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ARTICLE

Fishing Production and Fishing Changes in Hong Kong after the Ground Trawl Ban of 31st December 2012: A Geospatial Evaluation

Alastor M. Coleby[1*], Eric P.M. Grist[2*]

[1] *Environment and Resources Management, School of Continuing Education, Hong Kong Baptist University, Shek Mun, New Territories Hong Kong SAR, 999077,China*

[2] *College of Engineering, Mathematics & Physical Sciences, University of Exeter, Exeter, EX4 4PY, United Kingdom*

ABSTRACT

From data published by the Hong Kong SAR (HKSAR) government in their two sole fisheries surveys of 2006 and 2016/2017, the current authors produced regional maps using spatial interpolation to more accurately describe and estimate the geographic coverage of changes in fishing production in Hong Kong waters since the ground trawl ban of 2012 December 31st. These suggest the fishing industry has adapted to smaller craft, and that fishing production increased in several areas in the period after the ground trawl ban came into effect. In addition, the maps enable a smoother assessment to be made of the geospatial changes in fishing production which have occurred since the ground trawl ban and suggest a 'workaround' by fishermen. In particular, small fishing craft known as *sampans* are able to take advantage by being more suitable vessels for areas such as narrower or shallower bays. Marine plastics pollution is also a proxy indicator of these activities, as evidenced by discarded fishing gear that includes plastic nets, floats, and other fishing boat equipment.

Keywords: Fishing production; Commercial fishing; Marine plastics; Ground trawl ban

1. Introduction

The purpose of this paper is to investigate the potential impacts of the 2012 ground trawl ban by using a geostatistical analysis of published government fisheries data to compare fishing production intensities before and after the ban came into effect.

*CORRESPONDING AUTHOR:
Alastor M. Coleby, Environment and Resources Management, School of Continuing Education, Hong Kong Baptist University, Shek Mun, New Territories Hong Kong SAR, China; Email: a.m.coleby@gmail.com
Eric P.M. Grist, College of Engineering, Mathematics & Physical Sciences, University of Exeter, Exeter, EX4 4PY, United Kingdom; Email: epmgrist@gmail.com

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We quantify how fishing production and fishing have changed in the period between the two Hong Kong Government surveys of 2006 and 2016/2017. This is supported by additional photographic evidence from field observations of current fishing practices and discarded plastics fishing gear.

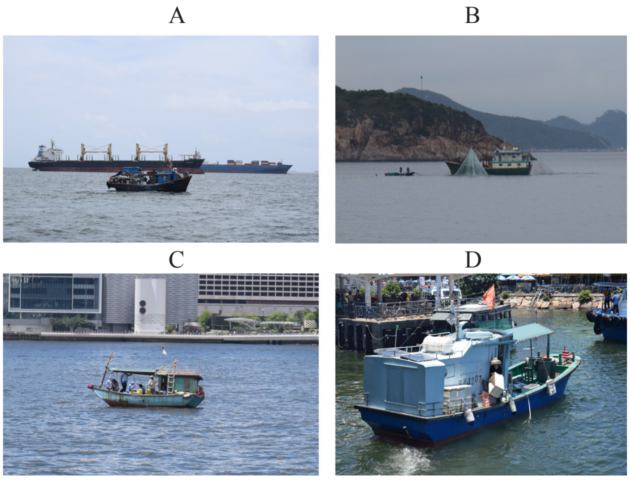

Figure 1. Field observations of recent fishing activities after the ground trawl ban of 31st December 2012 came into effect.

A. Fishing in the Lamma Channel West of Hong Kong Island: 22.24461N, 114.08899E June, 2020.

B. Banned Trawling Between Cheung Chau and Lantau Islands, Hong Kong 2020 at Northern Cheung Chau, 22.21594N, 114.03569E, June 2020.

C. Sampan Fishing in Victoria Harbour, Hong Kong at Hong Kong Island and the Southern Kowloon Peninsula: 22.29272N, 114.17226E, June 2020.

D. Polystyrene Foam Boxes Used in Local Sampan Fishing, Cheung Chau Island Public Pier, June 2020: 22.20798N, 114.02813E.

The Hong Kong Government has implemented a series of fisheries management measures for the conservation of marine resources and the promotion of sustainable development of the fishing industry. Alongside the prohibition of destructive fishing practices including a statutory ban on trawling in Hong Kong waters starting on 31 December 2012 (AFCD, 2022), other management measures were implemented, including the surveying and registration of local fishing vessels. Since the ground trawl ban, changes in fishing activity in Hong Kong have largely shifted from inshore and coastal trawling to line fishing by sampan (i.e., Class III vessels typically smaller than 15 m in length①) [1] as shown in **Figures 1A and 1D** alongside catches by shrimp boats, although trawling does continue in places. This may also be occurring unofficially as evidenced by these vessels turning off their navigational information transponders during nighttime trawls, which the authors have been able to confirm on shipping applications such as *ship-tracker*② [2] (see **Figure 1B**). Here, vessel monitoring system (VMS) technology has the potential to provide data as it has done for the offshore fleet but has yet to be applied in relation to inshore fishing [3]. Moreover, fisheries evaluation is made difficult by a scattered fishing effort, especially on large islands with remote fishing harbours [4], which is precisely the physical geography of the Hong Kong fisheries evaluated in this paper.

2. Geostatistical mapping of fishing production

We obtained spatial fisheries production data from the only two extensive Hong Kong Government surveys, which were performed in 2006 and 2016/2017, in which 720-hectare rectangular quadrat representative point sample values of fish caught were provided across the entire Hong Kong regional offshore region [5]. The survey sampling design employed a contiguous rectangular grid lattice with each grid rectangle covering 720 hectares and which covered the entire Hong Kong marine domain as defined in the Hong Kong Government Port Survey reports. We retained this grid in order to analyse the data consistently within all the generated maps. Both the Port Surveys of 2006 and 2016/2017 were conducted via interviews to collect information from local fishermen regarding their fishing operations and fisheries production. The sampling response covered the various types of local fishing vessels from different homeports and based on the information reported, the geographical distribution and levels of fishing operations and fisheries production were recorded.

These datasets were imported into a geostatisti-

① Hong Kong SAR 2013 Fisheries Homeport Interview Survey Findings [1].

