Report on the Relationships between Sargassum Events, Oceanic Variables, and Dolphinfish and Flyingfish Fisheries

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Cover photographs: Top: sargassum stranded along the east coast of Barbados. Bottom left: flyingfish catch from an iceboat. Bottom right: offloading dolphinfish at the Oistins jetty. Courtesy of Hazel A. Oxenford.

Abstract

The fisheries sector of the Eastern Caribbean is an integral component of the culture, economy and food security of this region. However, in recent times its vulnerability to climate variability and change has become very apparent. Unprecedented influxes of sargassum is one of the latest climate-related impacts on the fishery sector. As such, a 'sargassum subproject' was approved within the FAO/GEF Climate Change Adaptation in the Eastern Caribbean Fisheries Sector (CC4FISH) project to investigate the relationships between sargassum influxes and key fishery species. Here we attempt to unravel the relationships between sargassum abundance, fishery landings data and the behaviour of dolphinfish and flyingfish to inform future policy and management decisions in the fishery sector and develop adaptive response measures.

Although the two key species, dolphinfish and flyingfish, are caught together in the multi-species, multi-gear pelagic fisheries of the region, and both are essentially open ocean, pelagic, short-lived (annual) species, the mass sargassum influxes have affected the fishery landings of these two species quite differently, as a result of their different behavioural traits and the different methods of capture used by the fisheries. Since the onset of sargassum influxes to this region, dolphinfish landed weight has declined in Barbados, whilst increasing slightly or remaining stable in other states. Since dolphinfish abundance, as indicated by catch per unit of fishing effort (CPUE), appears to be relatively stable, a change in landings may reflect a change in number of fishing trips precipitated by a significant change in the profitability of fishing trips that rely on capture of both flyingfish and dolphinfish. The season of availability of the highly migratory dolphinfish has also changed. Very small fish are now available throughout much of the summer in association with sargassum, and the customary high abundance of larger fish in March and April has declined significantly, possibly as a result of a change in migratory behaviour precipitated by the sargassum. In contrast to dolphinfish, flyingfish landings have plummeted during periods of high sargassum abundance due to a significant decrease in their catchability using the traditional fishing techniques, likely exacerbated by reduced fishing effort (number of trips) because of lack of profit. Flyingfish appear to be using sargassum as spawning substrate and are therefore no longer attracted to the floating FADs used by the traditional fishery. There is no evidence that either the dolphinfish or flyingfish populations are being damaged by the sargassum.

Implications for future policy and management of the pelagic fishery include the need to assist the sector in adapting to the reality of continued sargassum influxes into the region. This could include developing new fishing techniques to increase catchability of flyingfish in the presence of sargassum, improving the efficiency of fishing vessels to increase the profit margin of fishing trips, and targeting alternative species that have become available to the fishery as a result of their association with sargassum. A precautionary approach should also be adopted to prevent negative impacts associated with a harvest focus on immature individuals.

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Contents

1. Introduction

1.1. Context of the study

The fisheries sector of eastern Caribbean small island developing states (SIDS) is critically important for livelihoods, income, food security and poverty reduction. It is also highly vulnerable to climate change and climate variability (Monnereau et al. 2015, Oxenford and Monnereau 2018), especially from more frequent Category 4 and 5 hurricanes, chronic sea level rise, ocean acidification and increases in sea surface temperature, and the increasing occurrence of marine 'heatwaves' causing widespread coral bleaching and coastal hypoxia. These changes have multiple impacts on the resource base itself (habitats and fish populations) (Oxenford and Monnereau 2017), as well as affecting fishing operations, and causing negative impacts across the broader fishery sector (post-harvest operations, fisheries infrastructure and fishing communities) (Monnereau and Oxenford 2017). One of the most recent symptoms of climate change together with ocean eutrophication is the occurrence of mass influxes of pelagic sargassum into the Caribbean that have been plaguing this region since 2011 (Franks et al. 2016) and having significant impacts on the fishery sector (Ramlogan et al. 2017, Oxenford and Monnereau 2018). These sargassum events have triggered much speculation among fishery stakeholders and scientists on the possible long-term implications for Caribbean fisheries. Of particular concern in the eastern Caribbean is their impact on two species of key importance to the region's oceanic pelagic fisheries, flyingfish (*Hirundicthys affinis*) and dolphinfish (*Coryphaena hippurus*), which make up a significant portion of the total annual pelagic fish catch in this region. As such, obtaining a better understanding of the underlying mechanisms associated with these sargassum influx events and their impacts on key pelagic species is of critical importance for developing adaptive response measures to climate change in the eastern Caribbean fisheries sector.

In recognition of this need a 'sargassum subproject' was proposed and approved under the FAO/GEF Climate Change Adaptation in the Eastern Caribbean Fisheries Sector (CC4FISH) project, which has a broader aim to increase overall resilience and reduce vulnerability to climate change impacts in the Eastern Caribbean fisheries sector. The aim of this sargassum subproject was to investigate and attempt to understand the relationships between sargassum influx events and the two key pelagic species, dolphinfish and flyingfish. The agreed intent was to use official catch and fishing effort data held by the fisheries divisions of the CC4FISH participating countries (Antigua, Dominica, Grenada, St Kitts and Nevis, St Lucia, Vincent and the Grenadines, Trinidad and Tobago) together with oceanographic parameters (available from NASA's Giovanni ocean data base) and an innovative indicator of sargassum occurrence (to be developed under this subproject) to explore relationships.

1.2. Key biological traits and fisheries for flyingfish and dolphinfish

The biology of flyingfish (*H. affinis*) and dolphinfish (*C. hippurus*), the implications of these biological traits for the local fisheries, and the importance of these two species to the fisheries of the eastern Caribbean have been extensively studied (see reviews for flyingfish: Oxenford et al. 2007, Headley 2010, CRFM 2014; for dolphinfish: Mahon and Oxenford 1999, Oxenford 1999, Headley 2010) and the key points are summarised here.

Flyingfish (predominantly *Hirundichthys affinis*) has been recognised as the single most important small pelagic species in the eastern Caribbean islands across seven countries from Dominica (15.3 °N) in the north to Trinidad and Tobago (10.5 °N) in the south (FAO-WECAFC 2002), and geographically coincident with the principal influx of water masses from the tropical North Atlantic (tNA). In Barbados, flyingfish typically make up approximately 60% of annual fish landings by weight and account for the highest value added benefits of all fish species landed (Mahon et al 2007). They have a discrete genetic population in the eastern Caribbean and migrate freely among the islands in this sub-region (Gomes et al. 1999). Peak catches are generally from March through June, temporally coincident with the early arrivals of Sargassum (Franks et al. 2016) in this area. Flyingfish is short-lived, essentially an annual species (Campana et al. 1993), reaching maturity from 5-7 months (Oxenford et al. 1994). They are batch spawners, depositing non-buoyant eggs on floating material from November through the following July with two spawning peaks apparent in January and May (Oxenford et al. 1994, Khokiattiwong et al. 2000). They are commonly caught with a combination of gillnets or dipnets together with Fish Aggregation Devices (FADs) composed of palm fronds or sugar cane leaves which are used by the flyingfish as spawning substrate (Oxenford et al. 2007, Headley 2010). Flyingfish consume mostly zooplankton and nekton and occupy a low trophic level of 3.03 (Mohammed *et al.* 2008). Juvenile and adult flyingfish are important prey for many large pelagic species and in the eastern Caribbean it has been estimated that more than 40% of the dolphinfish's diet consists of flyingfish (Oxenford and Hunte 1999, Heileman *et al.* 2008). As such these two species are strongly linked both biologically and through being the two primary targets of the pelagic fishery in the eastern Caribbean (Headley 2010, Fanning and Oxenford 2011).

Dolphinfish (*Coryphaena hippurus*) is considered to be the most important large pelagic fish landed by commercial fishers in the eastern Caribbean in terms of weight and revenue (CRFM, 2006). They are highly migratory but believed to have a distinct genetic population that is shared by the countries of the eastern Caribbean (Oxenford and Hunte 1986). They are seasonally available in this region between November and June with a peak in landings generally occurring between March-April. Dolphinfish is similar to the flyingfish in that it is a short lived (< 2 years), fast growing species, which reaches sexual maturity around 4-5 months (Oxenford, 1999). Like flyingfish they are batch spawners, but have higher fecundity. Unlike flyingfish however, they spawn in open water and peak spawning in this region appears to be from May to June (Oxenford, 1999). They are captured by hook and line on the same fishing trips as flyingfish (but using different gear). Adult dolphinfish are generally caught in association with floating objects (Gomes et al. 1998). In regions where sargassum is typically found (Gulf and Mexico, Sargasso Sea) juvenile stages of dolphinfish are reported to use sargassum mats (Comyns et al. 2002) and larger dolphinfish are caught more frequently outside the floating mats (Farrell et al. 2014). Dolphinfish are piscivorous and occupy a trophic level of 4.44, which is higher than that of flyingfish, their main prey (Mohammed *et al*., 2008).

2. Data acquisition

2.1. Fisheries catch and effort data

Information Efforts to obtain official catch and effort data for flyingfish and dolphinfish from CC4FISH participating countries (Eastern Caribbean Fisheries Divisions), suitable for the purpose of examining medium term (10-20 years) trends in total catches and in abundance of flyingfish and dolphinfish were

less successful than originally anticipated for a number of reasons outlined in a previous summary report (Cox and Oxenford 2018). However, a record of the data that were submitted and examined in the initial stages of the investigation is given in Table 1 for completeness, and a summary of the exploratory visual analysis of these data is provided in Appendix 1. Of note, Trinidad shared a time-series dataset that was closely aligned to the data fields requested, but only for dolphinfish as an incidental catch in the artisanal and longline fleets. St Vincent shared a long time-series of high resolution landings data for dolphinfish and flyingfish, although the latter is not a target species and is rarely landed, and no fishing effort data were available. As a result, we approached the Barbados Fisheries Division (a non-participating country) for assistance and they were able and willing to provide catch and effort data for both flyingfish and dolphinfish for a 24-year period (1994 - 2017). This dataset represents the most comprehensive and high resolution data obtained and was therefore the primary data used in the analyses.

Table 1. Record of data acquisition from Eastern Caribbean Fisheries Divisions of CC4FISH participating countries.

Fishery Division	Data Submission	Time period	Brief description
Antigua	No data available (species not targeted)	-	
Dominica	Unable to provide in a timely manner (hurricane Irma)	-	
Grenada	December 11th, 2017	2012 – 2016 (2013 missing)	Estimated monthly landings for flyingfish and dolphinfish per landing site
St Lucia	December 20th, 2017	2006 – 2016	Estimated yearly fish landings by species group and site Estimated value of fish landed Estimated total number of fishing trips per site
St Kitts and Nevis	December 12th, 2017	1995 – 2016	Yearly landings totals for dolphinfish and flyingfish
St Vincent	October 25th, 2017	2000 – 2016	Estimated monthly landings for dolphinfish and flyingfish
Tobago	No data provided		
Trinidad	February 8th, 2018	1998 – 2016	Estimated total landings for dolphinfish and flyingfish from the Trinidad artisanal and trawl fleets
		2002 – 2016	Estimated landings per trip and landing site for dolphinfish from the Trinidad longline fleet

2.2. Oceanographic data

Available oceanographic parameters that were considered to have a possible influence on, or be correlated with, the abundance of flyingfish and dolphinfish were selected for an initial investigation. These included: particulate organic carbon (POC), chlorophyll a concentration (Chla), dust wet deposition (DUW), and nighttime sea surface temperature (SST). These were downloaded from the open source Giovanni database of NASA, US Government (https://giovanni.gsfc.nasa.gov/giovanni/) for two one degree grid squares (60 x 60 nautical miles) to the east of Trinidad and Tobago (59.3° - 60.3° W, 10.5° - 11.5° N) and to the east of Barbados (59.5° - 58.5° W, 12.5° - 13.5° N) for the purposes of investigating the two fishery datasets from these countries (Figure 1). An exploratory analysis of these data, using the

Barbados grid square as a pilot, did not produce any informative relationships with the fishery data and thus were not pursued further. However, for completeness, these analyses are provided in Appendix 2.

