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# Anthropogenic fibres in white clams, *Meretrix lyrata*, cultivated downstream a developing megacity, Ho Chi Minh City, Viet Nam

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## ABSTRACT

Anthropogenic fibres are an emerging pollutant worldwide. The Can Gio mangrove area is located downstream of the Saigon River, and is characterised by high level of anthropogenic fibres originating from domestic and industrial textile and apparel manufacturing. In this area, biota is thus subjected to a high potential risk of anthropogenic fibre contamination. This study aims to characterise the accumulation of anthropogenic fibres in different tissues, i.e. gills, digestive systems, and remaining tissues, of white clams (*Meretrix lyrata*) cultivated in the Can Gio beach sand, during a seven-month sampling period. The results showed an average concentration of  $3.6 \pm 2.1$  fibres individual<sup>-1</sup> or  $2.7 \pm 2.4$  fibres g<sup>-1</sup> ww. Higher fibre accumulation was observed in remaining tissues than in gills and digestive systems, and no temporal variation was observed in all clam tissues. The intake of fibres by humans consuming clams was estimated to be 324 fibres inhabitant<sup>-1</sup> yr<sup>-1</sup>.

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## 1. Introduction

Microplastics (plastic items from 1 to 5000 µm in size; [Arthur et al., 2009](#)) have recently become an emerging environmental pollutant that has received increasing attention from researchers. Microplastics were first observed in the pelagic surface water of the Sargasso Sea in 1972 ([Carpenter and Smith, 1972](#)). Until now, microplastics have been found in all aquatic environments, in urban areas characterised by dense industrial activities and/or high population density and also in countryside areas characterised by intense aquacultural and agricultural activities ([Chouchene et al., 2021](#); [Costello and Ebert, 2020](#); [Lahens et al., 2018](#); [Li et al., 2020](#); [Ma et al., 2020](#); [Pan et al., 2021](#); [Patchaiyappan et al., 2021](#); [Ríos et al., 2020](#); [Strady et al., 2020, 2021](#); [Wang et al., 2020](#); [F. Wu et al., 2020](#)). Microplastics have also been observed in rivers and streams in remote areas such as Mount Everest, the Tibetan Plateau and Arctic and Antarctic areas ([González-Pleiter et al., 2020](#); [Jiang et al., 2019](#); [Lusher et al., 2015](#); [Napper et al., 2020](#); [Obbard, 2018](#); [Waller et al., 2017](#)). Microplastics are found in diverse shapes such as fragments, pellets, films, or fibres – with fibres being the most predominant shape ([Bikker et al., 2020](#); [Fu et al., 2020](#); [Harris, 2020](#); [Mao et al., 2021](#); [Napper et al., 2021](#)).

Anthropogenic fibres are defined as i) synthetic fibres that have a petrochemical origin (i.e. polyester, polyamide, polypropylene, etc.), ii) artificial fibres originating from artificial cellulose or silk (i.e. viscose and rayon), and iii) natural fibres (i.e. cotton and wool). These fibres are usually used as materials in many applications such as the textile and apparel industries, in production of fishing nets and geotextiles. Anthropogenic fibres are released into the aquatic environments from untreated and treated domestic and industrial wastewater ([Bui et al., 2020](#); [Hidayaturrehman and Lee, 2019](#); [Jiang et al., 2020](#); [Picó et al., 2021](#)), from fishing net degradation used in aquacultural and fishery activities ([F. Wu et al., 2020](#); [J. Wu et al., 2020](#)) or from geotextiles used for geotechnical, geo-environmental and civil engineering purposes ([Elena et al., 2018](#); [Wiewel and Lamoree, 2016](#)). Recently, sludge used as fertiliser or buried in landfills was found to be a source of fibres via leaching into surface water and groundwater ([Carreras-Colom et al., 2020](#)). The abundance of anthropogenic fibres in aquatic environments may generate negative environmental impacts on the ecosystem and biota. Various aquatic organisms mistake anthropogenic fibres for food and ingest them resulting in negative health impacts from the fibres themselves as well as toxic pollutants (i.e. heavy metals, persistent organic pollutants) in the environment adsorbed on the surface of the

fibres (Wright et al., 2013).

Among various aquatic organisms, bivalves play an important role in both freshwater and marine ecosystems due to their contribution to nutrient recycling, thus creating and modifying the habitat as well as affecting food webs (Vaughn and Hoellein, 2018). Moreover, bivalves are an important part of the global food supply. Due to anthropogenic activities, bivalve abundance and species richness are declining (Zhang et al., 2020); the presence of anthropogenic fibres could be one causative factor. Worldwide, studies have been carried out to assess the accumulation of microplastics or anthropogenic fibres in several marine and freshwater bivalve species. The results have shown that microplastics and fibres were prevalent in all the tested species (Berglund et al., 2019; Dowarah et al., 2020; Klasios et al., 2021; Li et al., 2015; Narmatha Sathish et al., 2020; Phuong et al., 2018, 2019; Su et al., 2018; Van Cauwenberghe and Janssen, 2014).