② Marine Traffic [2].

cal model employing ordinary kriging to interpolate between the sample point locations and generate geospatial fishing production maps for the Hong Kong Special Administrative Region (HKSAR) marine domain from GADM [6]. Geostatistical models have previously been used by the authors to enable geospatial metrics of interest to be interpolated on a regional basis in a wide variety of contexts, ranging from epidemiology to marine plastics pollution in order to enhance data visualization and estimation accuracy [7-9]. Ordinary kriging③ is a widely employed spatial interpolative method that gives the best linear unbiased estimate of the quantity at any location [10], based on the data collected from sample sites [11] (and see **Appendix 1** to **3**).

Ordinary kriging was thus employed here to produce separate maps of estimated fishing production for the years 2006 and 2016/2017, namely before and after the ground trawl ban of 2012 as shown below in **Figure 2**.

In terms of fishing production from all vessel types, the map based on 2006 data shown in **Figure 2A**, clearly implies that the highest fishing intensities were centred around the fishing ports and communities located in the outlying islands west of Hong Kong at Cheung Chau, Peng Chau, southwestern Lantau and northeast Lantau adjacent Tsing Yi to the north-west of Hong Kong Island. To the north, on the mainland side of Hong Kong, the bays of Pan Long Wan, and Sai Kung, Plover Cove in the northeast, and Double Island adjacent to mainland China also showed higher fishing productivity. A comparison of this map with the corresponding map for 2016/2017 as shown in **Figure 2B**, distinguished by an overall bluer coloration, clearly shows that there was an overall decrease in regional production. However, the latter map also revealed that despite the overall decrease, some areas still experienced an increase in fisheries production. Although production decreased in designated key marine protected areas after the trawl ban came into effect, our maps suggest that fishing intensity elsewhere, especially from smaller vessels such as sampans, increased in several inshore areas, thus posing concomitant environmental impacts. This is verified by a direct comparison of **Figure 2C** with **Figure 2D** showing the respective productions for sampans in 2006 and 2016/2017.

These fishing production changes are more clearly shown by change-in-fishing-production maps, which are shown in **Figure 3**, and were obtained by taking the differences in production between the respective geospatial maps of **Figure 2**. In the maps of **Figure 3**, areas of increased fishing production are shown in red and appear most noticeably around Lantau-island in the south and the channels located between marine protected areas in the southern waters such as that between Cheng Chau and Lamma Island.

In the map shown in **Figure 3D**, for 2016/2017, showing production changes for sampans, we could see that the higher intensity areas (shown in red) in this map corresponded reasonably well with those of **Figure 3A**, for all vessel types. Taken together these imply that since the trawling ban of 2012, fishermen have adapted to smaller craft such as sampans with a shift of fishing zones into the above areas and moreover with continuing widespread fish catches.

In particular, our sampan production change map shows clearly that sampan fishing increased in the period from 2006 to 2016/2017. This can be seen by the red colouration that represents increases mapped around Lantau Island and Cheung Chau in the southwest and Cape De Aguilar in the southeast, some of these overlapping with marine protected areas. These increases are also particularly apparent in the northeastern bays and inlets of Hong Kong waters around Hong Kong's New Territories adjacent to Plover Cover and Grass Island. This is further reinforced in the southern areas by the fact that they hold large community ports for the smaller Hong Kong fishing vessels (sampans) and indeed some of the larger ocean-going trawlers, for example shrimp boats that can also be seen fishing in southern waters. **Tables 1 and 2** below summarize quantitatively the estimated fish production and changes for all vessel types

③ Kriging is a multistep process; it includes exploratory statistical analysis of the data, variogram modeling, creating the surface, and exploring a variance surface [10].