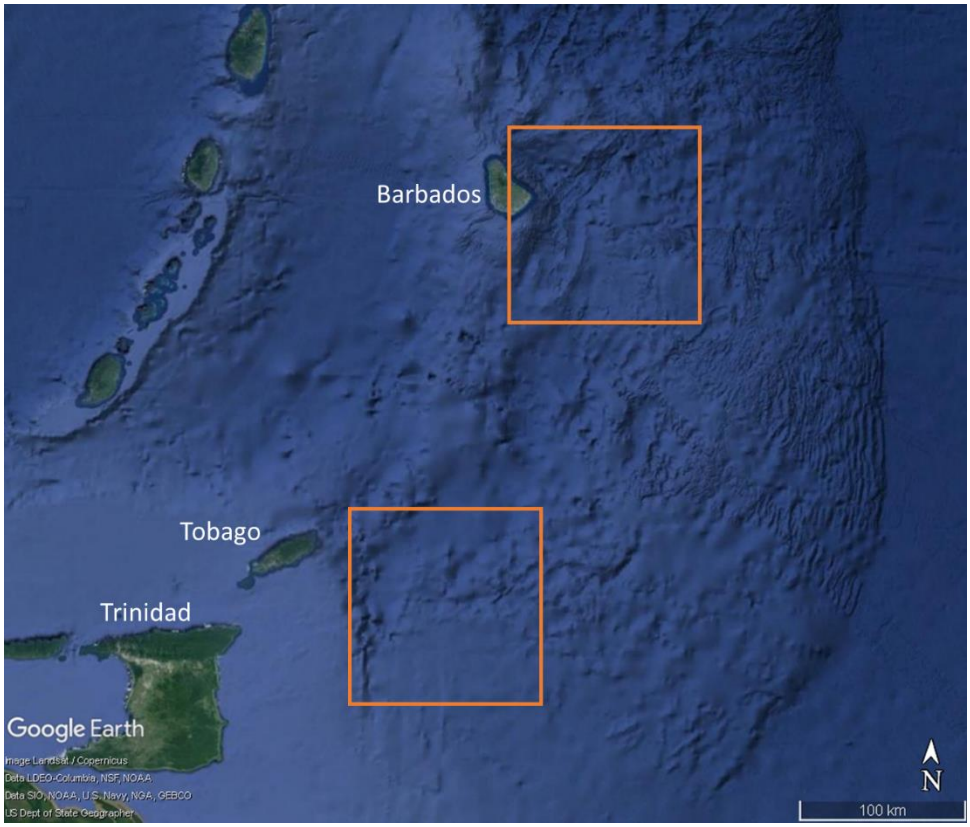

Figure 1. Location of grid squares used to investigate correlations between the presence of pelagic sargassum, oceanographic parameters and fishery catch data.

2.3. Sargassum abundance index

A quantitative index of sargassum abundance over the years for which fishery data were available was obtained using processed, monthly composites of alternative floating algae index (AFAI) satellite images provided by C. Hu from the Optical Oceanography Laboratory of the University of South Florida (https://optics.marine.usf.edu/projects/SaWS.html). The processing details for these satellite images is given by Wang and Hu (2017). We obtained a monthly index of sargassum intensity in the two areas of interest by calculating the total % cover (of each one-degree square) by the coloured pixels (in the composite AFAI satellite images) representing sargassum presence, to obtain a time-series of relative sargassum abundance in each area.

3. Trends in Barbados catch data

Data from the Barbados pelagic fishing fleet which targets both flyingfish and dolphinfish were used to examine the trends in catch and catch per unit effort (CPUE) over a period prior to and after the first sargassum influx events.

There are three distinct boat-types in the Barbados pelagic fishing fleet (dayboats, iceboats and longliners). Dayboats represent the most traditional design in the motorised fleet, target flyingfish and dolphinfish, and fish only during single-day trips, leaving port in the early morning and returning in the late afternoon. Iceboats, which were added to the fleet in the 1980s, also primarily target flyingfish and dolphinfish, using the same gear and number of crew as the dayboats. However, the boats are generally larger, have large, purpose-built ice holds and stay at sea for a week or more, fishing much further afield. The longliners, the most recent addition to the fleet in the 1990s also have large ice-holds, fish up to several hundred kilometres from shore, and generally stay at sea for up to two weeks. Although the longliners primarily target large tunas and billfish on subsurface longline gear, they do also go after flyingfish and dolphinfish, with these species generally representing about 20 -25% of their annual landed weight (Schuhmann et al. 2010).

3.1. Total landings

3.1.1. Annual landings

A 24-year time-series of total annual landings by the three boat types in the Barbados pelagic fleet is shown in Figure 2 for dolphinfish and flyingfish separately. The large inter-annual variation in landings of both dolphinfish and flyingfish are evident in the time-series of all three boat-types in the fleet, and are especially coherent over the last decade or so, suggesting that they are all reacting to the same drivers. As such the landings of the three boat-types were combined to examine changes in total landings by the fleet over the time-series (1994-2017) (Figure 3). Interestingly, the marked inter-annual variations in landings are quite different between the two species in this multispecies fishery, although the overall trend over the decade is one of decline in both species (Figure 3).

3.1.2. Monthly landings

The 24-year time-series of total monthly landings of dolphinfish and flyingfish is shown in Figure 4 separately for the three boat-types. The strong seasonality in the landings data for both species is coherent across all boat-types and indicates the strong seasonality in availability of these short-lived (essentially annual), migratory species to the Barbados pelagic fleet. As for the annual data, it was therefore deemed appropriate to combine landings data across all boat-types to examine patterns of change over the last decade (2007-2017) (Figure 5).

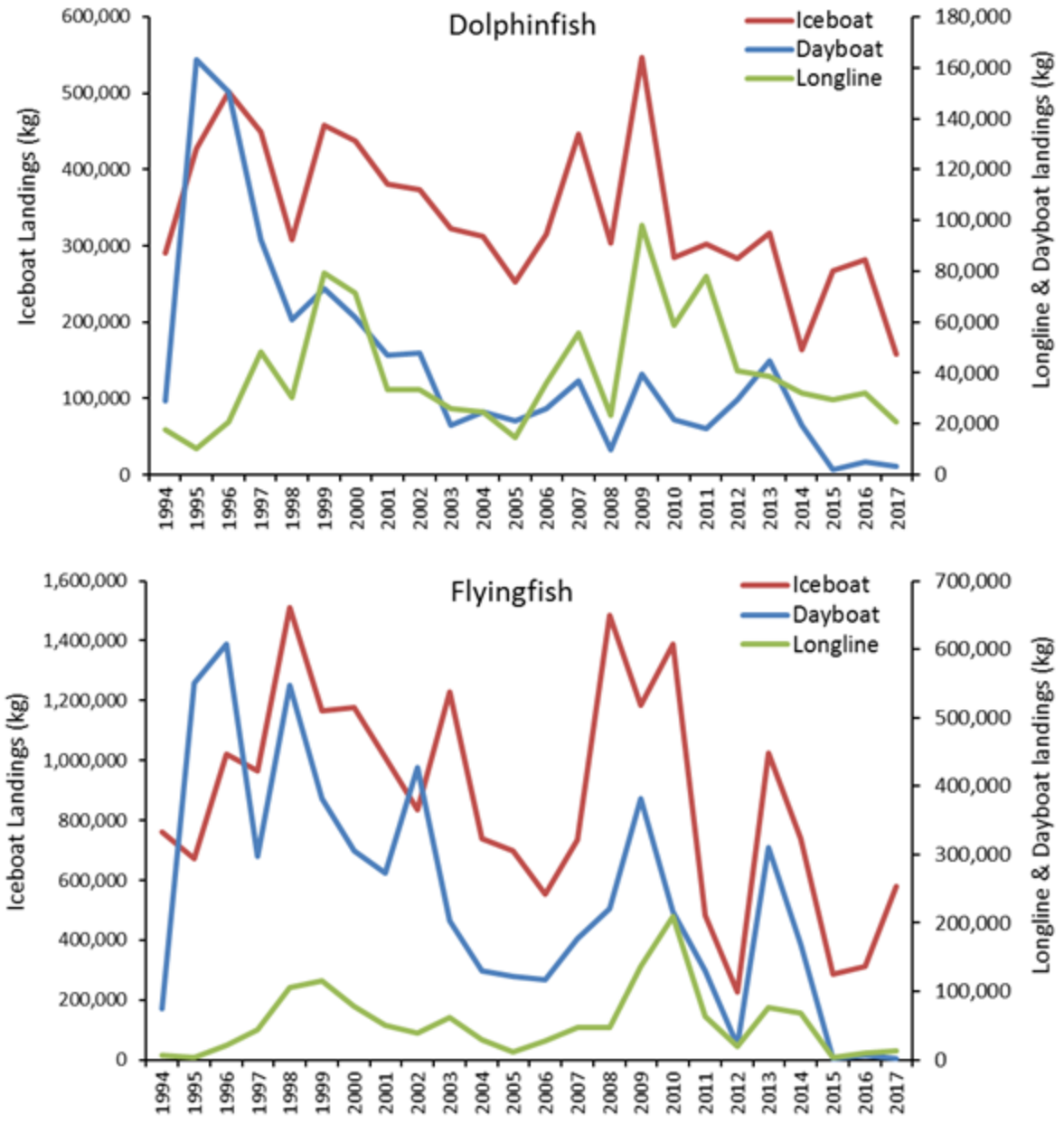

Figure 1. Time series (24 years) of annual landings by the Barbados pelagic fishing fleet for (a) dolphinfish and (b) flyingfish, shown separately for the three boat types. Note the scale difference of landings by the iceboats, indicating that they land considerably more than the other two boat types.

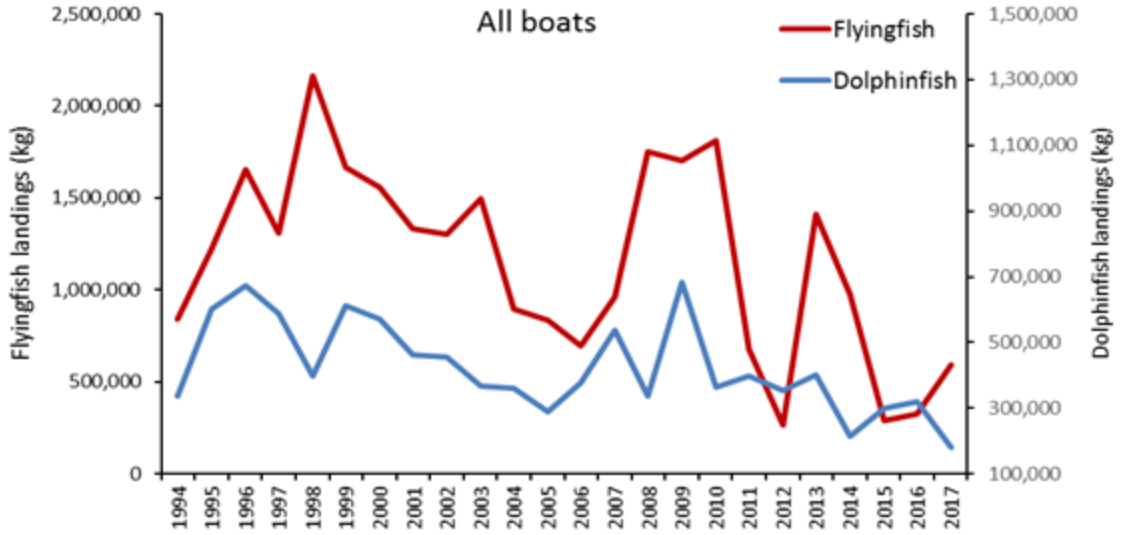

Figure 3. Time-series (2007-2017) of annual landings by all boats in the Barbados pelagic fishing fleet showing dolphinfish and flyingfish separately (note differently scaled axes).

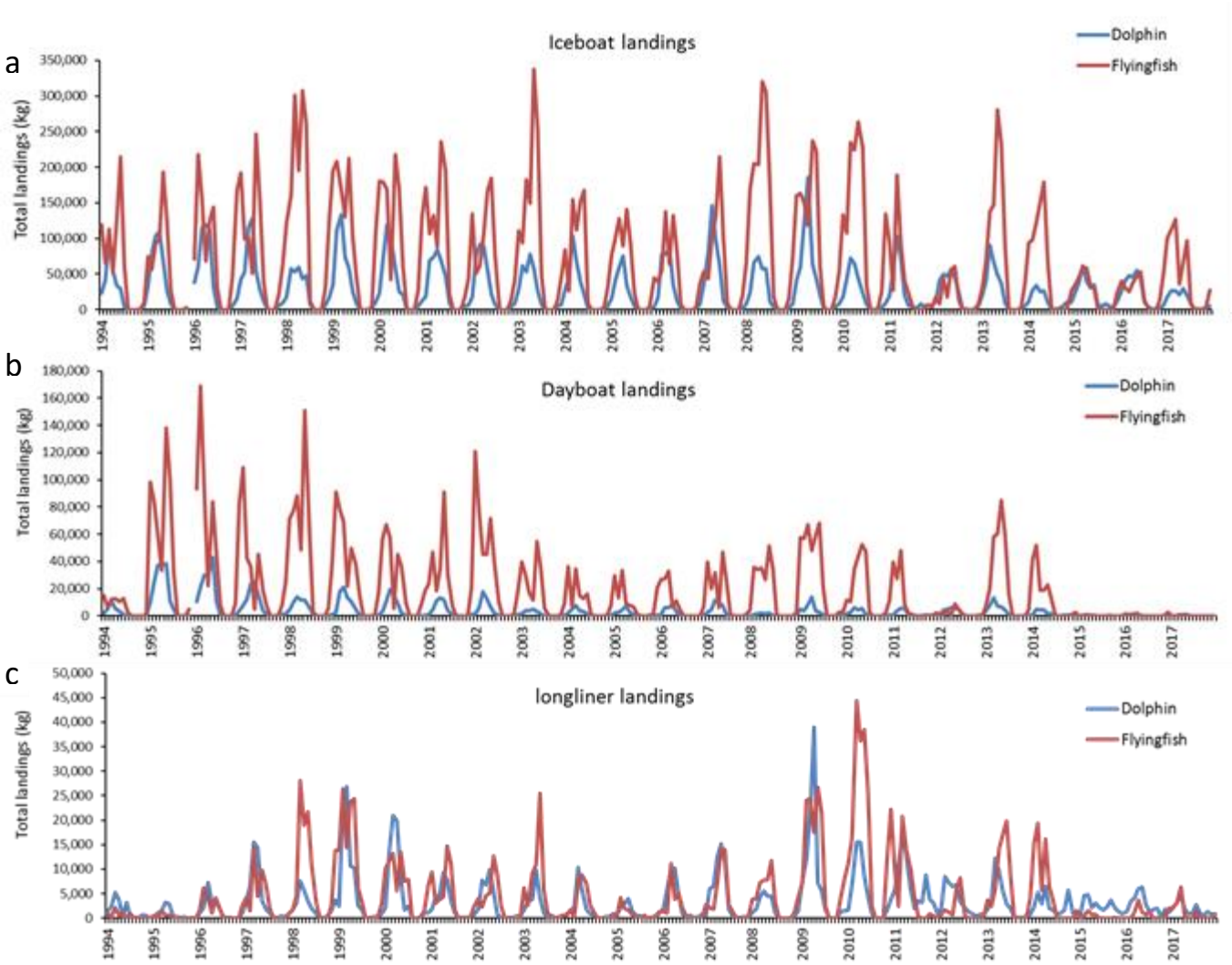

Figure 4. Time series (24 years) of monthly landings of dolphinfish and flyingfish by the Barbados pelagic fishing fleet for (a) iceboats, (b) dayboats and (c) longliners.

