have used those in many different ways (Briggs and Fvnge-Smith, 1994). Since there is no clear guideline and calculation varies from one site to another it was decided to apply different calculation methods that follow the same principle. The equation used in this study to estimate the nutrient load was suggested by Wallin and Hakanson (1991):

$$N_{l} = P \times (FCR \times N_{feed} - N_{fish})$$
(1)

where  $N_l$ : nutrient loading  $(g \times m^3)$ ; P: fish production  $(kg \times m^3)$ ; FCR: feed conversion rate (-);  $N_{feed}$ : percentage of nitrogen in feed (%);  $N_{fish}$ : percentage of nitrogen in snail (% wet weight).

Calculation of total N and P load often uses total surface area, amount of water discharge during culture with number of discharge and water volume at harvesting discharge in respective months. Nitrogen and phosphorus contents of discharged water during culture and harvest were accounted following Briggs and Fvnge-Smith (1994).

## 2.5.2. Estimation of flushing rate or dilution rate

The crucial part of the mass balance equation (Eq. 1) is the need to obtain a good estimate of the flushing time or dilution rate. Flushing rate can be obtained by using tidal amplitude:

$$\rho = Q/V \tag{2}$$

where:  $\rho$ : flushing rate  $(y^{-1})$ ; Q: total outflow  $(m^3)$ ; V: volumes  $(m^3)$ .

#### 2.5.3. Estimation of Carrying Capacity (CC)

For aquaculture, environmental carrying capacity can be converted into the number of hectares or volume of production cages or feed on a limited resource environment specifically receiving the wastewaters, bays, lagoons break. The carrying capacity (CC) is calculated using the simple equation proposed by Tran and Nguyen (2006):

$$CC = EC/PL$$
(3)

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where CC: Carrying capacity (tons per units);
EC: Environmental capacity (g \times m^3)
(EC = Thresh hold value for Total Nutrient –
Total Nutrient Loading);
PL: the average total pollutant load per tons of
fish production (g \times m^3).
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The carrying capacity represents thus the maximum number of "units" of aquaculture (ha/number of cages) for specific water bodies.

# 3. Results

# 3.1. Aquaculture distribution

The result of image fusion of THEOS data is shown in the Figure 2. This image product shows the fish cage culture sites clearly (inside red circle) because fish cage culture size is quite small having dimension as  $4 \times 4$  meters.



THEOS PANTHEOS MSTHEOS MS fusion(2m)(15m)(2m)Figure 2. THEOS image fusion (2m resolution) usingband combination 4,3,2 as RGB respectively

The object-based image analysis (OBIA) method was used to detect sea cage culture. The method has been proved to be suitable for processing high-resolution remote sensing images (Navulur, 2006). In this study, rulebased classification was used to extract aquaculture information.



Figure 3. Fish cage culture distribution map in the Northern Coastal Phu Quoc Island

The rules based on object attributes including area, compactness, elongation, band ratio and T-entropy eliminated some unwanted small objects, land object and other water body objects. The result was exported to shape file type (Figure 3).

# **3.2.** Environmental conditions

## 3.2.1. Dissolved oxygen (DO) concentrations

DO concentration was high in fish cage culture and fluctuated from 4.0 to  $9.61 \text{ mgL}^{-1}$  (Figure 4).





At high tide, DO concentration was higher  $(6.32 - 9.61 \text{ mgL}^{-1})$  than at low tide  $(4.00 - 7.13 \text{ mgL}^{-1})$  and has different significant statistics (P < 0.05). According to Boyd (1990), DO concentration standard for coastal aquaculture is more than 5 mgL<sup>-1</sup>, which means that DO concentration above is still suitable to growing fish cage. DO concentration tended to rise in the last sampling months; the reason is that at this time generally the sea level rises and the high waves dissolve the oxygen from the air into water.

## **3.2.2.** Biochemical oxygen demand (BOD) and chemical oxygen demand (COD) concentrations

BOD and COD concentrations were low in each sampling month and there are no different significant differences between each month at high tide (P > 0.05) and low tide (P < 0.05). BOD ranged from 0.23 to 1.47 mgL<sup>-1</sup> while COD ranged from 1.17 to 4.52 mgL<sup>-1</sup>. Nevertheless, BOD and COD have shown large fluctuations between high tide and low tide in June, August and October and vice versa in the other months (Figure 5 and 6). During period culture, BOD and COD concentration showed that nutrient material accumulation process occurred but not at high level and the range was still suitable to grow fish cage according to the Vietnamese water quality standard QCVN 10:2008/BTNMT (2008).



Figure 5. BOD concentration during period culture



Figure 6. COD concentration during period culture

## 3.2.3. Total suspended solids (TSS) concentration

TSS concentration was in the range from 1.96 to 34.3 mgL<sup>-1</sup>, at high tide from 3.00 to 22.8 mgL<sup>-1</sup> and 1.96 to 34, 3 mgL<sup>-1</sup> at low tide (P < 0.05) and tended to increase gradually each month. Comparing to the others months (Figure 7), TSS concentration was lowest in April (1.96 to 3.00 mgL<sup>-1</sup>). The limit of TSS concentration in coastal water quality standards was less than 50 mgL<sup>-1</sup> in aquaculture (Vietnamese water quality standard (QCVN 10: 2008/BTNMT)).