Due to plastic waste mismanagement and little public awareness regarding plastic pollution, Vietnam was ranked fourth among the top countries emitting the most plastic waste into the world's oceans (Jambeck et al., 2015). The abundance of microplastics in the aquatic environments of Vietnam is of concern and varies on a local scale, with the highest concentrations measured in dense urban zone and the lowest ones in remote areas (Strady et al., 2021). Ho Chi Minh City (HCMC, population more than 9 million inhabitants in 2019; GSO, 2019) and its surrounding provinces, form the economic centre of the country and are characterised by a high population density and intensive industrial activities, especially plastic industries, which include food packaging, textile, and apparel industries. The impacts of the urban and industrial activities on the Saigon River can be observed from the spatial and temporal fluctuations in the concentration of anthropogenic fibres from 22 to 519 fibres  $L^{-1}$  (Lahens et al., 2018; Strady et al., 2020). Located downstream of HCMC, the Can Gio Mangrove Biosphere Reserve (Can Gio mangrove) exhibits high biodiversity with more than 200 species of fauna and 52 species of flora (Nguyen, 2006). Aquaculture activities such as clam, shrimp, crab, and fish farming as well as fishing provide important livelihoods to local residents (Vo and Kuenzer, 2012). However, the ecosystem of the Can Gio mangrove is extremely vulnerable. It is impacted by both the upstream urban and industrial activities of HCMC, which release various organic and inorganic pollutants into the mangrove ecosystem (Costa-Bo"dderker et al., 2017, 2020; Nguyen et al., 2019a, 2019b; Tran et al., 2020), and local issues that directly lead to plastic release, such as solid waste mismanagement (e.g. garbage dumping in the countryside (Kuenzer and Vo, 2013; Pham et al., 2010)), loss and wear and tear of fishing nets, lines, and floats used in local aquaculture and fishing activities, and the absence of wastewater treatment facilities. A recent study found evidence of the presence of microplastics in the beach sand and seawater of the Can Gio mangrove area (32 to 93 microplastics  $kg^{-1}$  and 6 items  $L^{-1}$ , respectively (Vo et al., 2021)). However, to date, the accumulation of microplastics (or anthropogenic fibres) in the Can Gio mangrove's biota has not yet been investigated. Therefore, the objective of this study was to characterise the accumulation of anthropogenic fibres in different tissues of white clams (*Meretrix lyrata*) cultivated at the Can Gio beach by analysing white clams of a similar size range collected monthly. More specifically, the study aimed to examine: (i) the contamination level of anthropogenic fibres in clams, (ii) the mechanisms of anthropogenic fibre accumulation in the different tissues, (iii) the estimation of the annual ingestion of anthropogenic fibres by humans through clam consumption, and (iv) the necessary measures required to reduce accumulation of fibres in clams.

## 2. Materials and methods

### 1. Study area

The Can Gio Mangrove Biosphere Reserve (10° 22'–10° 44' N and 106° 46'–107° 01' E) is a part of HCMC with a low population density

(71,526 inhabitants, population density: 102 inhabitants  $km^{-2}$ , HCMC statistical yearbook 2019). The Can Gio mangrove area is subjected to an asymmetric semidiurnal tidal regime and characterised by a tropical monsoon climate. In 2016, the dry season lasted from January to April, while the rainy season continued from May to December with a monthly precipitation of 400–500 mm from August to October (IMHEN, 2018). The study site is located at Can Thanh, where long and wide natural sand flats are found near the estuaries of the Long Tau and Soai Rap Rivers. The sea currents also follow the monsoon climate regime, flowing from the southwest to the northeast during the rainy season and vice versa during the dry seasons (Fang et al., 2012).

### 2.2. White clam (*Meretrix lyrata*)

The white clam *Meretrix lyrata* (Sowerby, 1851) is a bivalve mollusc commonly found in South East Asia. In Vietnam, white clam farming is an important aquaculture industry for both domestic consumption and export (TCTS, 2016). White clams are distributed in sandy tidal flats (e.g. sand percentage of 60%–90% (Ngo, 2006)), mainly in the mid- to low-tidal zone where the slope is relatively flat (Nguyen, 1996). Adult clams are found buried in the substrate at a depth of approximately 2–6 cm (Nguyen, 2016). The clams feed on phytoplankton species and other suspended matter in seawater through filter feeding. Among other ecological factors, water temperature and salinity have an important influence on the growth and survival rate of the clams. Therefore, the harvesting duration depends on their living conditions and occurs at the Can Thanh site in the Can Gio beach area after 18–20 months of harvesting (Tran et al., 2009). In clam farming areas, polyethylene nets are often used to enclose the clam culture area (Nguyen, 2016).

### 3. Sampling

White clams (*Meretrix lyrata*) were collected monthly in the Can Thanh cultivation area of Can Gio beach (Fig. 1) from March to August and in October 2016 with approximately 30–50 medium-sized clam individuals harvested each month. Tran et al. (2020) defined three seasonal periods based on monthly precipitation for 2016: a dry season including the March and April sampling months, a transition period including the May–July sampling months, and a rainy season including August and October sampling months. The clams were stored in sterile polyethylene Ziploc bags, immediately transported to the laboratory, and then stored at  $-18^{\circ}C$  for further analysis.

### 4. Sample preparation and digestion

To prevent potential fibre contamination from the bags themselves, the clams were thoroughly rinsed with filtrated tap water and carefully dissected to separate the gill (G), digestive system (D), and remaining tissues (R). The shell length was measured individually. The wet weight (ww) of the G, D, and R of each clam was also recorded individually (Fig. 2). For each sampling month, the G, D, and R of the clams were combined for three individuals of similar size to achieve five pools. The total number of tested (and dissected) individuals was 105 over the seven months of the study, corresponding to a total of 35 pools. The combined samples of the G, D, and R were placed separately in 250 mL Erlenmeyer flasks for digestion using a protocol adapted from (Dehaut et al., 2016). Approximately 150 mL KOH 10% (Merck®) was poured in each Erlenmeyer flask and the samples were covered with aluminium foil, placed on a hot plate at  $40^{\circ}C$  for 24 h, and manually agitated gently. The samples were then filtrated through glass fibre filters (Whatman®, GF/A, 1.6  $\mu m$  pore size) using a glass filtration unit connected to a vacuum pump. The filters were stored in sterile Petri dishes for stereoscopic observation.