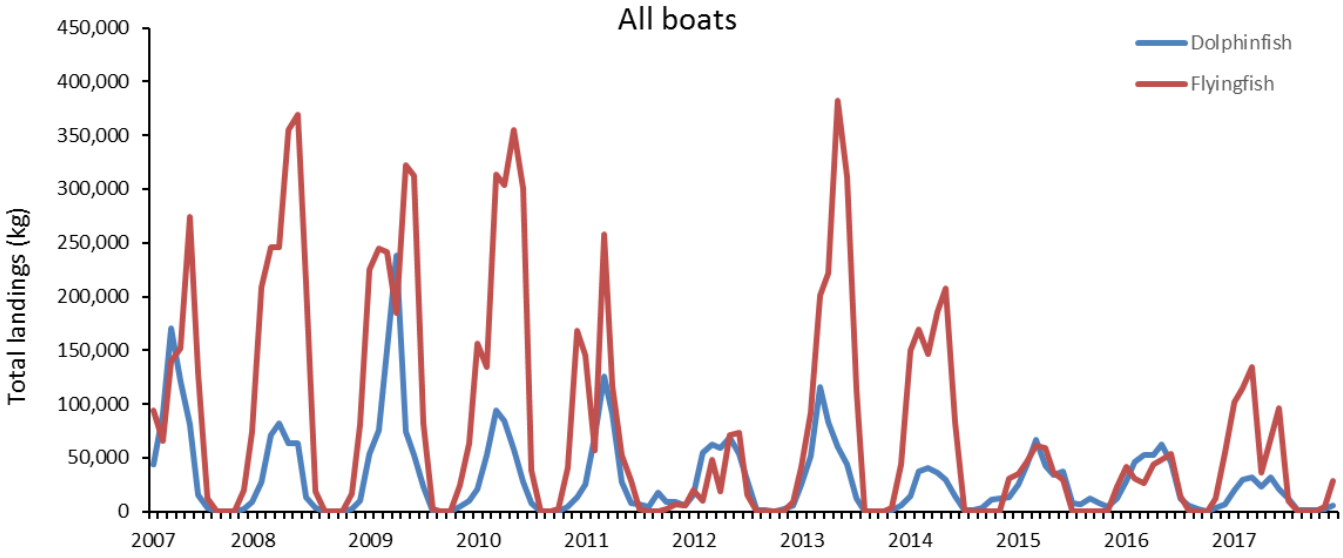

Figure 5. Time-series (2007-2017) of monthly landings by all boats in the Barbados pelagic fishing fleet showing dolphinfish and flyingfish separately.

3.2. Catch per unit effort (CPUE)

Catch per unit of standard fishing effort is typically used as an indicator of relative fish abundance or availability to the fishing fleet. Here we use a relatively crude index of fishing effort (fishing trip) since it is the only available measure of fishing effort recorded in the official database.

The fishing effort (trips) are quite different among the different boat-types in the pelagic fleet, varying from single-day trips (dayboats) to multiple-day trips lasting up to two weeks (iceboats and longliners). Furthermore, the fishing effort specifically targeted at capture of flyingfish and of dolphinfish varies between the boats that always target these species (i.e. dayboats and iceboats) and those that only sometimes target them (i.e. longliners). It is therefore not appropriate to combine data from the three boat-types when looking for trends in the CPUE (as catch per trip).

Since iceboats contribute, on average, significantly more landings of both dolphinfish and flyingfish to the country's total annual landings, than either the dayboats or longliners (Figure 6), the iceboat fleet was selected for examination of CPUE data, as a relatively crude index of fish abundance/availability.

3.2.1. Annual CPUE

The CPUE time-series shows marked inter-annual variability, particularly for flyingfish (Figure 7). Interestingly, these correspond closely with the inter-annual fluctuations seen in the total landings data for the same period (Figure 3) indicating that variation in total landings are likely driven by marked changes in the abundance (or availability) of dolphinfish and flyingfish in the area harvested by the Barbados fishing fleet. Also of interest is the lack of a notable decline in the CPUE of flyingfish or dolphinfish over this period in contrast to the trend seen in the total landings data (Figure 3). This suggests

a decline in the number of trips being recorded or the number of trips actually fished, rather than an overall decline in stock abundance of either species over this 24 year period.

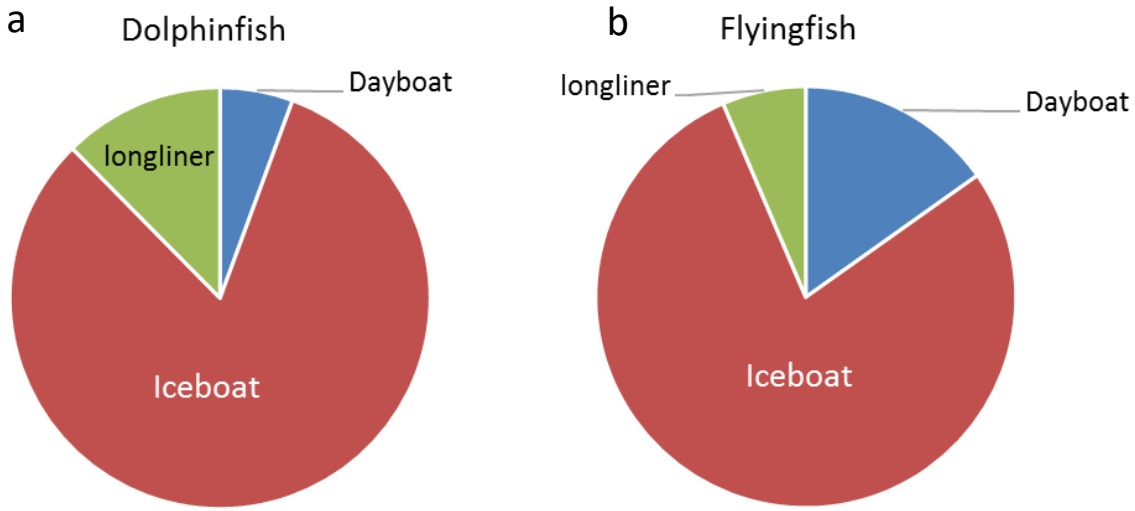

Figure 6. Relative contribution of the three boat-types in the Barbados pelagic fleet to the annual landings of (a) dolphinfish and (b) flyingfish. Data are annual values averaged over the period 2007-2017.

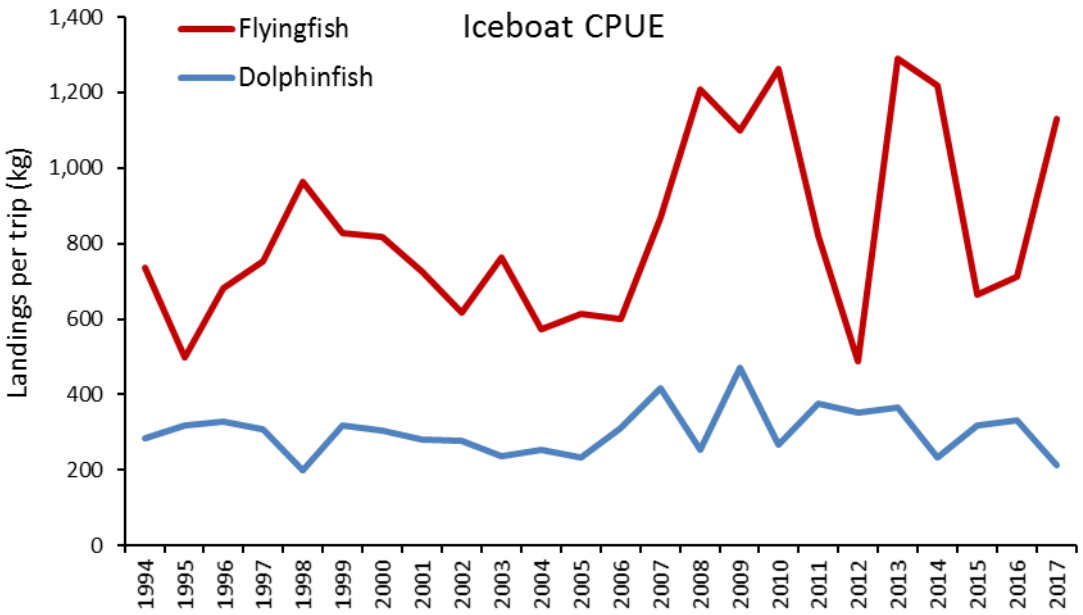

Figure 7. Time-series (1994-2017) of mean annual CPUE (landings per trip) for dolphinfish and flyingfish by the Barbados iceboats.

3.2.2. Monthly CPUE

The 24-year time-series of mean monthly CPUE of dolphinfish and flyingfish by the iceboat fleet is shown in Figure 8. The frequent breaks in the data occur because trips with no catch are not recorded in the database. As such, it is impossible to distinguish between periods of low abundance (when there is no catch) or periods when there are no trips. However, the strong seasonality seen in the total landings data for the iceboats (Figure 4a) is still clear from this time-series (Figure 8), indicating the distinct seasonal availability of dolphinfish and flyingfish in this area. As indicated by the annual CPUE data, there is no apparent decline in overall abundance of either species over this time frame, although the seasonal patterns in the latter part of the last decade appear to be somewhat different. For example, the clear seasonal peak in abundance of dolphinfish around March has essentially disappeared and they appear to be available throughout much of the year (Figure 8a), whilst for flyingfish the seasonal pattern in availability (December - June) has become much more erratic (Figure 8b).