Figure 7. TSS concentration during period culture

#### 3.2.4. Total nitrogen (TN) concentration

Total nitrogen (TN) concentration was high in June at  $0.65 \pm 0.16 \text{ mgL}^{-1}$  and low in August at  $0.22 \pm 0.003 \text{ mgL}^{-1}$  during culture time (Figure 8). Conceptually during culture period (February to October), the nitrogen concentration increases from stocking to harvesting time, in June is the time for harvesting so nitrogen concentration is the highest and from August to October is the time for stocking so nitrogen concentration is the lowest. The effluent standard for coastal aquaculture of total nitrogen is 4.0 mgL<sup>-1</sup> (PCD, 2008).



Figure 8. Total nitrogen (TN) concentration at each water samples site

#### 3.2.5. Total phosphorous (TP) concentration

As the same period sampling of TN, TP concentrations were also high in June at  $0.34 \pm 0.02 \text{ mgL}^{-1}$  and low in August at  $0.08 \pm 0.05 \text{ mgL}^{-1}$  during culture time from February to October (Figure 9). The standard of TP concentration for coastal aquaculture is  $0.4 \text{ mgL}^{-1}$  (PCD, 2008). Phosphorus concentration in the study area did not show significant variations from stocking to harvest period.



Figure 9. Total phosphorous (TP) concentration at each water samples site

#### 3.2.6. Chlorophyll-a concentration

In study area, chlorophyll-a concentration was also high in June at  $1.38 \pm 0.01 \ \mu g L^{-1}$  and low in August at  $0.39 \pm 0.11 \ \mu g L^{-1}$  during culture time (Figure 10). Similar to phosphorus concentration, the concentration was highest at harvesting time in June and lowest at stocking time in August. The effluent standard for coastal aquaculture of chlorophyll-a is from 0.1 to 0.4  $\mu g L^{-1}$ (ANZECC/ARMCANZ, 2000).



Figure 10. Chlo-a concentration during culture period

## 3.3. Carrying capacity

#### **3.3.1.** Nutrient loadings

The trash fish used for cobia culture contained 1.5% nitrogen and 0.072% phosphorus and the nitrogen and phosphorus found in the laboratory samples content in Cobia fish nutrients were 1.92% and 0.062%, respectively. These laboratory experimented nutrient content in the feed and fish were used in the newly developed FCRbased nutrient loading equation and the nutrient loadings from trash fish were calculated. The feed conversion rate (FCR) given by the farmer is 8. The pollutant loads were the highest in June and August (harvest period) from 2.047 to 2.095 mgL<sup>-1</sup> and decreased in October (stocking time) at 1.511 mgL<sup>-1</sup> for nitrogen and from 0.096 mgL<sup>-1</sup> to 0.098mgL<sup>-1</sup> in June and August and decrease at 0.070 mgL<sup>-1</sup> in October for phosphorus. Despite, such increase in variation is still within water quality standard for coastal aquaculture of 4.0 mgL<sup>-1</sup> for nitrogen and 0.4  $mgL^{-1}$  for phosphorus (PCD, 2008).

#### 3.3.2. Nutrient concentration distribution

The average of total nitrogen amount in the water environment calculated from February to October was in the range from 5.56 to 8.145 tons with the highest value in August and the lowest value in October. In case of phosphorus, the values varied from 0.38 to 0.259 tons. The nutrient concentration values decreased from June to August because of the decrease in cobia production from 77.57 to 64.53 tons and feed feeding from 994 to 778.75 kg × day<sup>-1</sup>.

#### 3.3.3. Environmental capacity

The environmental capacity for total nitrogen of cobia culture in five times period sampling (February, April, June, August and October) in non-culture sites and in culture sites is presented in Table 1.



# Figure 11. Environmental capacities in cobia cage culture (total nitrogen concentration)

The concentration of total nitrogen was lowest in June and highest in August. Conceptually, the environmental capacity decreases in June (harvest time) and increase in August and October (stocking time). Environmental capacities for cobia cage culture in study area including non-culture sites, culture sites and pollutant loadings are showed in Figure 11 based on total nitrogen.