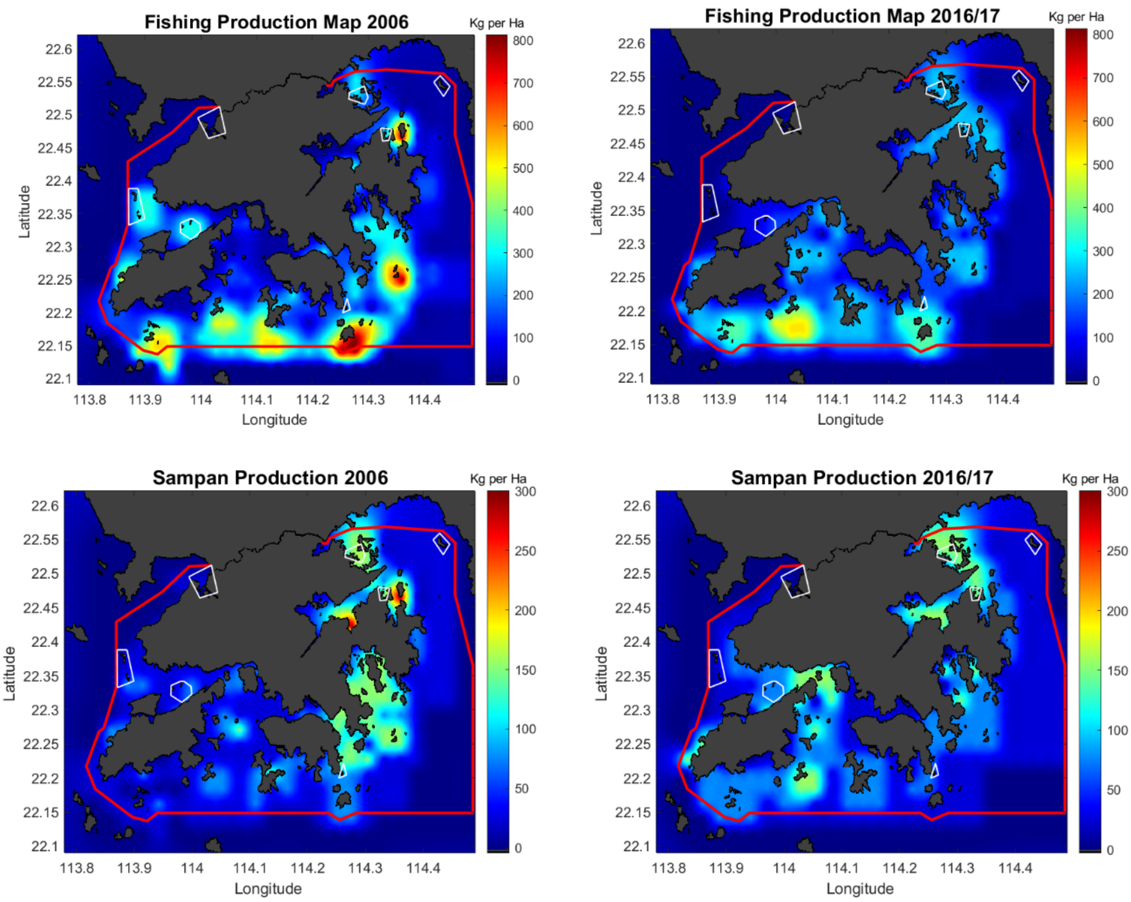

Figure 2. Fishing production maps for all vessel types and sampans in Hong Kong water, shown in kg per hectare by the colour scale on the right of each map. Maps were derived by geostatistical interpolation with ordinary kriging from data collected by the Port Surveys of 2006 and 2016/2017 [5]. Marine protected areas are highlighted (white boundary lines) and the HKSAR maritime boundary is superimposed (solid red). Scale 1:500000.

A. (Top left). Fishing Production from all vessel types in Hong Kong 2006, (scale 0 to 800 kg per hectare),

B. (Top right). Fishing Production from all vessel types in Hong Kong 2016/2017, (scale 0 to 800 kg per hectare).

C. (Bottom left). Fishing Production from sampan small boat fishing in Hong Kong 2006, (scale 0 to 300 kg per hectare).

D. (Bottom right). Fishing Production from sampan small boat fishing in Hong Kong 2016/2017, (scale 0 to 300 kg per hectare).

compared with sampans based on data for the two HKSAR surveys in 2006 and 2016/2017.

The fishing change maps of **Figures 2 and 3**, thus present a novel data visualization of the HKSAR government fishing surveys of 2006 and 2016/2017 for identifying changes in fisheries production.

Table 1, shown above summarizes the raw data based on 720-hectare quadrat tonnage, whilst **Table 2**, summarizes fishing production based on the interpolated data pixel tonnage, obtained from kriged values extracted from the maps in **Figure 2**. It can be seen that the kriged estimates in **Table 2**, are consistently below those estimated from raw data in **Table 1**, due to statistical smoothing from kriging interpolation and restriction to map values lying strictly within the HKSAR maritime boundary limits. Based on the raw data extracted from the HKSAR surveys, **Table 1**, thus shows that sampan fishing as measured in 2016/2017 had indeed increased after 2006 in terms of the regional area fished (measured in 720-hectare quadrats) and in fishing production tonnage of fish landed. Specifically, the number of quadrats fished by sampans increased by 11% while the estimated tonnage of fish they landed increased by 16% (1,980 tonnes). These values contrast markedly when compared with the fishing changes recorded for all vessel

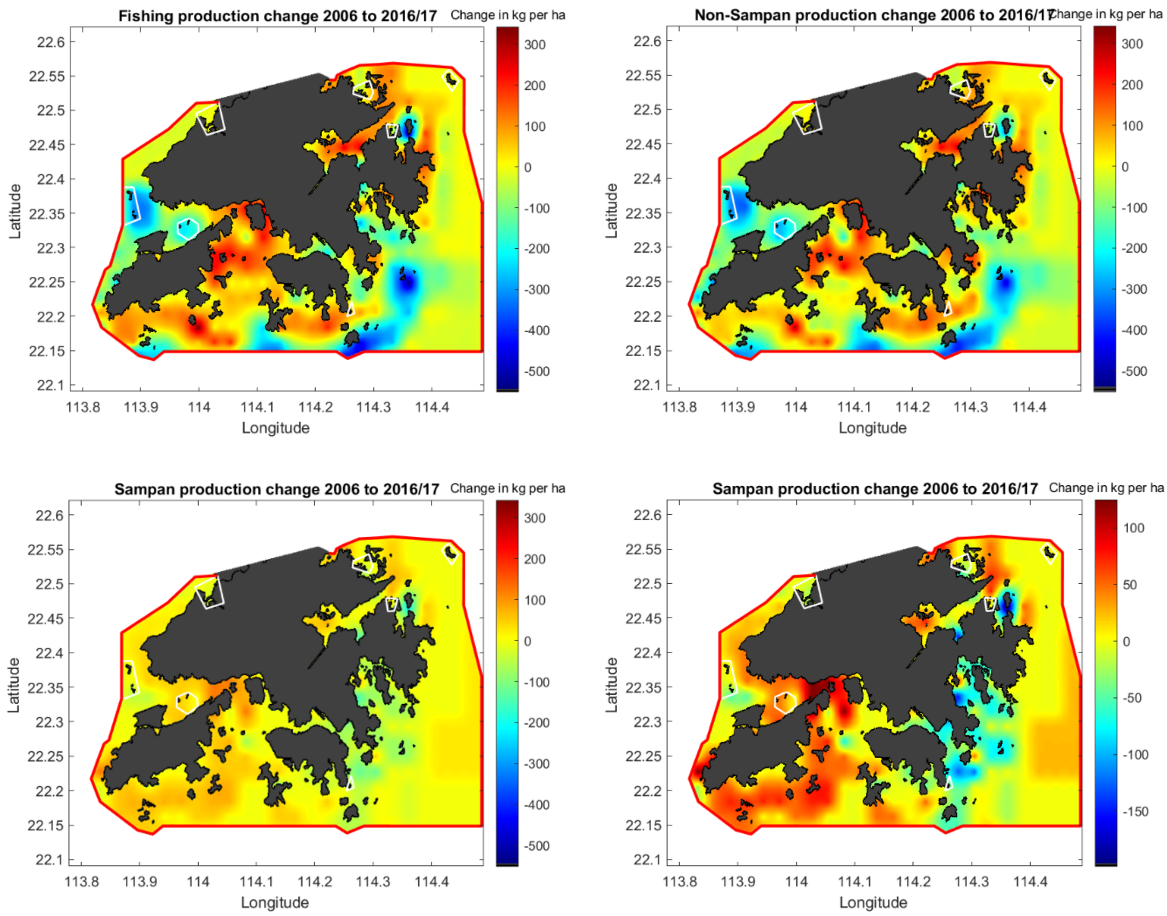

Figure 3. Comparison of change in fishing production [kg per hectare] for all vessel types, non-Sampans, and Sampans within the HKSAR maritime region (solid red line) for the survey periods of 2006 and 2016/2017. Marine protected areas are superimposed (solid white lines). Scale 1:500000.