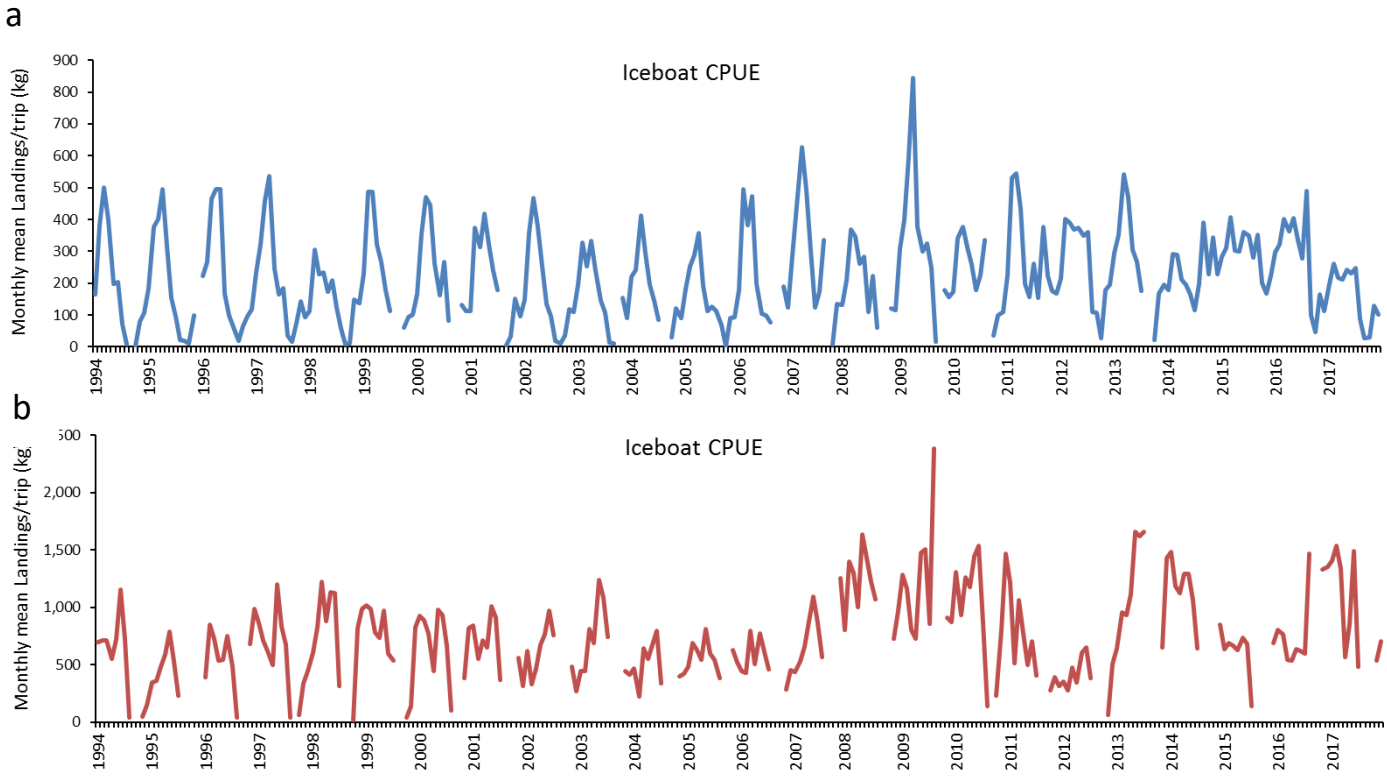

Figure 8. Time series (24 years) of mean monthly CPUE (landings per trip) of (a) dolphinfish and (b) flyingfish by the Barbados iceboats.

4. Sargassum influx events

A time-series of sargassum abundance since 2007 is shown in Figure 9 for Barbados and Trinidad at annual and monthly resolution. The timing and pattern of increasing occurrence and severity of sargassum influxes over the years since the first substantive influx in 2011 is clearly apparent and very similar for both countries, with the exception of a peak off Barbados in August 2016 which was not seen in the Trinidad time-series. Since 2015 it also appears that Barbados is experiencing slightly more sargassum. The influxes have so far occurred every three years, and lasted for two years each time.

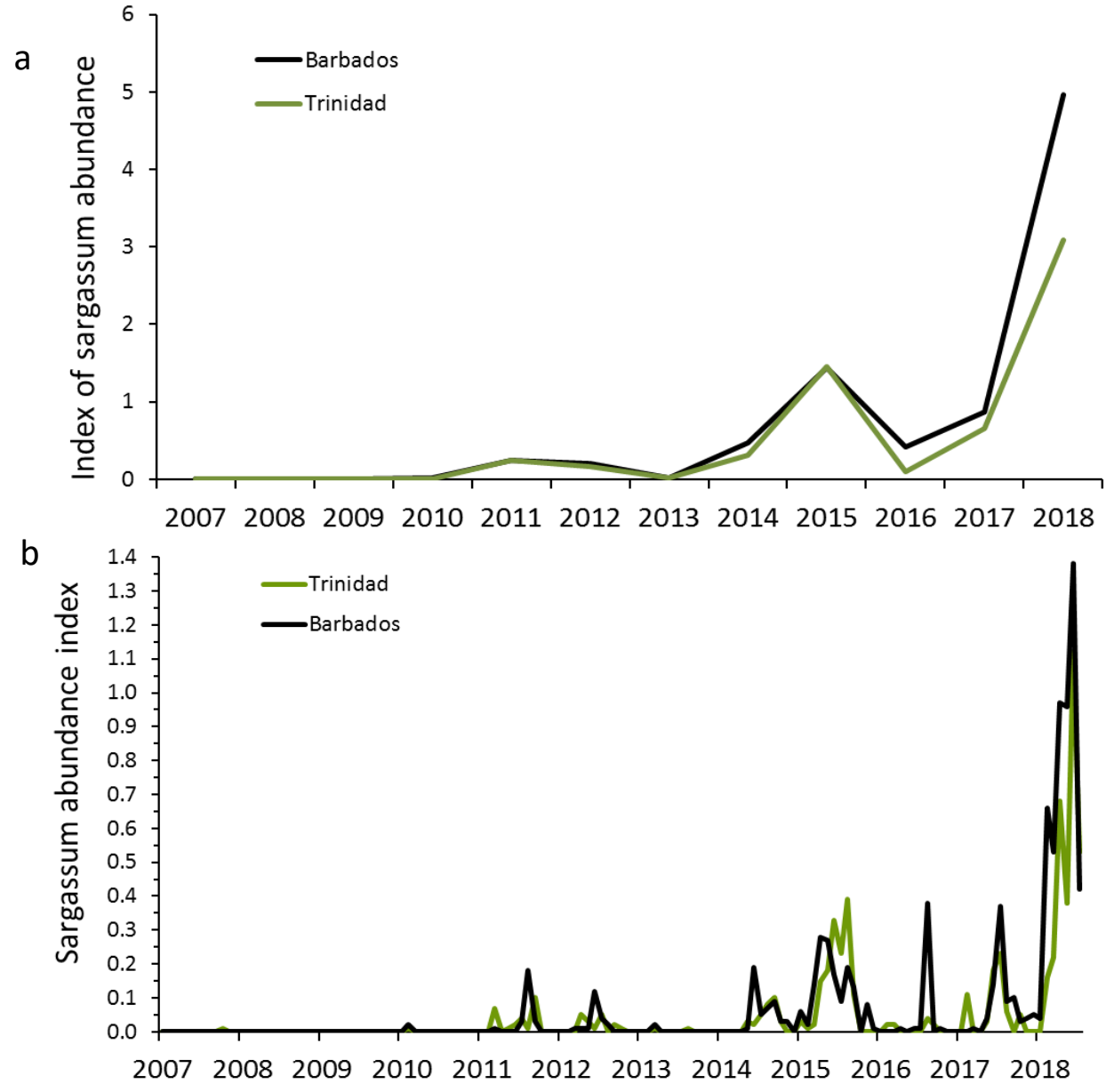

Figure 9. Time-series of relative sargassum abundance for Barbados and Trinidad shown as (a) annual total and (b) monthly indices. Data are based on presence of sargassum detected in one-degree grid squares to the east of the islands (location shown in Figure 1).

5. Relationships between sargassum and the pelagic fishery

5.1. Fishery landings

5.1.1. Barbados

Total recorded landings of dolphinfish and flyingfish in Barbados have both shown a distinct decrease in weight since the beginning of the new 'sargassum era' (i.e. since 2011). Mean monthly landings of dolphinfish have decreased since June 2011 by 36.8% from 35,571 kg to 22,104 kg a month. Likewise, those of flyingfish have decreased by 51.5% from 89,606 kg to just 43,447 kg per month since the first sargassum influxes (Figure 10). This represents an average annual loss of landings of 161.6 mt of dolphinfish and 554 mt of flyingfish a year.

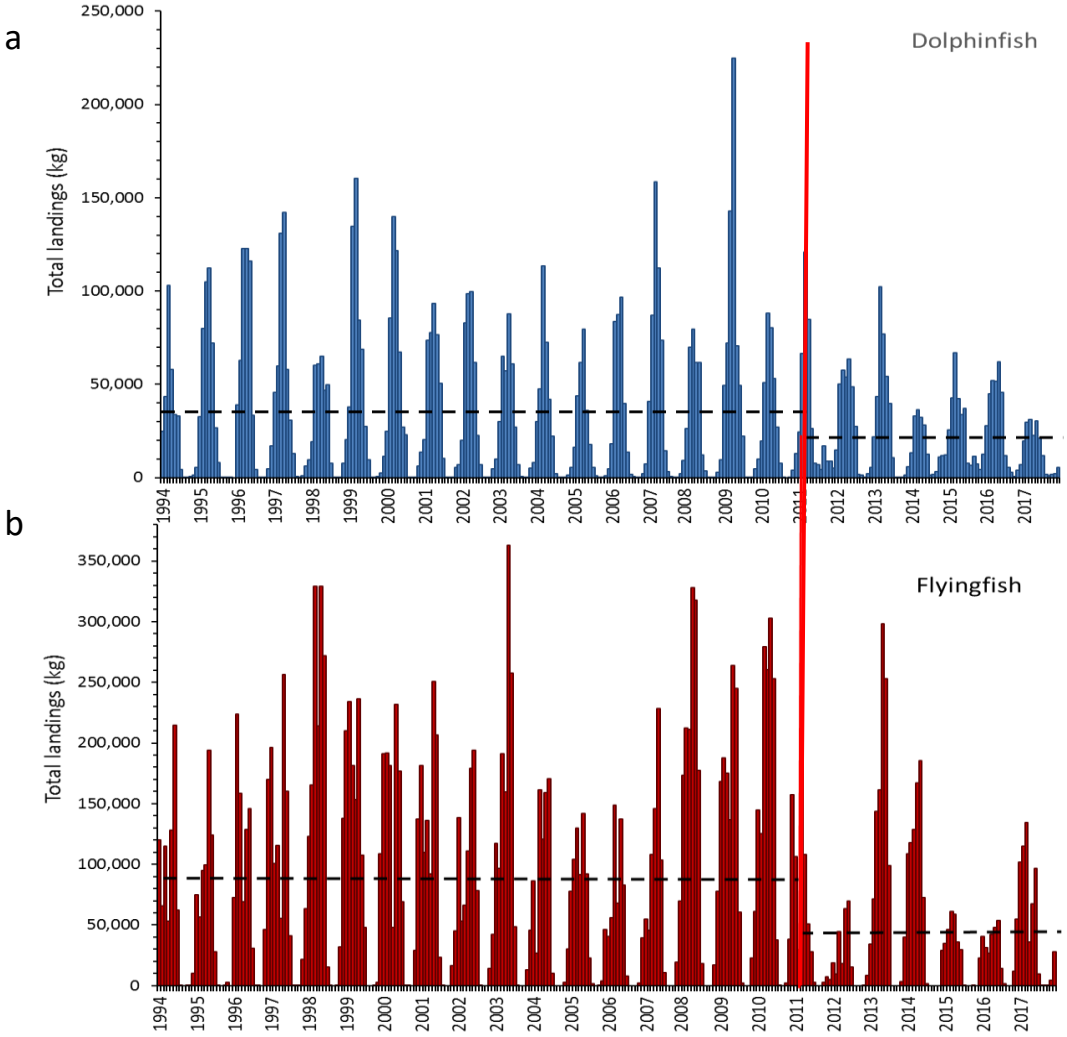

Figure 10. Time-series of monthly recorded landings for (a) dolphinfish and (b) flyingfish by the Barbados pelagic fishing fleet, showing the change in mean monthly landings before and after the first sargassum influx in June 2011. Red line marks the separation of pre- and post-sargassum influxes and dashed black lines show mean monthly catch in the two periods.

A direct comparison of monthly total dolphinfish and flyingfish landings in Barbados with sargassum presence in the vicinity (Figure 11), showed a clear linkage, that is especially strong for flyingfish (Figure 11b). However, the relationship is not a direct linear one. The relationship is also complicated by the fact that flyingfish and dolphinfish are highly seasonal and the first arrivals of sargassum generally peaked just prior to the traditional pelagic fishing season when these migratory species would not normally be available. Furthermore, the loss in fishery landings over the years has not been proportional to the increasing levels of sargassum presence that have occurred since 2011.