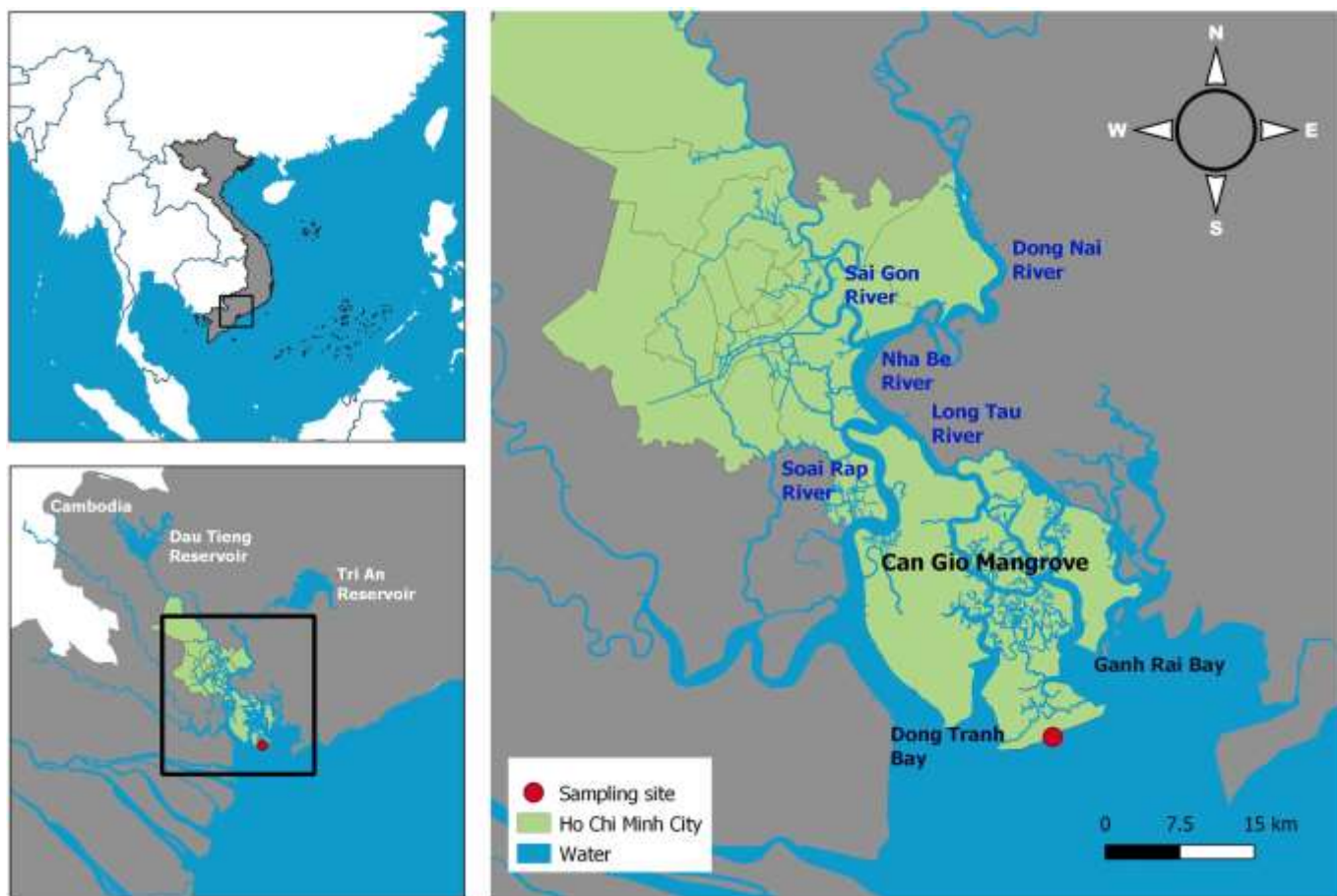


Fig. 1. Study area map with sampling site for white clams (*Meretrix lyrata*) in the Can Gio mangrove area.

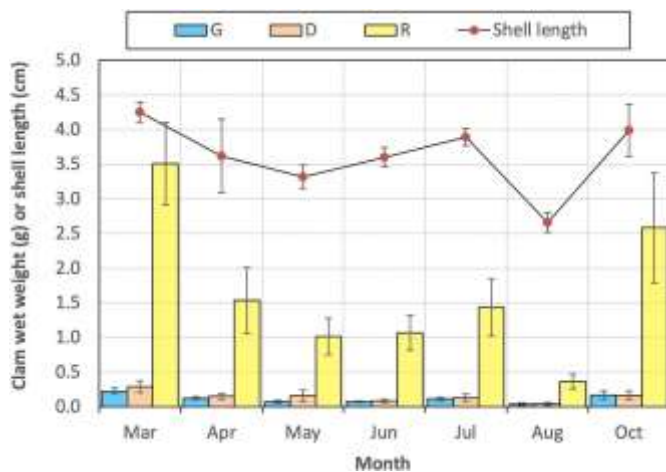


Fig. 2. Monthly average shell length (cm) and monthly average wet weight (g) of gills (G), digestive systems (D) and remaining tissues (R) of white clam (*Meretrix lyrata*) collected in the Can Gio mangrove area over the sampling period.