A. (Top left). Overall fishing production change based on catch taken from all vessel types.

B. (Top right). Fishing production change based on catch taken from vessels other than sampans.

C. (Bottom left). Fishing production change based on catch taken from sampans.

D. (Bottom right). Fishing production change in C, with rescaled colouring for greater contrast.

Table 1. Estimated fishing production changes in the Hong Kong maritime region occurring in the period between 2006 and 2016/2017 based on the HKSAR surveys raw data (summarized from Appendix 4, Tables A1 to A4).

Estimated Fishing Change between surveys	Number of quadrats fished			Total fishing production (tonnes)		
	2006	2016/17	% Change	2006	2016/17	% Change
All vessels	313	291	–7.02	36,504	30,744	–15.77
Sampans	267	296	10.86	10,980	12,960	15.57
Sampans production proportion %	-	-	-	30.80	41.28	-

Table 2. Estimated fishing production changes strictly within the HKSAR maritime boundary in the period between 2006 and 2016/2017 based on the spatial interpolative fishing production change maps of Figure 2.

Estimated Fishing Change	Total fishing production (tonnes)		
vessel type	2006	2016/2017	% Change
All	27,969	21,479	–23.20
Sampans	7,016	8,381	19.46
% Sampans/All	25.08	39.02	

types, which respectively *decreased* by 7% in terms of the area fished and 16% (5,760 tonnes) in terms of their production tonnage.

Table 2, further provides more accurate estimates from kriging for fishing production, which concur with the directional changes (increase/decrease) observed for each respective **Table 1** quantity, but also suggest that the respective production changes are greater. In particular, from 2006 to 2016/2017 the production from all vessel types decreased by 23% (by 6,490 tonnes) while sampan production increased by 19% (by 1,365 tonnes) thereby rising from 25% to 39% of the respective total fishing production in each measured year.

Figure 4 below provides a further visualization of these datasets, here in terms of empirical distributions. These plots show estimated production changes based on the pixel value counts, where a pixel is defined as the unit square of area 1.2554 hectares (ha) at the GADM [6] map resolution, determined for each map of **Figure 3**. They again exhibit the overall increase in production for sampans (see **Figure 4B**) in contrast with the overall decrease for all vessel types (see **Figure 4A**) through histograms of pixel counts extracted from the respective geospatial fishing production maps of **Figure 3**. The histogram bars are shaded green (or yellow) for positive (or negative) contributions with the respective cumulative distributions achieved by summation of these bars shown in **Figures 4C and 4D**. These latter graph areas are shaded red (or black) to indicate a negative (or positive) cumulative production value. For sampans the

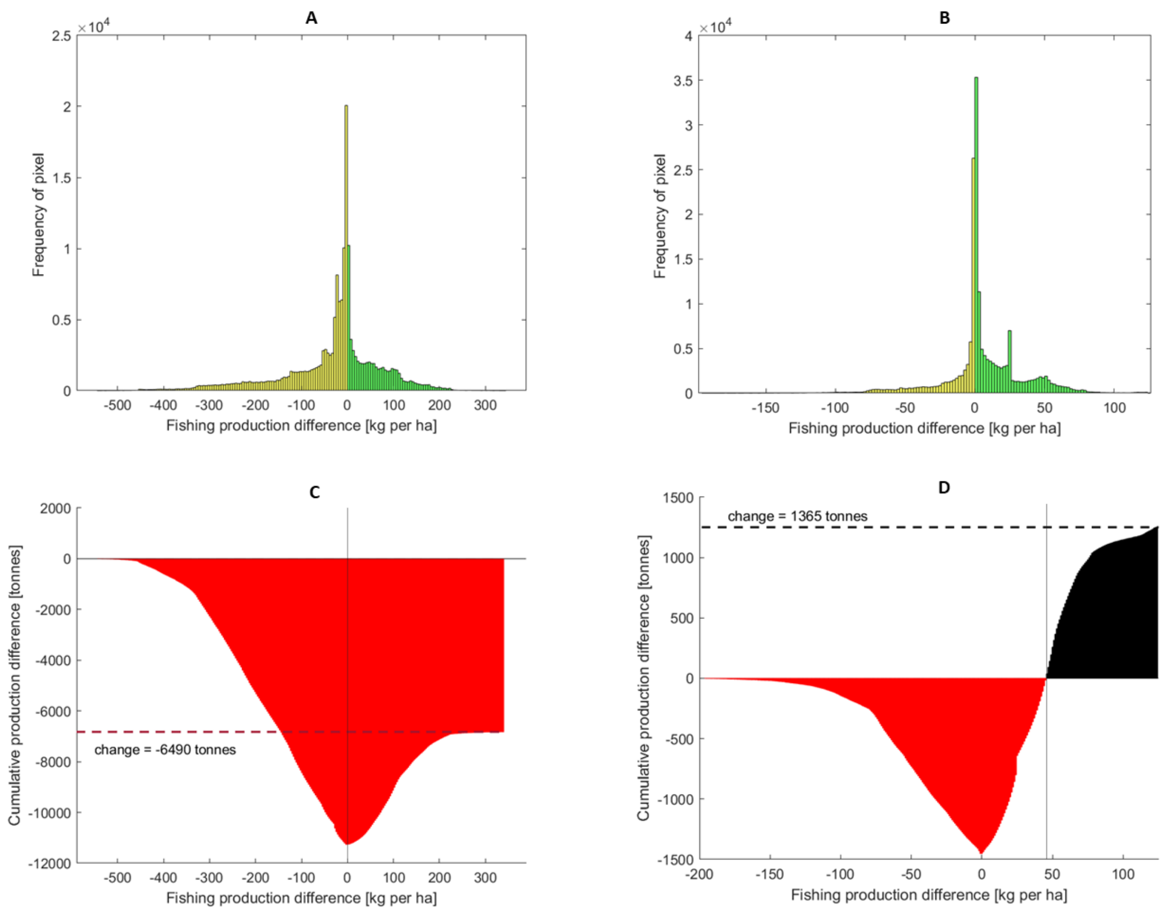

Figure 4. Estimated fishing production changes in the period 2006 to 2016/2017 strictly within the HKSAR maritime boundary. The plots compare sampans catch tonnage (B and D) with tonnage from all vessel types (A and C) based on distributions of pixel value frequencies in the interpolative maps obtained with kriging of Figure 3. In (A and B) histogram bars are shaded green (yellow) indicating positive (negative) contributions, in (C and D) cumulative total production plot areas are shaded black (red) indicating positive (negative) cumulative totals across the kriged map surface. Fishing production from sampans increased by 1365 tonnes, while all vessel types decreased by 6490 tonnes.

overall production increase is clearly seen by the cumulative curve rising above zero into the black, whilst that for all vessel types always remains well within the red.