#### Table 1. Environmental capacity and carrying capacity in snail net culture

| Months   | Parame<br>ters | Environmental capacity (g/m <sup>3</sup> ) |              |                 | Carrying capacity |
|----------|----------------|--|--------------|-----------------|-------------------|
|          |                | Non-culture site                           | Culture site | Pollutant loads | (tons)            |
| February | TN             | 3.88                                       | 3.84         | 2.19            | 574.59            |
|          | TP             | 0.21                                       | 0.16         | 0.13            | 708.20            |
| April    | TN             | 3.52                                       | 2.87         | 1.62            | 380.18            |
|          | TP             | 0.19                                       | 0.15         | 0.10            | 507.10            |
| June     | TN             | 3.28                                       | 2.85         | 1.23            | 290.96            |
|          | TP             | 0.18                                       | 0.11         | 0.08            | 428.64            |
| August   | TN             | 3.81                                       | 3.59         | 1.72            | 379.65            |
|          | TP             | 0.25                                       | 0.23         | 0.15            | 709.74            |
| October  | TN             | 3.65                                       | 3.53         | 2.14            | 727.81            |
|          | ТР             | 0.26                                       | 0.24         | 0.19            | 1383.88           |

Table 1 also shows the environmental capacity of cobia cage culture for total phosphorus from February to October in non-culture sites and in culture sites. The changes of environmental capacity are visualized by chart plots and shown in Figure 12. Most of environmental capacity of nutrient loadings is lower than those in culture and non-culture sites and also there is no significant variation in the environmental capacity values of the culture and non-culture sites. This implies that cobia density culture is still not a threat to the environment.



Figure 12. Environmental capacities in cobia cage culture (total phosphorus concentration)

## 3.3.4. Carrying capacity

Carrying capacity can be calculated as the potential production and number of cages in total fish area that can be fed in the field and ensured that the nutrient emissions do not exceed the environmental standards (using two parameters including total nitrogen and total phosphorus). The carrying capacity of cobia culture was calculated for total nitrogen and for total phosphorus (Table 1). The carrying capacity was the lowest in June because of high nutrient pollutant loadings this month and then fluctuation increasing in the other month due to tidal amplitude in each sample collection.

#### 3.3.5. Maximum number of cobia cage culture

Based on the estimation of carrying capacity, cobia can be cultured from 64 to 226 cages (based on total nitrogen) and from 94 to 253 (based on total phosphorus) with cage size as 4 m  $\times$  4 m  $\times$  2.5 m for culture duration around 10 months (Table 2). According to this result, the maximum allowed number of cages can be selected from 64 to 226 for cobia rearing based on total nitrogen in study area to avoid the negative environmental impact.

#### Table 2. Maximum number of cobia cage culture

| Months   | Production<br>(tons) | No.<br>fish | Maximum no. of<br>fish cages |     |
|----------|----------------------|-------------|------------------------------|-----|
|          |                      | cages       | TN                           | ТР  |
| February | 54.66                | 17          | 179                          | 220 |
| April    | 60.18                | 17          | 107                          | 143 |
| June     | 77.57                | 17          | 64                           | 94  |
| August   | 72.57                | 19          | 99                           | 186 |
| October  | 64.53                | 20          | 226                          | 253 |

#### 3.3.6. Regression models

Regression analysis was done to estimate the relationship between potential production (dependent variable) and independent variables including amount of feeding and environmental capacity. Linear equation for potential production based on nitrogen and phosphorus are as following:  $Y_{\rm N} = 1,148.48 + 1.67 \,\mathrm{F} + 805.53 \,\mathrm{EC}_{\rm PL} \tag{4}$ 

 $Y_{\rm P} = 972.19 + 1.29 \,\mathrm{F} + 5,515.14 \,\mathrm{EC}_{\rm PL} \tag{5}$ 

in which: Y<sub>N</sub>, Y<sub>P</sub>: Potential production for nitrogen and phosphorus (tons),

F: Feeding amount ( $g \times m^{-3}$ ), EC<sub>PL</sub>: Environmental capacity for pollutant loadings ( $g \times m^{-3}$ )

This shows that potential production positive correlation with feeding amount and environmental capacity for pollutant loadings both total nitrogen and total phosphorus. The analysis also indicated a significant effect of feeding amount and environmental capacity on the potential production since they showed a high correlation through the coefficient of determination ( $\mathbb{R}^2$ ) values equal 0.999 and 0.993 for nitrogen and phosphorus respectively and significant ( $\mathbb{P} < 0.05$ ) (F test).

# 4. Conclusion

Fish cage culture was analysed using THEOS imagery in 2011 by OBIA method, which served to develop a fish cage culture distribution map in the study area.

In study site, environmental quality parameters including DO, COD, BOD, TSS, TN, TP and Chlorophyll-a showed that environmental conditions were suitable for cobia growing.

Carrying capacities of cobia cage culture were estimated from 290.96 to 727.81 tons based on total nitrogen and from 428.64 to 1,383.88 tons based on total phosphorus during period culture.

Maximum cobia cages can be cultured from 64 to 226 cages based on total nitrogen and from 94 to 253 cages based on total phosphorus from February to October. As a precautionary measure, the maximum number of fish cage culture should be based on total nitrogen data.

The developed model estimates that the carrying capacity of adult Cobia fish in this system can reach 727.81 tons (nitrogen) and 1,383.88 tons (phosphorus) at the threshold levels of water quality standard (4 mgL<sup>-1</sup> for nitrogen and  $0.04 \text{ mgL}^{-1}$  for phosphorus).

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