## 2.5. Stereoscopic observation

The anthropogenic fibres on the filters were observed using a Leica stereoscope S6D with the measurement software LAS. The morphology of the fibres, including length and colour, was recorded. As recommended by (GESAMP, 2019), stereomicroscopic identification of microplastics without spectroscopic confirmation can be performed for

microplastics of the class size [300–5000  $\mu\text{m}$ ]. Due to the absence of  $\mu\text{FTIR}$  (Microscopic Fourier Transformed Infrared) or similar equipment allowing systematic identification of particles lower than 300  $\mu\text{m}$ , we selected an observation size range of 300 to 5000  $\mu\text{m}$  for this study. The anthropogenic fibres were recognised according to the following criteria: a fibre should be an elongated line with equal thickness, not tapered towards the ends, presenting three-dimensional bending, no visible cellular or organic structures, and homogeneous colour (Fig. 3). The straight, transparent, or whitish fibres were excluded to avoid biological or organic origin.

## 2.6. Sample contamination control

A specific quality control procedure was established, based on a recommendation from Dehaut et al. (2016), to prevent sample contamination from airborne particles, water, reagent, and glassware used during the analysis. First, the work area in the lab was wiped with wet tissues. The technician always wore cotton laboratory clothes and sterile hand gloves. All the steps from sample dissection, digestion, to stereoscopic observation were carried out with little air circulation and using an air conditioner rather than a fan. The exposure time of the sample to the ambient air was reduced to a minimum. The number of people working in the lab was also restricted. Tap water for rinsing clams, glassware, and milli-Q water for preparing KOH solution were filtrated through glass fibre filters (Whatman®, GF/A, 1.6  $\mu\text{m}$  pore size) before use. Glassware and samples were covered with aluminium foil to avoid airborne fibre contamination. Quality controls were performed during the two steps: digestion atmospheric control DAC and observation atmospheric control OAC (Strady et al., 2021). The controls presented very little/no airborne contamination: DAC = 1 to 4 fibres (n = 3





**Fig. 3.** Anthropogenic fibres observed in white clams (*Meretrix lyrata*) collected in the Can Gio mangrove area.

replicates) and OAC = 0 to 1 fibre (n = 3 replicates).

### 2.7. Result analysis

The average fibre concentration over the entire survey and monthly average fibre concentration per individual clam and per gram wet weight of tissues (ww) were determined from observation results. The average fibre concentration over the entire survey and the monthly average fibre concentration in different parts of the clam (per tissue and per gram ww of each tissue) were also calculated. Kruskal Wallis statistical tests were performed to assess temporal variation of fibre accumulation in clams and in different clam tissues by using XLSTAT®.

## 3. Results

### 1. Abundance of anthropogenic fibres in clams

Over the seven-month survey, anthropogenic fibres were observed in all the clam pools and in all the sampling months (Table 1). Considering

each clam individual, the average fibre concentration over the entire survey was  $3.6 \pm 2.1$  fibres individual<sup>-1</sup>. The monthly average fibre concentration fluctuated from  $2.6 \pm 0.6$  fibres individual<sup>-1</sup> in April, to  $5.8 \pm 3.1$  fibres individual<sup>-1</sup> in March (Fig. 4a). This fluctuation did not show temporal differences over the sampling months (Kruskal Wallis test,  $p > 0.05$ ).

Accounting for each gram of wet tissues, the average fibre concentration over the entire survey was  $2.7 \pm 2.4$  fibres g<sup>-1</sup> ww. The monthly average fibre concentration varied from  $0.9 \pm 0.3$  fibres g<sup>-1</sup> ww in October to  $6.9 \pm 3.2$  fibres g<sup>-1</sup> ww in August (Fig. 4b). This variation presented a statistical difference over the entire survey period (Kruskal Wallis test,  $p < 0.05$ ).

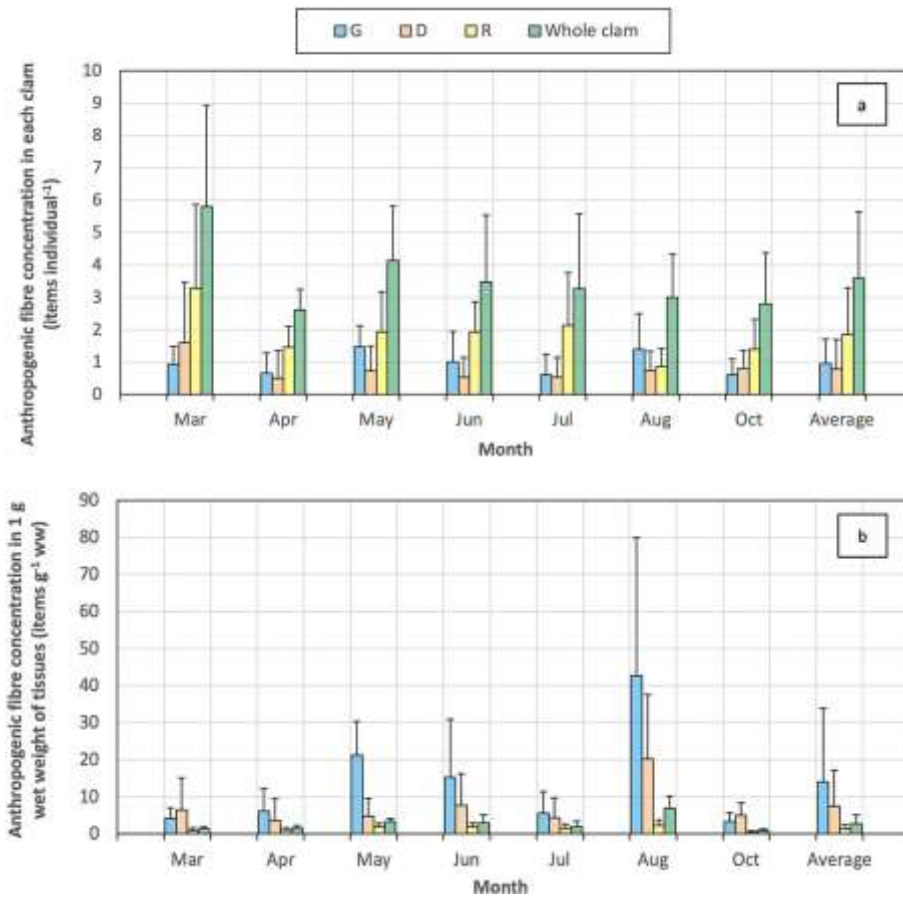
### 3.2. Abundance of anthropogenic fibres in clam tissues