These changes in fishing production and fishing practice are supported by the observed presence of shrimp boats in large numbers in the southern waters, perhaps replacing the heavier catches of the ground trawlers banned locally in 2012. **Table 3** below also shows that the number of fishing sampans jumped most markedly by 402 vessels in 2013 from 2012 (402 = 1604–1184) immediately after the ground trawl ban came into effect and continued to increase, reaching a peak number of 1,997 vessels in 2015, but decreasing only slightly in 2016 when the second port survey was undertaken. Likewise, outboard open sampan fishing boats were at their peak in 2012 at 2,835 vessels which had only decreased slightly to 2,617 boats by the time of 2016/2017 port survey. Notably since the 2012 ground trawl ban, all other fishing vessels had decreased from their peak of 2,208 in 2011 to 1,997 by 2016. These datasets, extracted from the Hong Kong Marine Department's data on licensed vessels therefore provide further evidence of a shift towards inshore sampan fishing activity since the ground trawl ban took effect.

3. Field observations of sampan fishing boat activity and plastics gear

We conducted field observations of selected outlying islands, coastal and inner harbour sites of the Hong Kong marine area. The sites were selected on the basis of their proximity to sampan fishing activity with the locations selected for scoping environmental impact at a central point between Hong Kong's marine parks, reserves, protected, and priority areas④ [13], such as those of south-east Lamma and Lantau Islands. On a regional basis these locations are in the environs where the ground trawl ban would be expected to have the most impact. The locations of these sites are shown in the regional map of Hong Kong in **Figure 5** below.

Table 3. Relevant types and estimated numbers of local fishing vessels by 2017.

Class III	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
Fish Carrier	2	2	3	19	21	17	23	25	26	31
Fishing Sampan	911	859	865	846	922	1184	1604	1958	1997	1982
Fishing Vessel	1922	1791	2122	2126	2208	2166	2137	2003	2030	1997
Outboard Open Sampan	2654	2550	2559	2580	2698	2835	2772	2613	2575	2621
Total	5489	5202	5549	5571	5849	6202	6536	6599	6628	6631

Figure 5. Map of Hong Kong Selected Site locations.

Source. GeoInfo Map [14], URL: https://www.map.gov.hk/gm/ Scale 1: 200000.

④ Marine Protected Areas in Hong Kong [13].

The results of this visual plastics survey are summarized qualitatively in **Table 4** below and shown with two typical sample photos of our field observations.

We found that the types of plastic debris identified could almost always be associated with sampan fishing activity and included: Plastic Fishing Line, Plastic Fishing Nets, Plastic Fishing Net Floats (see **Figure 6D**), Polystyrene Boxes and floats (a significant source of local microplastics pollution—**Figures 6C and 6B**), Polypropylene Rope, Plastic Fuel or Water Drums, and Discarded Plastic Bottles.

Thus, it could be verified through field observation that plastic-based fisheries equipment is used not only for netting materials, but also for traps, floats, dredges and lines, as well as for boat construction and maintenance, fish hold insulation and fish crates. Containers made with polystyrene foam in Hong Kong as elsewhere are ubiquitous because they are cheap, lightweight and water and thermal resistant [15,8]. Although at a global scale, fishing gear is estimated to compose less than 10% of total marine debris by volume [16], the degree of plastic fishing gear occurrence can be highly variable at smaller spatial scales when based on locality [17]. The impacts of marine debris (also known as *abandoned, lost or otherwise discarded fishing gear* (ALDFG), see **Figures 6B, 6C, and 6D**) derived from fisheries are particularly concerning in remote areas of Hong Kong and outlying islands, such as seen on Cheung Chau and Peng Chau coastlines as exhibited in **Table 4** and **Figure 6**.

Table 4. Typical sampan fishing plastics found washed up on Hong Kong Beaches.

<table>
<tr><td colspan="3">
Typical Fishing Boat Discarded Plastics* Found on Hong Kong Beaches 10th of June 2020</td><td colspan="2">
Sampan With Plastic Fishing Gear Types 28 March 2022</td></tr>
<tr><td>Type</td><td>Plastic Fishing Line</td><td>Plastic Fishing Nets</td><td>Plastic Fishing Net Floats</td><td>Plastic Buckets</td></tr>
<tr><td>Condition</td><td>Whole or in part</td><td>Broken or Discards</td><td>Broken or still attached to Nets</td><td>Whole or in fragments</td></tr>
<tr><td>Type</td><td>*Polystyrene Boxes</td><td>*Polypropylene Rope</td><td>Plastic Fuel or Water Drums</td><td>*Discarded Plastic Bottles</td></tr>
<tr><td>Condition</td><td>Whole, broken usually as microplastics</td><td>Whole or in pieces</td><td>Whole or in fragments</td><td>Bottles and or bottle-caps, and microplastics</td></tr>
<tr><td>Type</td><td>*Polystyrene Floats</td><td colspan="3" rowspan="2"></td></tr>
<tr><td>Condition</td><td>Whole, broken usually as microplastics</td></tr>
</table>