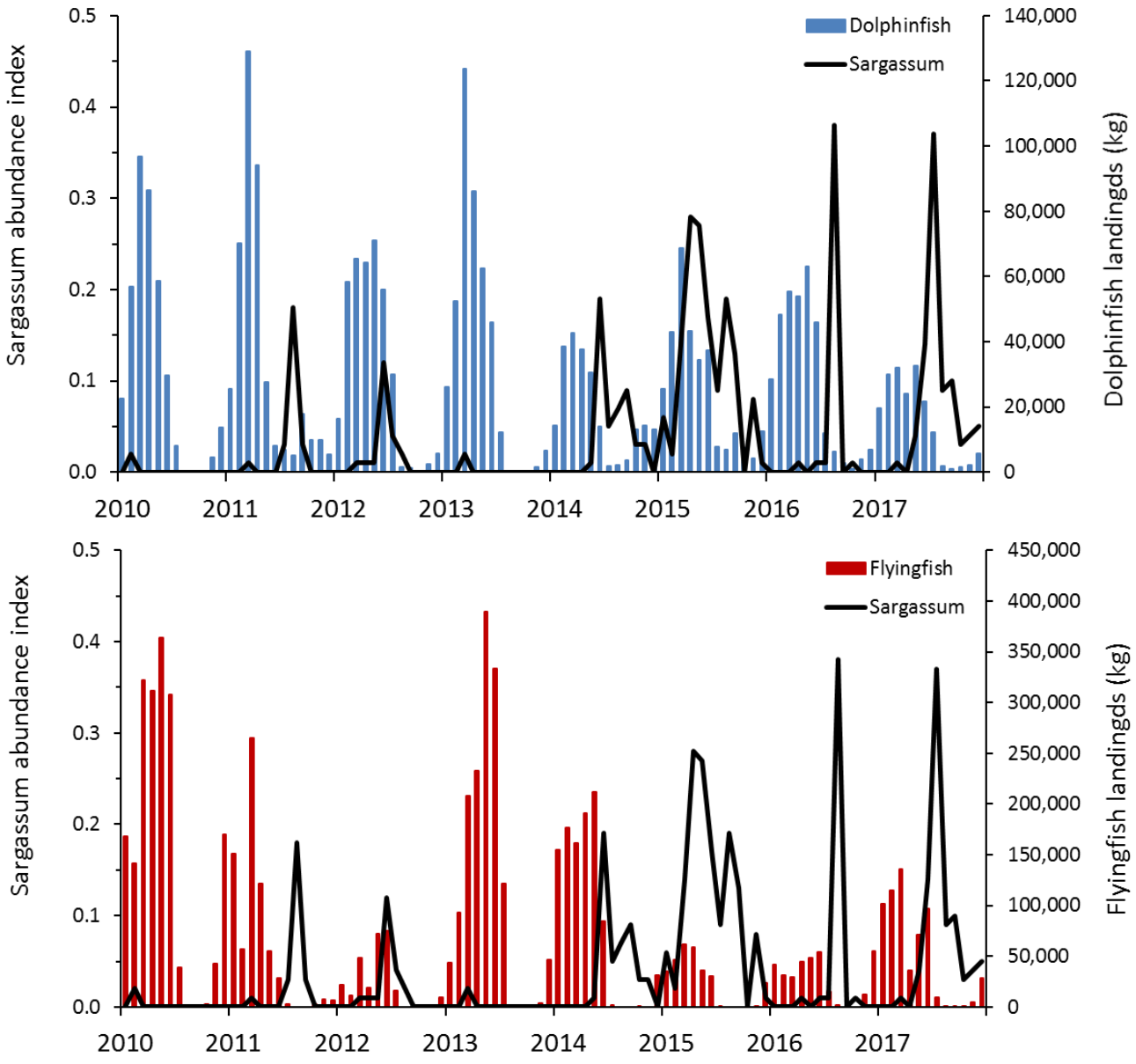

Figure 11. Comparison of sargassum abundance and landings data for (a) dolphinfish and (b) dolphinfish for Barbados.

With regard to dolphinfish, the presence of significant amounts of sargassum in mid-2011 appears to have resulted in an unusual pattern of landings during that summer (when dolphinfish are not normally present) followed by a slightly unusual pattern of monthly landings through the 2012 fishing season (Nov 2011 -July 2012), with no customary peak of abundance in March, but more months of medium-level catches than normal (Figure 11a). A second slightly smaller influx of sargassum in mid-2012 appears to have had a much smaller impact on landed weight in the 2013 fishing season, although the 2014 fishing season recorded lower landings again. Since the increasingly severe influxes of sargassum from mid-2014, dolphinfish landings have been considerably smaller in the traditional peak months of March and April but lower levels of catches have continued over a longer season than normal (Figure 11a). This was especially apparent in the summer of 2015 when dolphinfish were again landed right through the summer. The new summertime and early season catches of dolphinfish have been overwhelmingly dominated by very small juvenile fish that appear to be travelling with the floating sargassum mats. These small-sized fish were not previously available to the fishery and their capture in recent years has caused an outcry among some fishers, fisher groups, consumers and fishery managers, prompting the negotiation of a recommended harmonized minimum size for dolphinfish in the eastern Caribbean (CRFM 2016).

With regard to flyingfish in Barbados, the first significant influx of sargassum in mid-2011 had a dramatic impact on the flyingfish fishery with extremely low catches occurring thereafter and throughout 2012 (Figure 11b). However, in 2013 with very little evidence of sargassum presence, landings of flyingfish returned to pre-sargassum levels but did not exceed these levels as might be expected if inhibited harvest increases the population size. Since 2014 when the sargassum influxes resumed and became more severe, the flyingfish landings have remained low and the season when they were typically available has become shorter (Figure 11b). The landings however have not decreased in a linear manner with increased levels of sargassum.

5.1.2. Trinidad

Monthly dolphinfish landings data available from the longline and artisanal fleets of Trinidad, where dolphinfish is not a primary target species, show a somewhat different pattern than apparent for the Barbados pelagic fleet (Figure 12). For the longline fleet there seems to be a relatively distinct period of low catches prior to the first sargassum influx in March 2011 and higher catches after this (Figure 12a), in contrast to the pattern seen in Barbados (Figure 10). However, this pattern is not so clear in the catches of the artisanal fleet (Figure 12b). The landings data also indicate a lack of the very distinct seasonality that is evident in the Barbados data. These differences likely reflect the fact that dolphinfish is not a primary target species of these Trinidad fleets. Furthermore, the recorded catches by these two fleets represent a small fraction of (20 fold less than) the amount recorded in Barbados.

A closer examination of the dolphinfish landings data during the last decade of sargassum influxes by the two Trinidad fleets does not reveal any clear link with sargassum at a monthly resolution, nor any coherence in the pattern of landings between the two fleets except for the clear March and March/April peaks in landings by the two fleets in 2011 and 2013 (Figure 13).

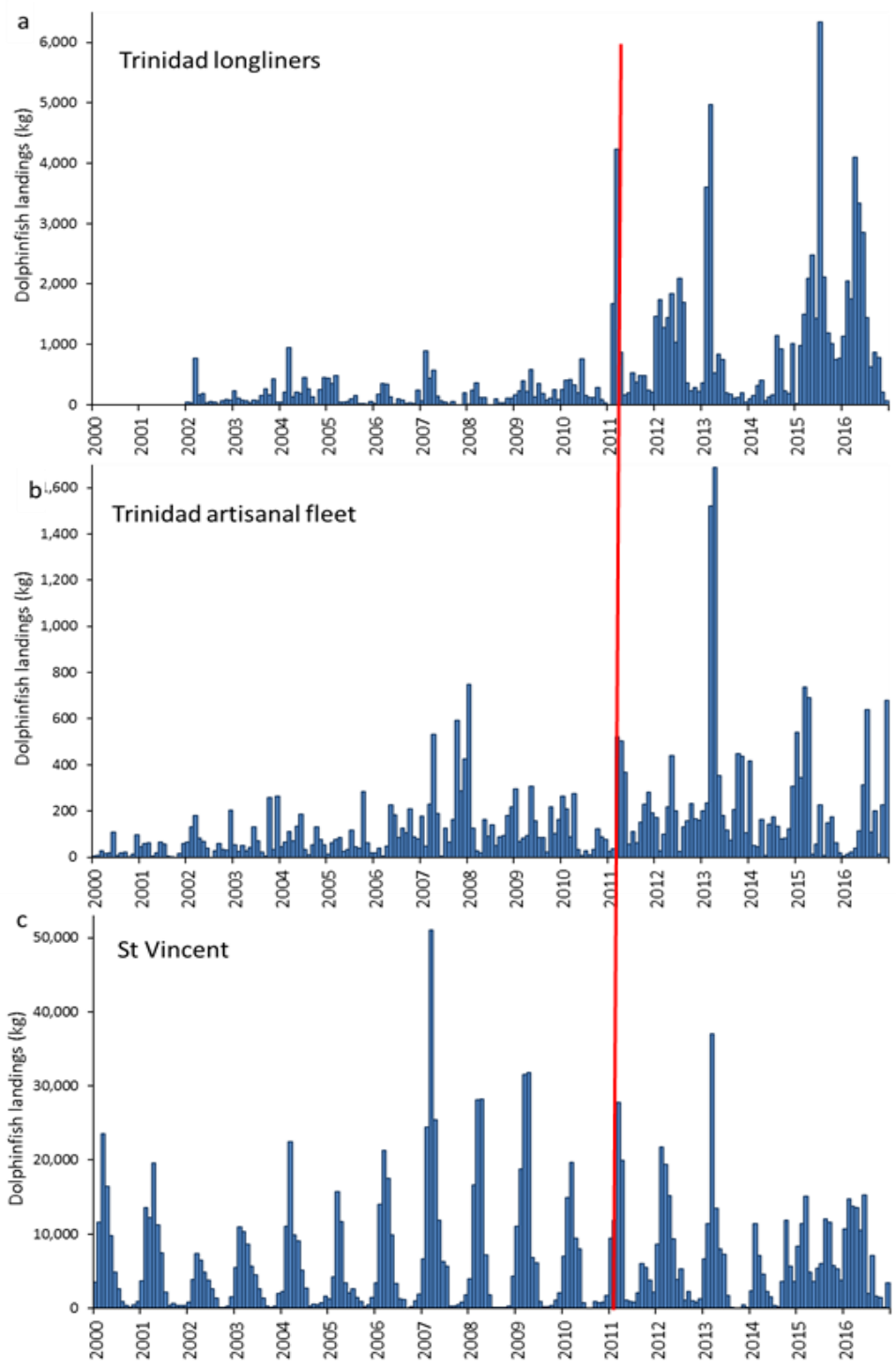

Figure 12. Time-series of monthly recorded landings for dolphinfish from (a) the Trinidad longline fleet, (b) the Trinidad artisanal fleet, and (c) the pelagic fleet in St Vincent showing the change in mean monthly landings before and after the first sargassum influx in June 2011. Red line marks the separation of pre- and post-sargassum influx periods.

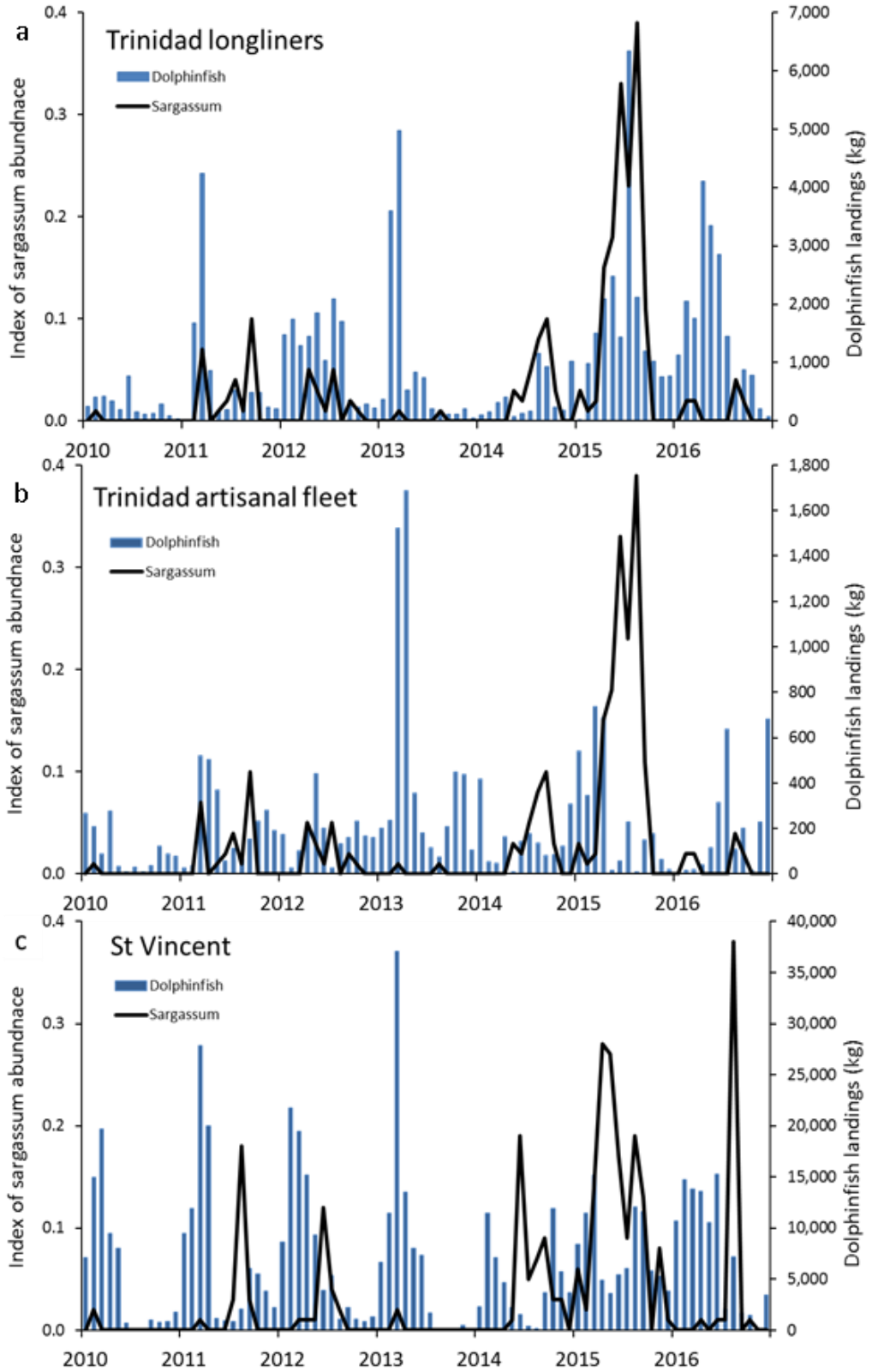

Figure 13. Comparison of sargassum abundance and landings data for dolphinfish by (a) the Trinidad longline fleet, (b) the Trinidad artisanal fleet and (c) the pelagic fleet of St Vincent. Sargassum index data for Barbados is used as a proxy for St Vincent.