In clam tissues, anthropogenic fibres were found in 97% of all pools of remaining tissues, 89% of all pools of gills, and 74% of all pools of digestive systems (Table 1). For each clam individual, the average fibre concentration over the entire survey was  $1.0 \pm 0.8$  fibres individual<sup>-1</sup> in

**Table 1**

Data on the number of tested pools, the number of pools with presented fibres and the number of anthropogenic fibres for a whole clam individual and for gills (G), digestive systems (D), and remaining tissues (R) for white clams (*Meretrix lyrata*) collected in the Can Gio mangrove area.

Month	Number of tested pools	Number of pools found fibres in				Number of fibres observed in			
		G	D	R	Whole clam	G	D	R	Whole clam
Mar	5	5	4	5	5	14	24	49	87
Apr	5	4	3	5	5	11	8	25	44
May	5	5	4	5	5	22	11	29	62
Jun	5	5	3	5	5	15	8	29	52
Jul	5	4	3	5	5	9	8	32	49
Aug	5	4	4	4	5	21	11	13	45
Oct	5	4	5	5	5	9	12	21	42
All	35	31	26	34	35	101	82	198	381
(%)		88.6%	74.3%	97.1%	100.0%	26.5%	21.5%	52.0%	

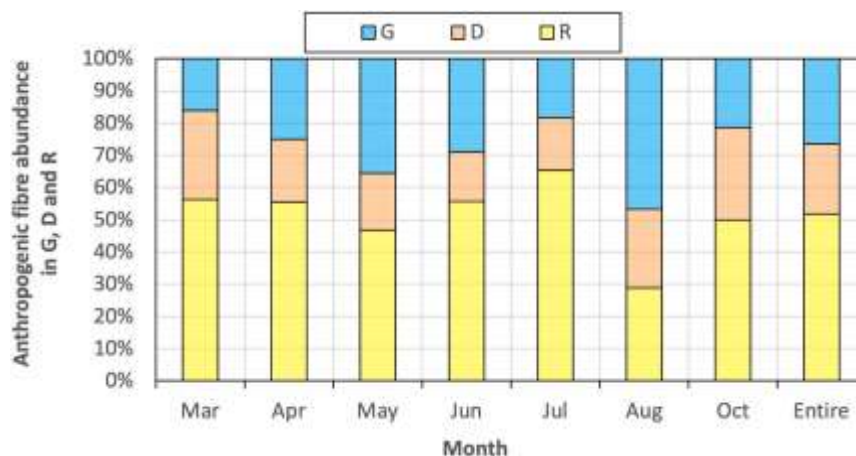


**Fig. 4.** Average concentration over the entire survey and the monthly average concentration of anthropogenic fibre in white clams (*Meretrix lyrata*) collected in the Can Gio mangrove area for the entire clam tissues and for gills (G), digestive systems (D) and remaining tissues (R) calculated for (a) one clam individual, and (b) 1 g wet weight of tissues.

gills,  $0.8 \pm 0.9$  fibres individual<sup>-1</sup> in digestive systems, and  $1.9 \pm 1.4$  fibres individual<sup>-1</sup> in remaining tissues. Fibre concentration in remaining tissues presented a statistical difference to that in gills and digestive systems (Kruskal Wallis test,  $p < 0.05$ ). Over the entire survey, the tissue distribution can be summarised by 52% of fibres observed in remaining tissues, 26% observed in gills, and 22% in digestive systems (Fig. 5). The monthly average concentration varied from 0.6 to 1.5 fibres individual<sup>-1</sup> in gills, 0.5 to 1.6 fibres individual<sup>-1</sup> in digestive systems, and 0.9 to 3.3 fibres individual<sup>-1</sup> in remaining tissues (Fig. 4a). The

remaining tissues presented the highest monthly fibre counts (47% to 65%) compared to gills (16% to 35%) and digestive systems (15% to 29%), except in August where the highest fibre abundance was observed in gills (47%) rather than in remaining tissues (29%). For each tissue, there was no statistical difference in fibre concentration over the sampling months (Kruskal Wallis test,  $p > 0.05$ ).

In terms of 1 g wet weight of each tissue, gills presented a higher average fibre concentration over the whole survey with  $14.0 \pm 19.8$  fibres g<sup>-1</sup> followed by digestive systems with  $7.4 \pm 9.7$  fibres g<sup>-1</sup> and



**Fig. 5.** Partitioning of anthropogenic fibre abundance in gills (G), digestive systems (D) and remaining tissues (R) in white clam (*Meretrix lyrata*) collected in the Can Gio mangrove area for every month and for the entire survey.

remaining tissues with  $1.4 \pm 1.1$  fibres  $\text{g}^{-1}$ , with a significant statistical difference in fibre concentration per gram wet weight between the tissues (Kruskal Wallis test,  $p < 0.001$ ). Monthly, fibre concentrations in gills varied from a minimum of 3.3 fibres  $\text{g}^{-1}$  ww in October to a maximum of 42.7 fibres  $\text{g}^{-1}$  ww in August (Fig. 4b). In digestive systems, they varied from 3.7 fibres  $\text{g}^{-1}$  ww in April to 20.2 fibres  $\text{g}^{-1}$  ww in August. In contrast, fibre concentrations were stable in remaining tissues, from 0.5 to 2.3 fibres  $\text{g}^{-1}$  ww. For each tissue, the temporal variation of fibre concentration in 1 g did not present any statistical variation over the sampling months (Kruskal Wallis test,  $p > 0.05$ ).