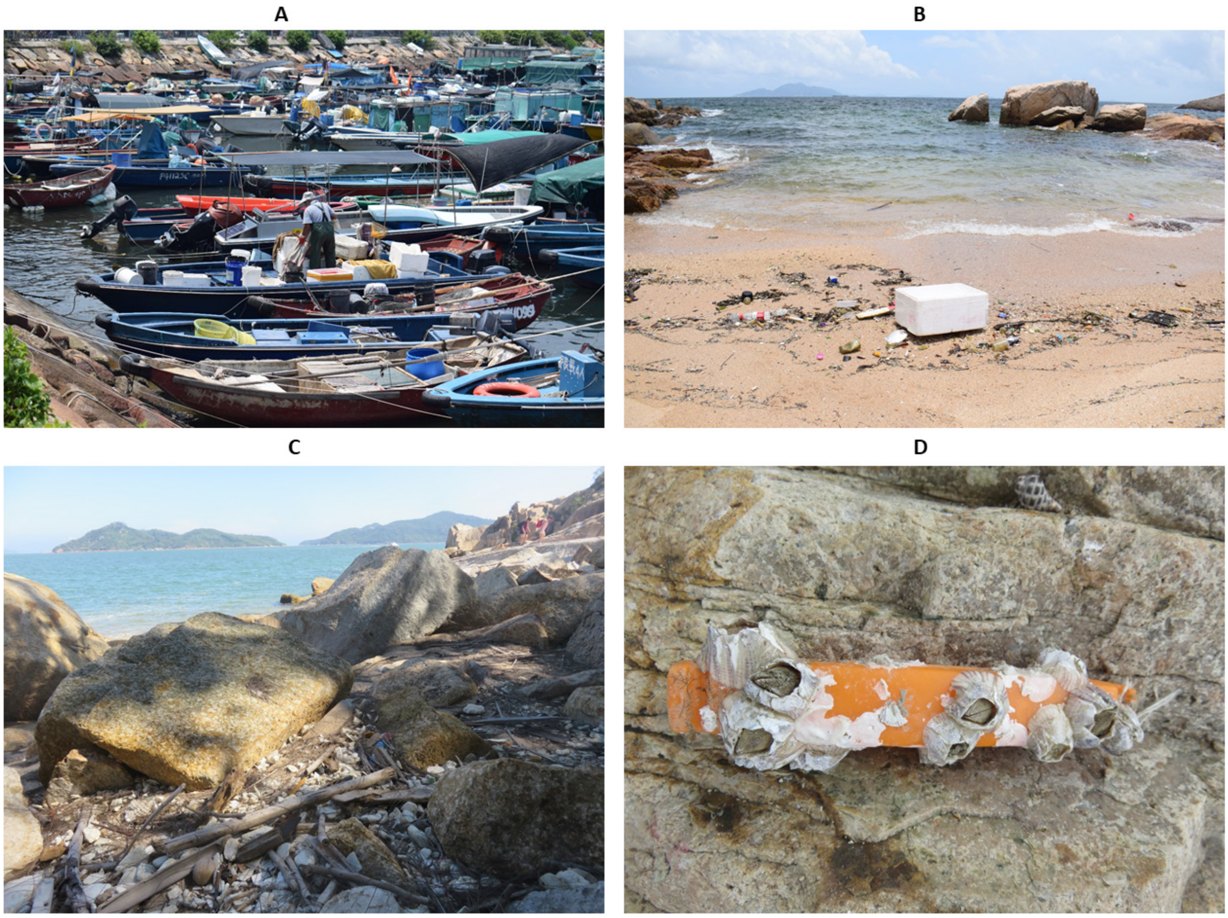

Figure 6. A. Sampans with Polystyrene Foam Boxes and Floats at Cheung Chau Island Harbour, August 2020: 22.21014N, 114.02827E. B. Discarded Polystyrene Foam Box and Microplastics Pollution at Nam Tam Bay, Southern Cheung Chau Island, September 2020: 22.20342N, 114.03379E. C. Polystyrene Foam Box Breakup Pollution, a cause of microplastics pollution, South-eastern Peng Chau Island, May 2018: 22.2836N, 114.04709E. D. Barnacles attached to plastic fishing net float at South-eastern Peng Chau Island, April 2018: 22.28105N, 114.04523E. Typically, in most transects of marine plastics described elsewhere, negative MP gradients were observed from nearshore to offshore, which showed that coastal fishing, alongside tourism, and rivers were the main sources of marine plastics in inshore coastlines [18].

4. Discussion

The fishing production and fishing change map produced in this paper from HKSAR government fishery survey raw data, provide a handle on assessing the possible impacts of the 2012 ground trawl ban. They highlight two key findings:

(1) fishing production by all vessel types had dropped by 2016/2017, meaning there were overall fewer areas being fished than in 2006 and overall fishing production also decreased.

(2) fishing production by sampans had increased by 2016/2017 and the number of areas being fished similarly increased.

These results are consistent with our hypothesis that by adapting to smaller fishing vessels (sampans), fishing production and by implication the environmental impact from discarded plastics emanating from these vessels probably increased after the 2012 ground trawl ban. These changes in fishing production were evidenced in the fishing production changes maps shown in **Figure 3**, which demonstrate that fishing production intensified markedly in some areas after the ground trawl ban came into effect. From this, it could be speculated that sampans were taking advantage of the situation as more suitable vessels for those areas (e.g., narrower, shallower bays) which is also supported by the greater plastics pollution likely from their activities resulting from increases in inshore fishing.

Whilst land-based sources of marine plastic pollution continue to gain attention, such marine-based sources are to date much less investigated [19]. The widespread incidence of *abandoned, lost or otherwise discarded fishing gear (ALDFG)* in Hong Kong calls for further investigation. Moreover, fisheries evaluation is made difficult by scattered fishing effort [4] that occurs around the Hong Kong outlying islands and remote fishing harbours often adjacent to marine protected areas. Despite laws⑤⑥ [20,21] that regulate discarding waste at sea, our field observations show that in outlying areas this legislation is not having the desired outcome. Research on fishing activity plastics in similar areas found that litter was predominantly plastic (87%) and mostly associated with fishing/boating (34%) [22]. Thus robust, quantifiable evidence of spatial and temporal patterns of inshore fishing activity is urgently required to assist management in the face of a growing number of designations of marine protected areas (MPA) [3].