5.1.3. St. Vincent

A long time-series of dolphinfish monthly landings data was also available for the pelagic fleet of St. Vincent and is shown in Figure 12 with the Trinidad data. Similar to the Barbados data (Figure 10), this directed fishery shows a strong seasonality in landings and the same change in the seasonal pattern in the last few years of this decade, with a loss of the pronounced peak catches in March-April, but an extended period of landing throughout the summer months (Figure 12c). Interestingly however, there is no apparent decline in the mean monthly landings before (6,455 kg) and after (6,641 kg) the sargassum era.

A closer examination of the dolphinfish landings data during the last decade of sargassum influxes by the St Vincent fleet (Figure 13c) shows a pattern that is almost identical to that seen in the Barbados data (Figure 11a). Like Barbados, the first significant arrival of sargassum in mid-2011 brought a bounty of small dolphinfish that were harvested during the summer months. Again like Barbados, the second influx of sargassum in mid-2012 seemed to have had little impact on the normal pattern of monthly catches through 2013 but very low catches were experienced through 2014. The pattern of extended availability of dolphinfish and a lack of the March-April peak catches is also apparent in the St Vincent data over the last few years (Figure 13c).

5.1.4. Other eastern Caribbean islands

Annual resolution data provided by other CC4FISH partners can be used to corroborate some of the patterns seen in the higher resolution data sets of Barbados, Trinidad and St Vincent. For example, the dolphinfish data from St Kitts and Nevis and St Lucia showed no clear decline in dolphinfish landings associated with the onset of sargassum influxes (Appendix 1, Figure A1-1a), although they too reported extremely high catches of very small dolphinfish associated with the sargassum mats. The flyingfish data from St Lucia indicated the same precipitous drop as in Barbados, following the 2011 influx, a recovery in the period of low sargassum between 2013-2014 and a second significant drop in 2015-2016 with the second significant influx of sargassum (Appendix 1, Figure A1-1b).

5.2. Fish availability (CPUE)

The CPUE data for the Barbados iceboats was considered to be the most reliable index of fish abundance and shows an interesting relationship with the sargassum influxes over the last decade (Figure 14). At an annual resolution the presence of dolphinfish does not seem to have been closely linked to the increasing levels of sargassum in the area, as can be seen by the lack of any significant change in the dolphinfish CPUE (Figure 14). The flyingfish, however, show a dramatic and direct response to sargassum influxes with a sharp reduction in abundance or at least availability to the fishery after the first appearance of sargassum in 2011, a recovery in 2013 and 2014, before another dramatic decline in 2015 with the next influx (Figure 14). Interestingly the CPUE data available from St Lucia for this period confirms the drastic reduction in availability of flyingfish with the onset of sargassum influxes (Appendix 1, Figure A1-2).

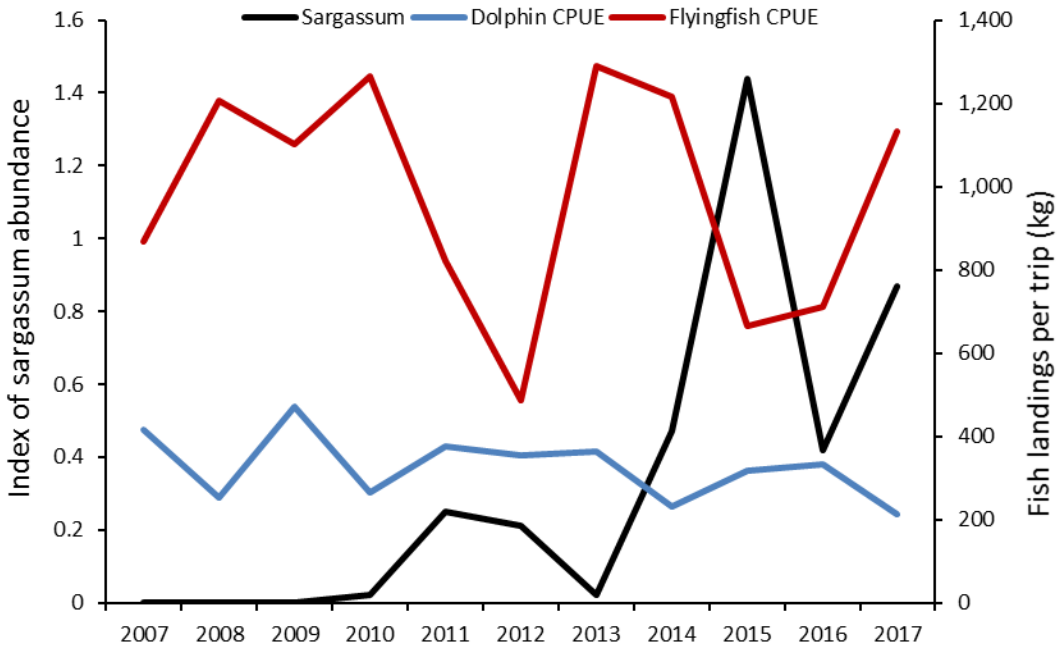

Figure 14. Annual mean (landings per trip) of Barbados iceboats for dolphinfish and flyingfish shown together with the index of sargassum abundance.

6. Changes in fisher and fish behaviour

Looking at the changes in fisher and fish behaviour that have occurred as a result of the onset of sargassum influxes in this region, helps to explain some of the impacts that are apparent in the fishery landings data, especially the differences seen in the landings between dolphinfish and flyingfish.

Pelagic fishers in the eastern Caribbean were taken by surprise with the first influxes of sargassum in 2011, having never before experienced this phenomenon. The sargassum posed significant challenges at landing sites making access to and from moored boats very difficult, and the launching of beached boats problematic. The floating sargassum mats both nearshore and offshore made access to the boats and transit to and from fishing grounds difficult (and potentially dangerous at night), more time-consuming, and sometimes even impossible. As a result, many fishing days were lost (Ramlogan et al. 2017), resulting in lower fish landings overall (for both dolphinfish and flyingfish).

Fishers also had problems with their fishing gear. For example, trolling lines deployed to capture dolphinfish became fouled with the sargassum weed, such that the bait or lure could not be seen or the hook was rendered ineffective. As a result, fishers had to spend more time retrieving and clearing the lines and thus became less efficient at harvesting dolphinfish.

Figure 15. Flyingfish eggs on sargassum that washed ashore in Barbados, providing proof that they are using the sargassum as a spawning substrate.

Most dramatic was the change in effectiveness of the fishing methods used to capture flyingfish. Fishers reported that there were no flyingfish to catch, because none were coming to the FADs. The most intuitive explanation for why flyingfish were apparently absent (i.e. flyingfish stopped gathering around the fishers' FADs) with the first influxes of sargassum was that they could instead spawn on the abundant floating weed (Figure 15) and therefore no longer found the small FADs a particularly attractive option as spawning substrate. As such, the primary method of catching flyingfish became ineffective and catches plummeted. Local fishers have also noted that flyingfish appear to be fleeing sargassum mats, possibly after a quick deposit of eggs, which may indicate predator avoidance behaviour (Kinch and Oxenford in press). Furthermore, fishers reported that they could only attract flyingfish to the boats at night, precluding capture by the large dayboat fleet. Another issue reported by fishers was that the surface gillnets used to capture flyingfish quickly became clogged with weed, preventing flyingfish from becoming entangled in the nets, and also causing significant damage to the nets. These observations by fishers together with knowledge of the flyingfish biology and ecology (Kinch and Oxenford, in press) provides a plausible explanation as to why the flyingfish fishery has been so badly affected.

The CPUE data suggests that dolphinfish abundance has not changed greatly in response to the sargassum, even though, at least in Barbados the landings have declined. This is not surprising, given that sargassum is known to support higher ocean biomass of large pelagic species (Laffoley et al. 2011). However, the sargassum has made the very young dolphinfish that travel with it, available to the pelagic fisheries of the eastern Caribbean which explains the new summertime catches and decreased size of fish now typically caught in sargassum years. Heavy fishing pressure on these immature dolphinfish may have negative consequences for the long-term sustainability of the southeastern Caribbean dolphinfish stock (see Oxenford 1985).

Over the eight years since the first sargassum influxes, fishers have been adapting to the 'new normal'. This has included adopting a number of modifications to prevent boat engine damage, the increased use of weather apps and radio communication to help avoid large sargassum mats, and innovations to

improve boat access. Fishers have also made alterations to the fishing gear and even the target species (Speede et al. 2019, Speede in press). Small dolphinfish and other species associated with the sargassum, including immature almaco jacks, tripletails and ocean triggerfish are now being actively harvested in large numbers. Smaller mesh gillnets are also being imported and deployed to catch small flyingfish before they are ready to spawn. These changes could help explain why the landings have not continued to decline in response to a continued increase in the abundance of sargassum that has occurred, particularly over the last two years (2017/2018).

7. Summary conclusion

- High resolution fishery catch and effort data at the species level over uninterrupted times-series in excess of ten years are either not available or hard to access in this sub-region.
- Available physiochemical oceanic variables (POC, Chla, SST, DUW) showed no obvious relationships with landings data for dolphinfish or flyingfish in the eastern Caribbean (Barbados).
- Using AFAI composite satellite images to detect coverage by sargassum provided a credible, quantitative, index of sargassum abundance at both monthly and annual scales that could be used to examine relationships with fishery data at scales relevant to individual small islands.
- A long-term (over 24 years) decline in the recorded landings of dolphinfish and flyingfish in Barbados was evident. However, since this was not evident in the CPUE data, it most likely reflects a reduction in overall fishing effort and/or a reduction in the coverage of the official recording system, rather than a decrease in the abundance of dolphinfish and flyingfish stocks. This is corroborated by a lack of decline in any of the other long-term landings datasets from other eastern Caribbean states that target the same stocks.
- There has been a marked decline (-37%) in the landings of dolphinfish in Barbados since the first influxes of sargassum in 2011, translating to an annual catch reduction of 162 mt. This is believed to be mainly due to a decrease in fishing effort by the pelagic boats (fewer days at sea), as well as the smaller sized fish.
- The multispecies nature of the pelagic fishery and high reliance of the Barbados fleet on catching both flyingfish and dolphinfish during fishing trips, could result in boats making fewer trips, if the loss of one species (in this case flyingfish) significantly affects the profitability of the trip. Furthermore the loss of flyingfish, the primary bait used to catch dolphinfish could also be responsible for lower catches. This may also explain why the decrease in landings of dolphinfish by the Barbados fleet was not detected in the few available data sets of other eastern Caribbean states targeting the same stock, since they rely much less on flyingfish. They did however report catching much smaller sized fish, as did Barbados.
- The expansion in seasonal availability of dolphinfish in years of sargassum influxes is largely due to the presence of high numbers of very small dolphinfish associated with the sargassum in the summer months, making them available to the fishery at a time when dolphinfish were typically absent from the eastern Caribbean. The flattening of the seasonal pattern in landings, reduction in the proportion of large adult fish and lack of a significant peak in March-April suggests a disruption in the migratory behaviour of dolphinfish caused by the presence of sargassum. This

may ultimately impact the centre of the stock if mature spawning fish are not following the traditional route.

- There has been a marked decline (-52%) in the landings of flyingfish in Barbados since the first influxes of sargassum in 2011, translating to an annual catch reduction of 554 mt. This is believed to be mainly due to a combination of reduced fishing effort (especially by the dayboats) and a substantive reduction in the catchability of flyingfish as a result of behavioural changes by flyingfish in the presence of sargassum (i.e. spawning on sargassum rather than the fishers' FADs). This dramatic decline in catches is also corroborated by the scant datasets for flyingfish from other eastern Caribbean states.
- The CPUE data also shows a drastic reduction in catch rates of flyingfish during periods of high sargassum abundance, indicating that flyingfish are either not available for capture or have substantially reduced catchability. The latter supports the hypothesis that flyingfish are spawning in the sargassum and no longer attracted to the FADs.
- The rapid recovery of flyingfish catch rates (and landings) to previous levels in years when sargassum is absent, suggests that the population is not depressed by the current levels of fishing.
- The fact that catches of flyingfish are not declining in proportion to the continuing increase in abundance of sargassum could be, in part, due to the efforts of fishers adapting their fishing techniques (using smaller sized gillnets, travelling in search of areas with low sargassum presence and fishing at night).
- The significant reduction in landings of flyingfish in particular, during years of high sargassum abundance, together with the evidence to date that suggests sargassum influxes will continue to occur as the 'new normal', implies a continuation of significant economic loses and livelihood disruption in the pelagic fishing sector of the eastern Caribbean, particularly for Barbados because of its traditional reliance on flyingfish (contributing around 60% of total fish landings). As such, continued efforts to help fishers adapt to this reality will be key in sustaining the sector.
- Sargassum is having significant impacts on the pelagic fishery in large part because of behavioural changes in the key pelagic species in the presence of sargassum, rather than negative impacts on the population sizes of dolphinfish and flyingfish themselves. As such, adaptation measures should focus on making fishing trips more economically efficient, developing alternative fishing techniques to increase catchability of flyingfish in the presence of sargassum, and harvesting alternative species that have become available because of their association with the sargassum. However, a precautionary approach should be adopted to address the potentially negative impacts of changes in fishing practice that result in the harvest of very small (immature) dolphinfish and flyingfish.