### 3.3. Fibre length distribution

Within the observation size range [300–5000  $\mu\text{m}$ ], the median fibre length over the survey period was of 627  $\mu\text{m}$ . Fibres shorter than 1000  $\mu\text{m}$  represented nearly 70% of total fibres. Taking into consideration the temporal variation of fibre length, monthly median fibre length varied from 571  $\mu\text{m}$  in April to 667  $\mu\text{m}$  in March, and did not indicate any temporal statistical difference (Kruskal Wallis test,  $p > 0.05$ , Fig. 6a). Fibres longer than 2000  $\mu\text{m}$  or even up to 5000  $\mu\text{m}$  were also observed every month. Notably, beyond the observation size range, seven long fibres up to 11,000  $\mu\text{m}$  and many fibres shorter than 300  $\mu\text{m}$  were also recognised and not recorded in our results.

Over the survey period, considering fibre length in clam tissue, the median fibre length was 561  $\mu\text{m}$  in gills, 611  $\mu\text{m}$  in remaining tissues, and 775  $\mu\text{m}$  in digestive systems. No statistical difference in fibre lengths between tissues was observed (Kruskal Wallis test,  $p > 0.05$ , Fig. 6b).

### 3.4. Fibre colour partition

Over the survey period, colour partition of anthropogenic fibres showed a dominance of blue fibres (61%) followed by red (30%) and other colours including transparent, grey, and green (9%). Blue and red fibres were observed in all sampling months, blue fibres were observed in all pools, while red fibres were observed in 94% of all pools. Accordingly, monthly colour partition showed similar colour distribution over the survey period (Fig. 7).

## 4. Discussion

### 1. Level of contamination: comparison to other bivalve species

The presence of anthropogenic fibres in all clam pools and all sampling months confirms the contamination by anthropogenic fibres of white clams (*Meretrix lyrata*) reared in the Can Gio beach area. The

average concentration of fibres over the whole survey was  $3.6 \pm 2.1$  fibres individual $^{-1}$  or  $2.7 \pm 2.4$  fibres  $\text{g}^{-1}$  ww. This fibre concentration is at the same level of those previously observed in worldwide bivalve species (Phuong et al., 2019; Su et al., 2018; Narmatha Sathish et al., 2020; Gedik and Eryasar, 2020; Phuong et al., 2018). Microplastic concentrations were of 2.6 items individual $^{-1}$  or 0.29 items  $\text{g}^{-1}$  ww in green mussels (*Perna viridis*) collected in Central Vietnam (Phuong et al., 2019), 0.4–5.0 items individual $^{-1}$  or 0.3–4.9 items  $\text{g}^{-1}$  ww in Asian clams (*Corbicula fluminea*) from Taihu Lake, China (Su et al., 2018), 0.6–1.3 items  $\text{g}^{-1}$  ww in clams (*Donax cuneatus*) from the Tuticorin coast of the Gulf of Mannar, India (Narmatha Sathish et al., 2020), 0.69 items individual $^{-1}$  or 0.23 items  $\text{g}^{-1}$  ww in Mediterranean mussels (*Mytilus galloprovincialis*) (Gedik and Eryasar, 2020),  $0.61 \pm 0.56$  items individual $^{-1}$  in blue mussels (*Mytilus edulis*), and  $2.10 \pm 1.71$  items individual $^{-1}$  in the Pacific oyster (*Crassostrea gigas*) from the French Atlantic coast (Phuong et al., 2018). Notably, the differences of laboratory digestion protocols with or without density separation steps between the studies may lead to different extraction efficiency and thus to different concentrations measured in different studies. Moreover, the types and shapes of items considered, i.e. microplastics or anthropogenic fibres, and the differences of observation size range makes these comparisons even trickier.

### 4.2. Accumulation mechanism of anthropogenic fibres in Can Gio white clam tissue

The abundance of anthropogenic fibres in remaining tissues was more prevalent than in digestive systems and gills, over the entire survey as well as in most of the sampling months (Table 1 and Fig. 5). Accordingly, the remaining tissues owed the highest rate of anthropogenic fibres accumulation among all the clams' tissues analysed in this study.

Thus far, the gills and digestive system were observed as the most prevalent organs involved in the accumulation of microplastics by aquatic organisms (Su et al., 2019). The respiration, ingestion, digestion, and excretion processes play a crucial role in the accumulation of non-digestible particles including microplastics in the body of the organism. In the present study, anthropogenic fibres were more abundant in remaining tissues implying a supplementary process for fibre accumulation in the organisms. In mussels, the adherence of microplastics to soft tissues was evidenced as a novel way to uptake microplastics beyond ingestion (Kolandasamy et al., 2018). Based on the adherence mechanism, the fibres in the surrounding waters and benthic sediments adhere to the clam tissues. We presume that the adherence mechanism is also applicable to white clams, depending on the following factors: i) the