Attributing plastics pollution to sources beyond empirical observations remains challenging and often contested among marine stakeholders and indeed fisheries researchers. In this context there has been increasing recognition of the need to address adverse ecological and socioeconomic effects of ALDFG particularly in urbanized coastlines⑦ [23-25] such as those of Hong Kong. Quantifying beach plastic litter worldwide through field surveys is also complicated, as plastic debris littered on inaccessible beaches might be excluded [26]. Studies of similar fishing areas in East Asia, such as those of Korea have found that operations accounted for 98.4% of the seabed litter by use, while non-fishing operations represented 1.6%. Even taking into account seasonal changes, the proportion of seabed litter from fishing operations in spring was 97.8% while that for autumn was 99.2% [27].

⑤ Hong Kong Government 1980. Dumping at Sea Ordinance (Cap. 466) 1995. Provides for control on marine dumping, and for connected purposes [20].

⑥ Hong Kong Government 1933. Summary Offences Ordinance (Cap.228) 1933: Contains provisions related to littering offences including marine littering [21].

⑦ Environmental Investigation Agency Report, April 2020 [23].

5. Conclusions

Although at the time of writing, the 2012 ground trawl ban in Hong Kong has been in effect for a decade, fishing especially from smaller boats such as sampans, remains widespread in several inshore areas. In terms of fishing catch our geostatistical maps show the highest concentrations were centred around the fishing ports and communities located in the outlying islands of Cheung Chau, Peng Chau, southwestern Lantau and northeast Lantau adjacent to Tsing Yi. Our field observations show that these local fishing communities who have their socio-economic needs met by the marine ecology appear to be lacking in commitment to conserving the very ecosystem that provides for their needs. Thus, the environmental impacts of plastics from equipment and containers used on fishing boats continue to compound the social and marine conservation challenges of widespread plastics pollution. The continuing impacts of this activity will include disturbance to the benthic and pelagic ecosystems the ground trawl ban was intended to restore. Fishery resources in Hong Kong are entirely open-access with virtually no management, except in limited areas of between 2 and 5% designated as marine parks and reserves (although fishing other than trawling, continues in marine parks under license) [28]. At the time of writing, more conventional fishery data and analytical tools are urgently required for future management alongside environmental monitoring of regular fishery activity.

6. Addressing the issues through stakeholder engagement

Because of ongoing data deficiencies on the impact of commercial fishing in Hong Kong, as of 2022 an independent fishing survey protocol by Hong Kong SAR's *Agriculture, Fisheries and Conservation Department* (AFCD) will establish a Standard Protocol for fishing surveys. This will provide data that are independent of reported catches by fishermen themselves, and establish a standard scientific protocol for the purpose of marine fishing regulation and sharing of fisheries data in Hong Kong waters [29]. Moreover, such sharing of data alongside fishing regulation may go some way to addressing the problem of marine plastics pollution and their ecological impact in this region and inform stakeholder engagement with the fishing industry and the wider marine sector. In the 2022/2023 policy address, the Hong Kong Government highlighted the importance of setting up a *"Holistic Nature Conservation Policy"* bringing together conservation and development, rather than treating them as competing goals. This policy aligned with China's 14th Five-Year Plan, Greater Bay Area Policy Areas, and the current draft of the Post-2020 Global Biodiversity Framework [30]. In response, the Worldwide Wildlife Fund [31] has called on policymakers to "…*strengthen measures to eradicate illegal fishing, including stronger collaboration between government agencies, cross-boundary collaboration with mainland China*".

In addition, to enhance fisheries management, this should include developing an Automated Identification System (AIS) to monitor fishing activities within Hong Kong and across the mainland maritime boundary. This would establish a reporting system to not only address the uncertainties in changing fisheries activity, but also address their environmental impacts. Moreover, because currently as of 2023, only 5% of Hong Kong's waters are designated as MPAs, conservationists have called for these to undergo a science-based planning exercise to include no-take reserves, Fisheries Protection Areas (FPA)s, species-specific conservation zones, community-based fisheries reserves, and other MPA designations [31]. Under the Hong Kong Government's proposed Holistic Nature Conservation Policy, the WWF as cited above, has thus recommended a joint stakeholder and environmental management plan to be implemented in all MPAs and proposed FPAs to conserve the marine ecology. We concur that this should consist of appropriate zoning and practices, including strict no-take zones and enforcing sustainable fishery practices. That would likely include controls on fishing gear discards and other plastics in a wider improved fisheries management.

Author Contributions

Alastor M. Coleby: Conceptualization, Data curation, Photography, Validation, Writing-original draft, review and editing. Eric P.M. Grist: Conceptualization, Data curation and visualization, Statistics, Modelling, Validation, writing-review and editing.

Conflict of Interest

There is no conflict of interest.

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Appendix

1. Kriging and variogram model specification

We employed ordinary kriging to generate all maps using a fitted exponential model variogram:

$$\gamma(h) = c\left[1 - exp\left(-\frac{h}{a}\right)\right] \tag{A1}$$

where *γ(h)* is the semi-variance, *h* is the lag distance and *c* (the 'sill') and *a* ('the range') are the constants determined for the given data set, here by using the *Nelder-Mead simplex* direct search method [32]. The choice of exponential variogram model provided the best fit to the empirical variogram data in all cases and as an unbounded model also verified isotropy and strong spatial autocorrelation in the data by demonstrating the achievement of the sill within a finite range, as exhibited in the accompanying variogram plots below. All maps and calculations were performed using MATLAB software [33].

2. Variogram plots

The assumptions of stationarity and isotropy underlying ordinary kriging are verified by inspecting the empirical variogram and checking this is bounded by the achievement of a sill at a finite range, which is confirmed in all the variograms generated and fitted with the exponential model shown here in **Figure A1**. This shows respective empirical variograms with n = 50 bins, (black squares) with a fitted exponential model (solid red line) and the sill that is converged to (dashed blue line) corresponding to each of the fishing production maps of **Figure 2**, generated from survey data for: (top left) all vessels 2006; (top right) all vessels 2016/2017; (bottom left) sampans 2006; (bottom right) sampans 2016/2017.