8. References

Campana, S.E., H.A. Oxenford and J.N. Smith. 1993. Radiochemical determination of longevity in flyingfish (*Hirundichthys affinis*) using Th-228/Ra-228. Marine Ecology Progress Series 100: 211-219

Comyns, B.H., N.M. Crochet, J.S. Franks, J.R. Hendon, and R.S. Waller. 2002. Preliminary assessment of the association of larval fishes with pelagic *Sargassum* habitat and convergence zones in the northcentral Gulf of Mexico. Proceedings of the Gulf and Caribbean Fisheries Institute 53:636-645.

Cox, S. and H. A. Oxenford. 2018. Summary report on the available catch and fishing effort data for flyingfish and dolphinfish in the Eastern Caribbean. Report to the FAO. Centre for Resource Management and Environmental Studies, University of the West Indies, Bridgetown: Barbados. 18 pp.

CRFM. 2006. Report of Second Annual Scientific Meeting – Port of Spain, Trinidad and Tobago, 13-22 March 2006. CRFM Fishery Report - 2006, Volume 1. 188 p.

CRFM. 2014. Sub-regional fisheries management plan for flyingfish in the eastern Caribbean. CRFM Special Publication No. 2. 42 p. + annexes.

CRFM. 2016. Recommended precautionary approach to management of the regional dolphinfish fishery. Management measure approved by the 10th Meeting of the Ministerial Council of the CFM, Montego Bay, Jamaica. 2pp.

Fanning, L.P, and H.A. Oxenford. 2011. Ecosystem issues pertaining to the flyingfish (*Hirundichthys affinis*) fisheries of the eastern Caribbean. Pp. 227-240, in: Fanning, L., R. Mahon and P. McConney (eds.) Towards marine ecosystem-based management in the Wider Caribbean, Amsterdam University Press, Netherlands.

FAO-WECAFC. 2002. Western Central Atlantic Fishery Commission Report of the Second Meeting of the WECAFC Ad Hoc Flyingfish Working Group of the Eastern Caribbean. FAO Fisheries Report No. 670, 156 pp.

Farella, E.R., A.M. Boustany, P.N. Halpin and D.L. Hammond. 2014. Dolphinfish (*Coryphaena hippurus*) distribution in relation to biophysical ocean conditions in the Northwest Atlantic. Fisheries Research 151: 177-190.

Franks, J.S., D.R. Johnson and D.-S. Ko. 2016. Pelagic Sargassum in the Tropical North Atlantic. Gulf and Caribbean Research 27: SC6-SC11.

Gomes, C., H.A. Oxenford and R.B.G. Dales. 1999. Mitochondrial DNA D-loop variation and implications for stock structure of the four-wing flyingfish, *Hirundichthys affinis*, in the central western Atlantic. Bulletin of Marine Science 64(3): 485-500

Headley, M. 2010. Harvesting of Flyingfish in the eastern Caribbean: A Bioeconomic Perspective. United Nations University Fisheries Training Programme, Iceland [final project]. 42 pps.

Hunte, W., R. Mahon and H.A. Oxenford. 2007. Synopsis of biological characteristics of the flyingfish, *Hirundichthys affinis*, relevant to assessment and management. p51-54 *in*: Oxenford, H.A., R. Mahon and W. Hunte (eds.) Biology and management of eastern Caribbean flyingfish. Centre for Resource Management and Environmental Studies, UWI, Barbados.

Khokiattiwong, S., R. Mahon, W. Hunte. 2000. Seasonal abundance and reproduction of the fourwing flyingfish, *Hirundichthys affinis*, off Barbados. Environmental Biology of Fishes 59,43-60

Kinch, A., and H.A. Oxenford. In press. Fishers' observations of climate change impacts on the flyingfish fishery in Barbados. Proceedings of the Gulf & Caribbean Fisheries Institute 71.

Laffoley, D.d'A., H.S.J. Roe, M.V. Angel, J. Ardron, N.R. Bates, I.L. Boyd, S. Brooke et. al. 2011. *The protection and management of the Sargasso Sea: The golden floating rainforest of the Atlantic Ocean. Summary Science and Supporting Evidence Case.* Sargasso Sea Alliance, 44 pp.

Mahon, R. 1999. Dolphinfish fisheries in the Caribbean region. Scientia Marina 63: 411-420.

Mahon, R., C. Parker, T. Sinckler, S. Willoughby and J. Johnson. 2007. The value of Barbados' fisheries: a preliminary assessment. Fisheries Division, Ministry of Agriculture and Rural Development, Barbados, Fisheries Management Plan Public Information Document No. 2, 24pp.

Mahon, R., H.A. Oxenford. 1999. Precautionary assessment and management of dolphinfish in the Caribbean. Scientia Marina 63 (3-4):429-438.

Mohammed, E., M. Vasconcellos, S. Mackinson, P. Fanning, S. Heileman and F. Carocci. 2008. A trophic model of the Lesser Antilles pelagic ecosystem. Scientific basis for ecosystem-based management in the Lesser Antilles including interactions with marine mammals and other top predators. FAO/Government Cooperative Programme FI:GCP/RLA/140/JPN Technical Document 2, 168 pp.

Monnereau, I. and H.A. Oxenford. 2017. Impacts of climate change on fisheries in the coastal and marine environments of Caribbean small island developing states (SIDS). Caribbean Marine Climate Change Report Card: Science Review 2017: 124-154.

Monnereau, I., Mahon, R., McConney, P., Nurse, L., Turner, R. and H. Vallès. 2015. *Vulnerability of the fisheries sector to climate change impacts in Small Island Developing States and the Wider Caribbean*. Centre for Resource Management and Environmental Studies, The University of the West Indies, Cave Hill Campus, Barbados. CERMES Technical Report No. 77: 81pp

Oxenford, H. A. 1999. Biology of the dolphinfish (*Coryphaena hippurus*) in the Western Central Atlantic: a review. Scientia Marina. 63 (3-4): 277-301.

Oxenford, H.A. 1985. Biology of the dolphin *Coryphaena hippurus* and its implications for the Barbadian fishery. PhD Thesis, University of the West Indies, Cave Hill Campus, Barbados. 366pp.

Oxenford, H.A. and I. Monnereau. 2017. Impacts of climate change on fish and shellfish in the coastal and marine environments of Caribbean small island developing states (SIDS). Caribbean Marine Climate Change Report Card: Science Review 2017, pp 83-114.

Oxenford, H.A. and I. Monnereau. 2018. Chapter 9: Climate change impacts, vulnerabilities and adaptations: Western Central Atlantic marine fisheries. Pp. 147-168 i*n*: Barange, M., Bahri, T., Beveridge, M., Cochrane, K., Funge-Smith, S., and Poulain, F. (eds.). Impacts of Climate Change on fisheries and aquaculture: Synthesis of current knowledge, adaptation and mitigation options. FAO Fisheries Technical Paper 627.

Oxenford, H.A. and W. Hunte. 1986. A preliminary investigation of the stock structure of the dolphin, *Coryphaena hippurus* in the Western Central Atlantic. Fishery Bulletin 84 (2): 451-460.

Oxenford, H.A., Mahon, R. and W. Hunte (eds). 2007. Biology and Management of Eastern Caribbean Flyingfish. Centre for Resource Management and Environmental Studies, UWI, Barbados. 268pp.

Oxenford, H.A., W. Hunte, R. Deane and S.E. Campana. 1994. Otolith age validation and growth rate variation in flyingfish (*Hirundichthys affinis*) from the eastern Caribbean. Marine Biology 118 (4): 585-592.

Ramlogan, N., McConney, P. and H.A. Oxenford. 2017. Socio-economic impacts of *Sargassum* influx events on the fishery sector of Barbados. CERMES Technical Report 81: 86pp.

Schuhmann, P.W., Oxenford, H.A., Staskiewicz T. and J. Walcott. 2010. Landings, costs, net profit and return on investment in two contrasting fisheries: Part 1 – The longline fishery. Economic Valuation of the Fisheries of Barbados: Second Project Report for Ministry of Agriculture, Government of Barbados, 59pp.

Speede, R.F. 2018. Best practices for Caribbean fishers coping with sargassum influx events. MSc Research Paper, Centre for Resource Management and Environmental Studies, the University of the West Indies, Cave Hill, Barbados, 86pp.

Speede, R.F., Cox, S-A. and H.A. Oxenford. 2019. Best practices for Caribbean fishers coping with sargassum. Centre for Resource Management and Environmental Studies, the University of the West Indies, Cave Hill, Barbados, 23pp.

Wang, M. and C. Hu. 2016. Mapping and quantifying Sargassum distribution and coverage in the Central West Atlantic using MODIS observations. Remote Sensing of the Environment 183: 356-367.

9. Appendices

Appendix 1: Exploratory analyses of catch data provided by CC4FISH participating countries

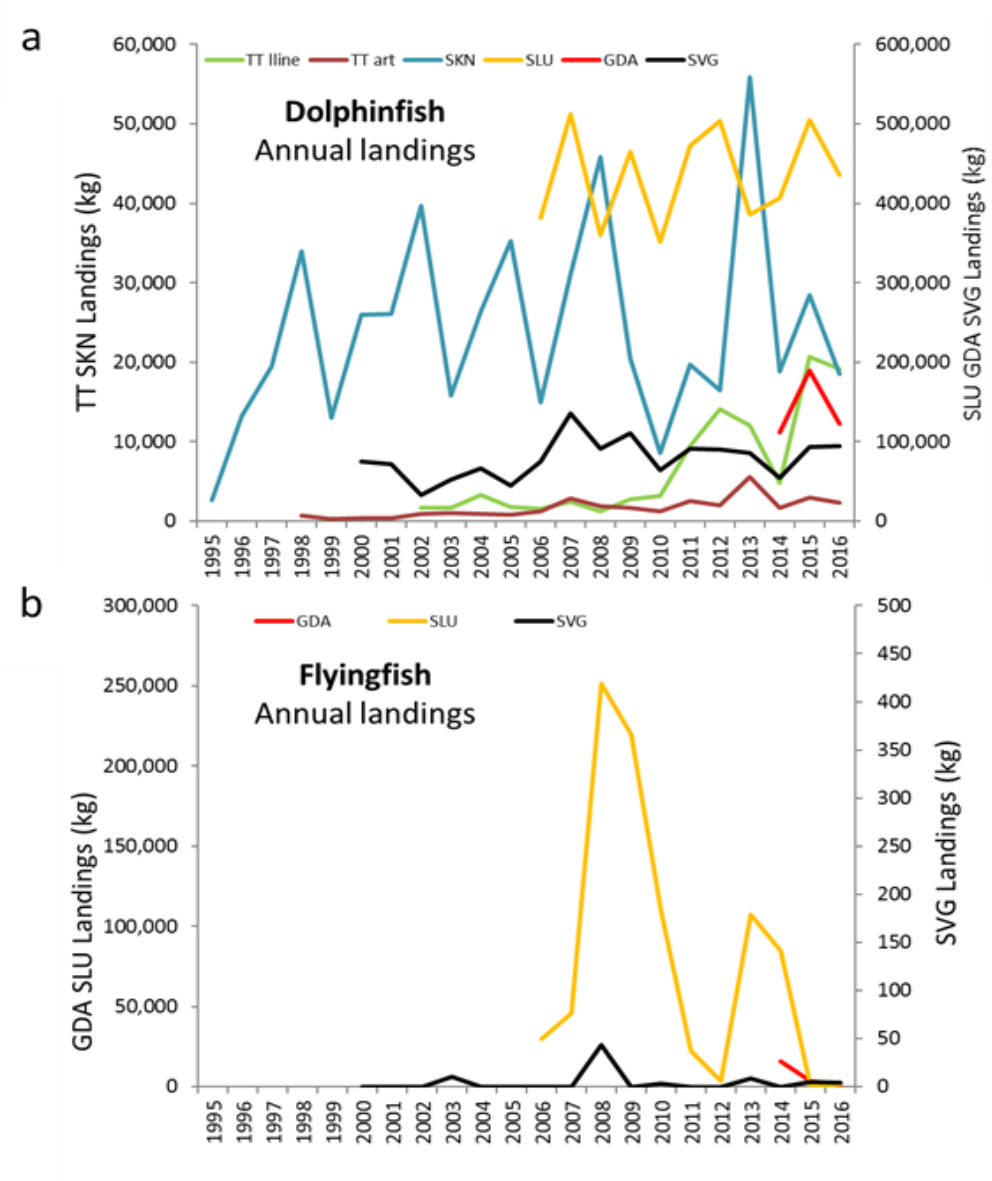

Figure A1-1. Time-series plots showing annual fishery landings data submitted by CC4FISH participating countries for (a) dolphinfish, and (b) flyingfish. Note the two vertical axes showing quantity of fish landed have scales that differ by10 fold for (a), and by 1000 fold for (b). Annual patterns were not coherent among country data sets and annual resolution was insufficient for correlation with sargassum abundance. GDA - Grenada, SKN - St Kitts and Nevis, SLU - St Lucia, SVG - St Vincent, TT art - Trinidad artisanal fleet, TT lline - Trinidad longline fleet.