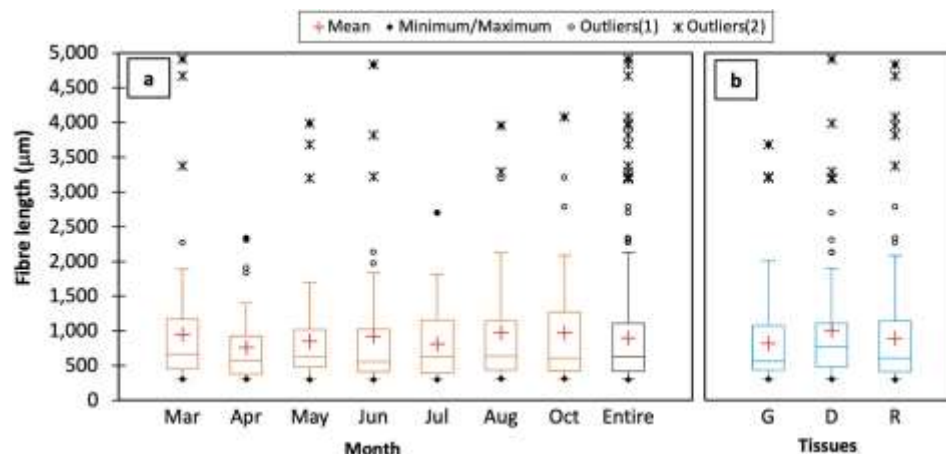


Fig. 6. Boxplots of anthropogenic fibre length observed in white clam (*Meretrix lyrata*) collected in the Can Gio mangrove area for (a) every month and the entire survey, (b) the clams' tissues including gills (G), digestive systems (D) and remaining tissues (R).

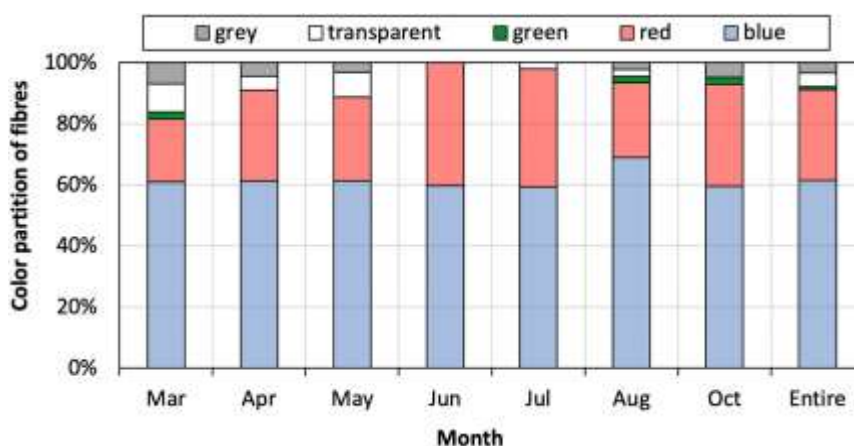


Fig. 7. Colour partition of anthropogenic fibres in white clam (*Meretrix lyrata*) collected in the Can Gio mangrove area for every month and for the entire survey.

concentration and vertical distribution of fibres in the sediment, ii) clam mobility in the sediment, and iii) dispersion of the fibres in the surrounding water due to the current and tidal regime, tropical climate conditions (rainfall and wind), and the variation of physico-chemical parameters in the environment. Upstream of HCMC and Saigon River, neither the hydrodynamics, monsoon climate conditions, nor the variation of physico-chemical parameters (pH, T, O<sub>2</sub>, conductivity, chlorophyll-alpha) affected the concentration of fibres in the surface water of the rivers (Strady et al., 2020). The change in rainfall regime, from dry to rainy season, and the change in wind direction did not influence concentrations measured in the atmospheric fallouts of HCMC (Truong et al., 2021). Therefore, we hypothesise that the tropical climate conditions and the tidal hydrodynamics do not influence the adherence of fibres in this environment; no temporal variation was observed affecting the ingestion of accumulated fibres (Figs. 4 and 5). A higher accumulation in the gills and digestive systems was observed in August but this did not correspond to any changes in environmental conditions that could support a higher accumulation. We thus hypothesise that a change in the microplastic sources to the surrounding environment could explain this observation. In the beach sediments of Da Nang, Central Vietnam, systematically higher fibre concentrations were measured in the upper sediment layer (0–5 cm) than in the lower one (5–10 cm) (Tran Nguyen et al., 2020). This pattern was also observed in the Bohai beach sediments (Yu et al., 2016) and in the Amazon macrotidal sandy beach sediments (Martinelli Filho and Monteiro, 2019). Therefore, the vertical distribution of fibres in the sediment, coupled with the clam burying mobility in the sediment up to a depth of 4–6 cm (Tran et al., 2009), might be important factors influencing the number of fibres that can be both ingested by clams or may adhere to their remaining tissues.

#### 4.3. Potential risk of anthropogenic fibres to human health via the ingestion of clams

As with many other bivalves, whole clams are consumed by humans, without the removal of the gastrointestinal tract. Fibres in clams are thus directly transferred to humans by ingestion leading to potential risks to human health.

The fibre ingestion by humans through clam consumption is estimated from the number of individual clams consumed in 2019 by one person and the average fibre concentrations measured in clams during this study. Our study was based on several hypotheses. First, we hypothesise that the consumption rate has not changed since 2010, as no data are available from 2011 to 2019, and that the average national clam mass consumption rate is 78%. These values were also derived from a national rate of clam consumption of 66,000 tons and total clam production of 85,000 tons (VNAD, 2011). Thus, with a clam production of

227,000 tons in 2019 (VCEN, 2020), the national clam consumption amount is estimated at 176,152 tons. Second, we hypothesise that the entire national population of all ages (96.48 million inhabitants; (GSO, 2019)) consume clams, which provides an estimated mass of clams consumed per person of 1.8 kg inhabitant<sup>-1</sup> yr<sup>-1</sup> in 2019. Third, we hypothesise that 1 kg of clams corresponds to roughly 50 individual clams. Fourth, we hypothesise that the average concentration of fibres per clam sold in the markets throughout the country in 2019 is similar to that found in this study, namely 3.6 fibres individual<sup>-1</sup>. Accordingly, the number of anthropogenic fibres ingested annually by one person from the ingestion of clams was estimated of about 324 fibres inhabitant<sup>-1</sup> yr<sup>-1</sup>. Once ingested, these fibres may release toxins into human body before being excreted after a certain time. Although studies on the toxicity of anthropogenic fibres to humans are still limited, the restriction of microplastics and anthropogenic fibres ingested by humans is necessary to beforehand prevent the potential health risks from fibre-related pollutants.