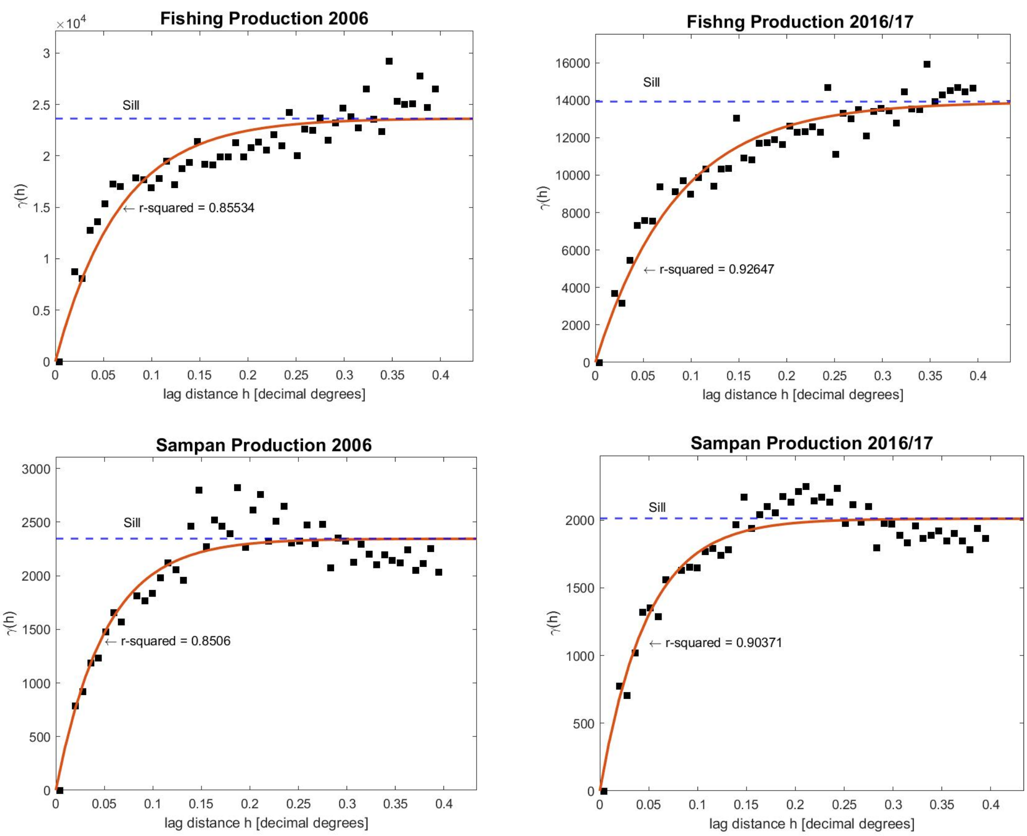

Figure A1. Variogram plots (black squares) with the fitted exponential model (red line) showing convergence to a sill (blue dotted line) and r-squared coefficient of determination values reflecting good fits to the data, corresponding to the maps in Figure 2, for: (top left) all vessels 2006; (top right) all vessels 2016/2017; (bottom left) sampans 2006; (bottom right) sampans 2016/2017. The lag distance *h* is shown in decimal degrees which at the latitude of Hong Kong can be taken to be approximately equidistant for longitude, and hence fixed as a unit of distance, with 0.1 decimal degree ≈ 10 km.

3. Kriging variance (as a measure of map reliability)

The plot of kriging variance shown in Figure A2 below illustrates that interpolation error with these data is dominated by the sampling design of the grid lattice (black dots), so is influenced effectively only through spatial sampling location information, which is fixed and therefore structurally identical for all of the survey data sets. As the spatial autocorrelation with all these data sets is strong, as demonstrated in the variogram plots in Section 3 above, this is the most suitable measure for reporting interpolation error and therefore overall reliability of the estimated map [34]. This map also demonstrates that the lowest kriging variance values, as indicated by blue, lie within the maritime boundary (red line), supporting the greater accuracy of smoothed estimations obtained from those data locations.

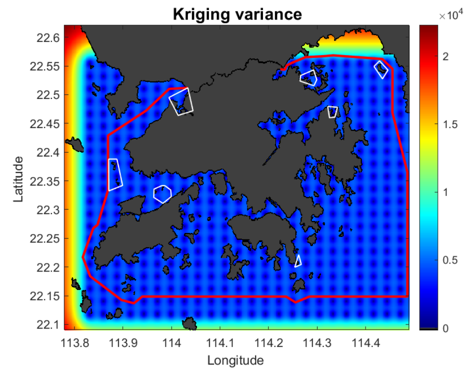

Figure A2. Kriging variance derived for the fish production survey data from all vessels in 2006. The spatial structure is identical for the other 3 data sets due to the fixed sampling design of a 720-hectare grid lattice used throughout. Scale 1:500000.

4. Tables A1 to A4

Estimated fishing production based on the mean range values of 720-hectare quadrats extracted from the HKSAR fishery surveys raw data of 2006 and 2016/2017.

Table A1. All vessels 2006.

Estimated fishing production 2006 (all vessel types)							
Quadrat mean production (kg/ha)	25	75	150	300	500	800	Total
Quadrat mean production (tonnes/quadrat)	18	54	108	216	360	576	-
Number of quadrats fished	100	48	80	57	23	5	313
Total fishing production (tonnes)	1800	2592	8640	12312	8280	2880	36,504

Table A2. All vessels 2016/2017.

Estimated fishing production 2016/2017 (all vessel types)							
Quadrat mean production (kg/ha)	25	75	150	250	350	500	Total
Quadrat mean production (tonnes/quadrat)	18	54	108	180	252	360	-
Number of quadrats fished	83	39	72	78	14	5	291
Total fishing production (tonnes)	1494	2106	7776	14040	3528	1800	30,744

Table A3. Sampans 2006.

Estimated fishing production 2006 (sampans)							
Quadrat mean production (kg/ha)	25	75	150	300	500	800	Total
Quadrat mean production (tonnes/quadrat)	18	54	108	216	360	576	-
Number of quadrats fished	166	58	41	2	0	0	267
Total fishing production (tonnes)	2988	3132	4428	432	0	0	10,980

Table A4. Sampans 2016/2017.

Estimated fishing production 2016/2017 (sampans)							
Quadrat mean production (kg/ha)	25	75	150	250	350	500	Total
Quadrat mean production (tonnes/quadrat)	18	54	108	180	252	360	-
Number of quadrats fished	147	112	37	0	0	0	296
Total fishing production (tonnes)	2646	6048	3996	0	0	0	12,690