#### 4.4. Necessary measures to reduce accumulation of fibres in clams

Microplastics are mainly released into aquatic environments via wastewater (Liu et al., 2021). Therefore, the reduction of microplastic release from wastewater could be an initiative. In Vietnam, the domestic wastewater treatment rate is quite low and represents approximately 13% of urban wastewater (MONRE, 2018). For industrial wastewaters, the percentage of industrial zones with a centralised wastewater treatment system varies from 16% for the industrial zones with small and medium sized enterprises to 88% for those with large-sized enterprises (MONRE, 2018). The treatments used in Vietnamese wastewater treatment plants (WWTPs) are: primary treatments (e.g. grit chamber and primary sedimentation tank) and secondary treatments (e.g. activated sludge, trickling filters, moving bed bioreactors and aerated lagoons). Thus far, the retention of microplastics in Vietnamese WWTPs has not been studied. At a global level, microplastic retention was observed as 40%–99% after the grit chamber and primary sedimentation tank, from 29%–97% after sand filtration, from 8%–99% after the coagulation step, and from 17%–98% after the conventional activated sludge treatment (i. e. secondary sedimentation tank) (Bui et al., 2020). The variables measured by the researchers depend on internal parameters (duration, chemical parameters) set up at the WWTP, the type and size of microplastics observed to evaluate their retention, and the management of the WWTP. Thus, the increase of the wastewater treatment rate coupled with supporting research to evaluate the microplastic retention and adapt the technology to achieve the highest retention evaluation could help reduce the release of anthropogenic fibres into the environment.

Another major source of fibres is from fishing equipment (F. Wu et al., 2020; J. Wu et al., 2020). Since their first introduction to the



fishing equipment industry, synthetic or semisynthetic fibres are now the main materials used to produce fishing nets and ropes (Lusher et al., 2017). Owing to aquaculture and fishery activities, a large quantity of fishing equipment are left or lost in aquatic environments. Jang et al. (2014) estimated that more than 44,000 tons of fishing equipment is lost annually in the Korean Sea. In European waters, derelict fishing equipment was found to contribute to 33% of the total litter items (Pham et al., 2014). Zhang et al. (2021) reported a higher concentration of microplastic fibres in the surface waters of the marine culture areas as compared to other areas in Weihai, China. Fibres were also recognised as the predominant type of microplastic ingested by commercial oysters (*Ostrea denselamellosa*) and razor clams (*Sinonovacula constricta*) collected from the aquaculture sites at Xiangshan Bay, China (F. Wu et al., 2020). A laboratory analysis of microplastic release by the degradation of fishing nets recovered from the Venetian Lagoon was carried out by Montarsolo et al. (2018). The results showed that under the simulated marine environment, textile filament fishing nets released 64–750 fibres g<sup>-1</sup>. In the Can Gio mangrove area, aquaculture and fishing activities are important for the livelihood of residents. In other words, the existence of fishing equipment in the environment, which is being used or lost, is guaranteed. In particular, in the Can Thanh sand flats, the use of fishing nets to enclose the clam culture areas has been observed. This leads to the release of anthropogenic fibres into the aquatic environment due to the aquaculture and fishing activities in this area. This source of fibres could be reduced by the recovery of the lost fishing equipment.

Recently, the Ho Chi Minh City council promulgated the Decision No. 2626/QĐ-UBND dated the 7th July 2020 on the Action Plan for Marine Plastic Waste Management in Ho Chi Minh City (2020–2030). Among various tasks, the reduction of anthropogenic fibre pollution and its release into the aquatic environment is addressed by focusing on reducing microplastic discharge from wastewater, reducing plastic waste, and on recovering lost fishing equipment.

## 5. Conclusions

This study confirmed the contamination of white clams (*Meretrix lyrata*) cultivated in the Can Gio sand beach with anthropogenic fibres with an average concentration over a seven-month sampling campaign of  $3.6 \pm 2.1$  fibres individual<sup>-1</sup> or  $2.7 \pm 2.4$  fibres g<sup>-1</sup>. The accumulation of the fibres in clams does not seem through ingestion and respiration processes only but may also be from the adherence of the fibres to the clam tissues. Moreover, fibres shorter than 1000 µm were predominantly found in the clams. An estimation of the number of fibres ingested by each person per year from clam consumption was approximately 324 fibres inhabitant<sup>-1</sup> yr<sup>-1</sup>. To reduce fibre ingestion by humans, measures for reducing the release of fibres into the environment, especially from wastewater and fishing equipment.

## CRediT authorship contribution statement

**Thuy-Chung Kieu-Le:** Conceptualization, Investigation, Writing – original draft, Writing – review & editing. **Quoc-Viet Tran:** Investigation, Writing – review & editing. **Tran-Nguyen-Sang Truong:** Investigation, Writing – review & editing. **Emilie Strady:** Conceptualization, Writing – review & editing, Supervision.

## 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.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.marpolbul.2021.113302>.

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