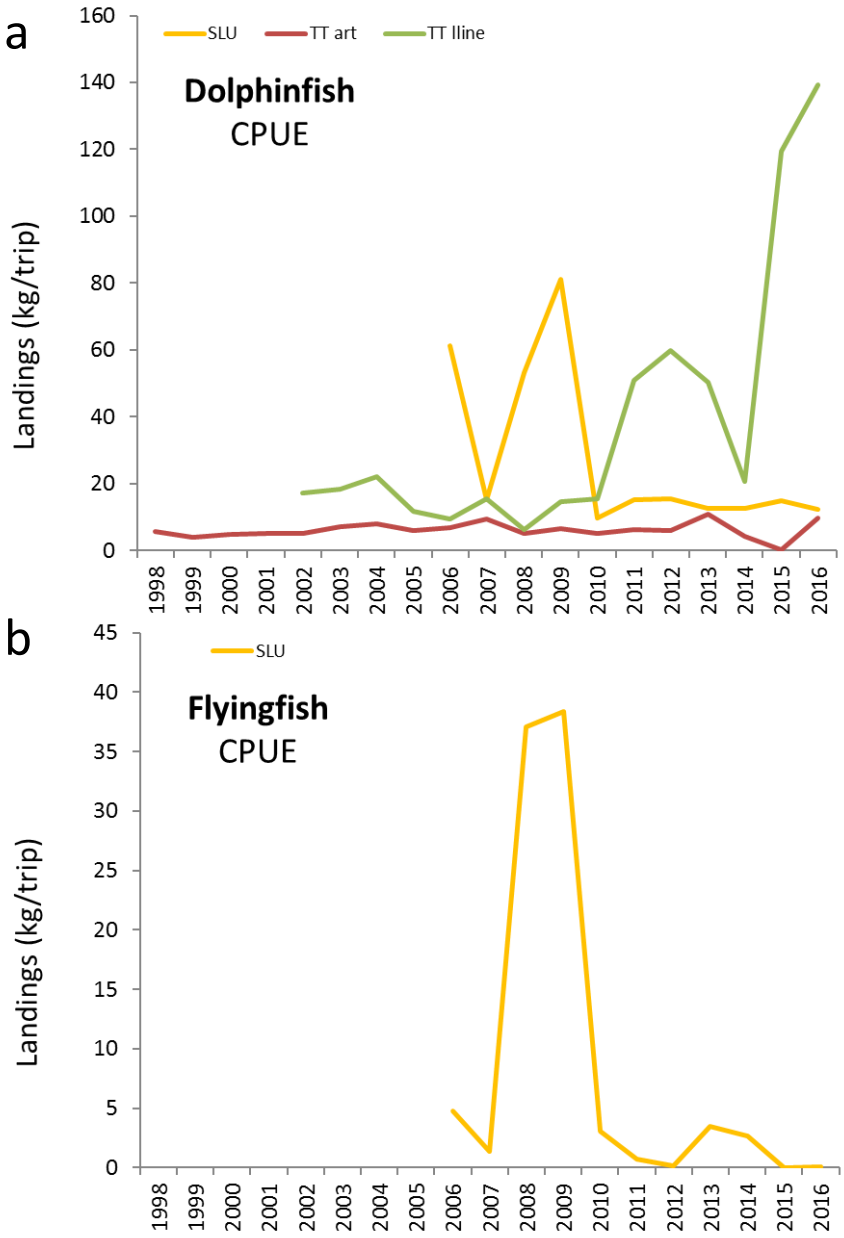

Figure A1-2. Time-series plots showing an index of fish abundance (as annual mean CPUE) submitted by CC4FISH participating countries for (a) dolphinfish, and (b) flyingfish. Annual patterns were not coherent among country data sets (for dolphinfish) and high interannual variation is indicated by the St Lucia data set for flyingfish. Lack of records for trips with zero catches constrains usefulness of index. SLU - St Lucia, TT art - Trinidad artisanal fleet, TT lline - Trinidad longline fleet.

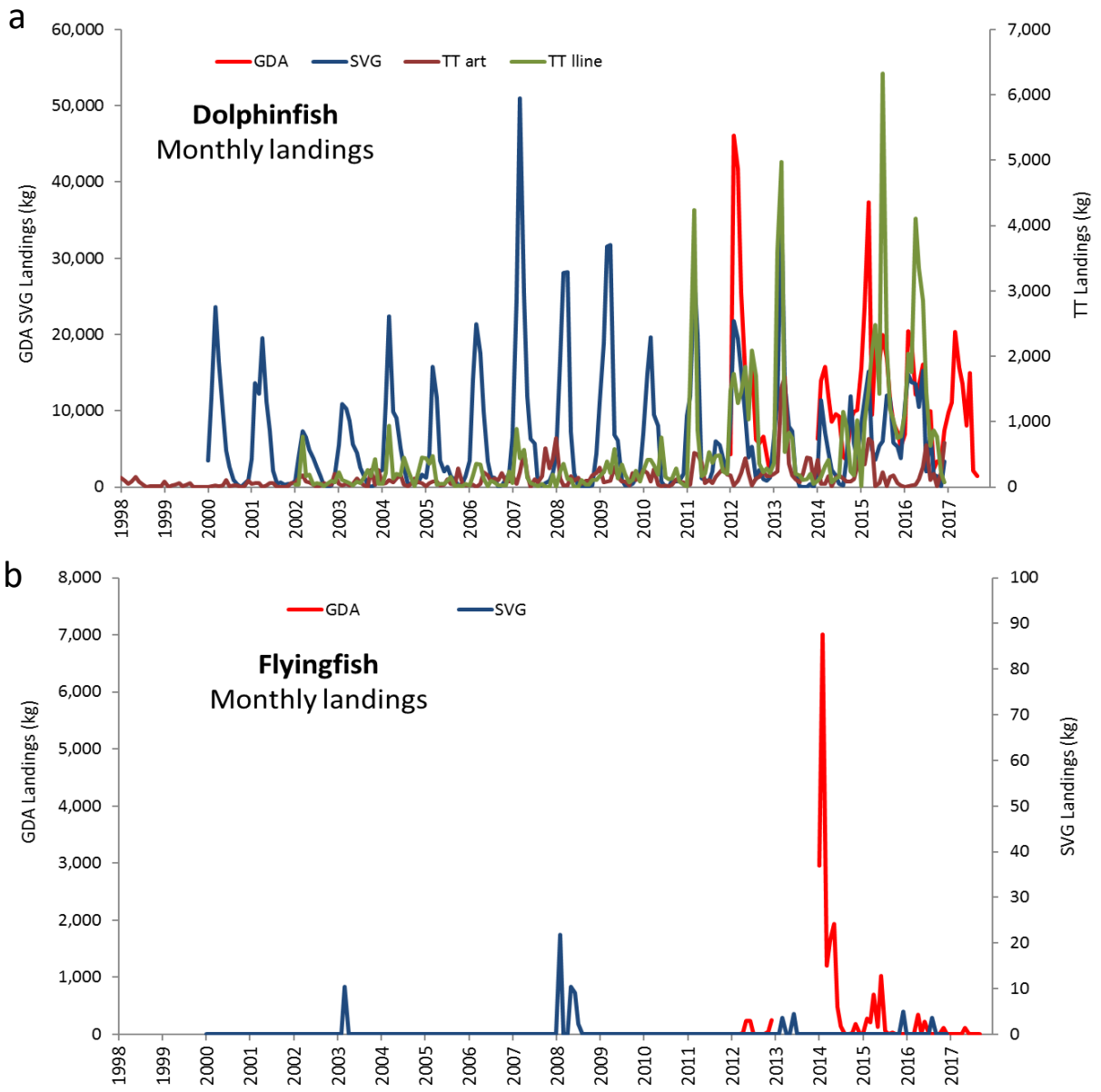

Figure A1-3. Time-series plots showing monthly fishery landings data submitted by CC4FISH participating countries for (a) dolphinfish, and (b) flyingfish. Note the two vertical axes showing quantity of fish landed have scales that differ by10 fold for (a), and by 100 fold for (b). Peak years and poor years were not coherent among country data sets for dolphinfish and data were insufficient for flyingfish. GDA - Grenada, SVG - St Vincent, TT art - Trinidad artisanal fleet, TT lline - Trinidad longline fleet.

Appendix 2: Exploratory analyses for oceanographic variables

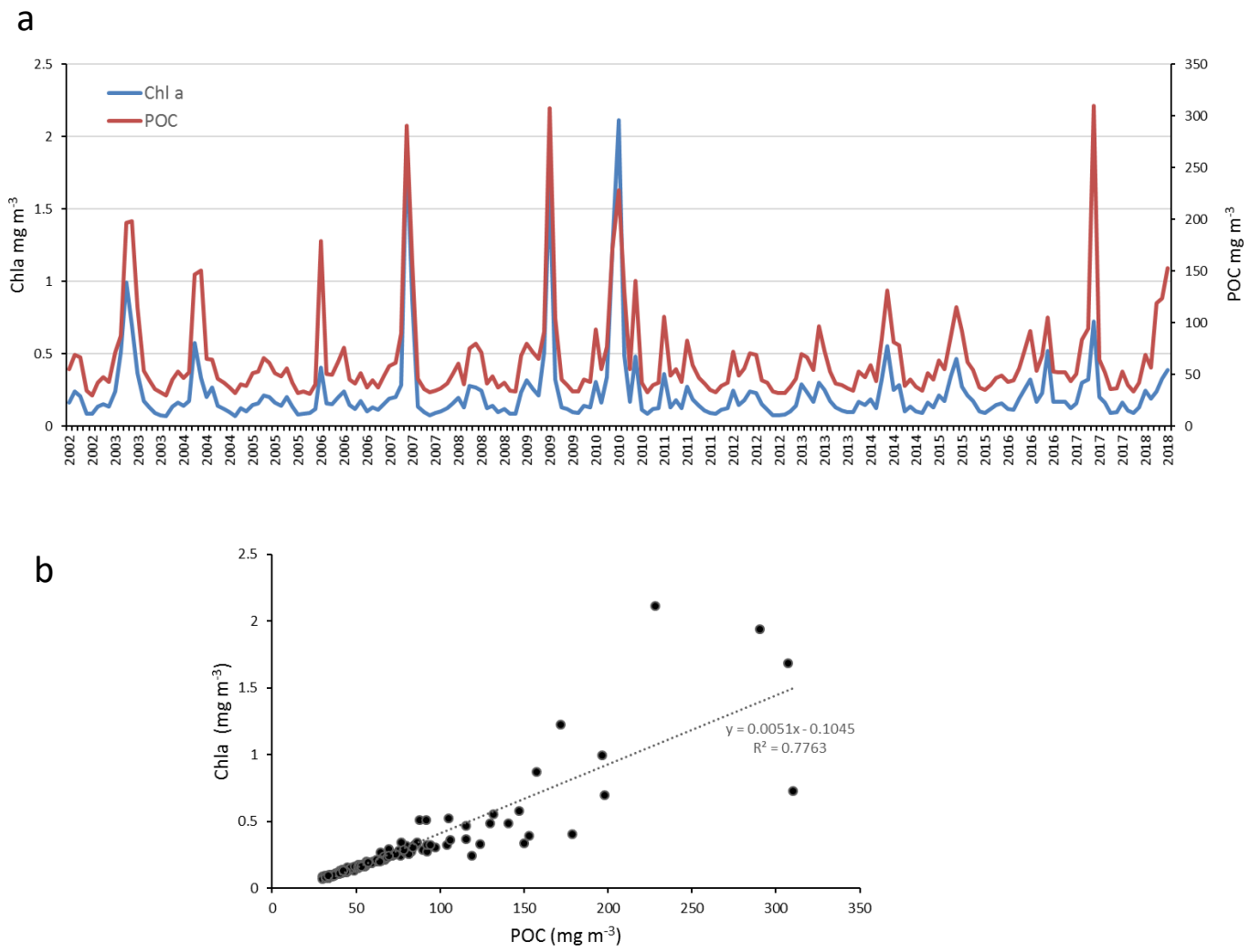

Figure A2-1. Plot of monthly mean chlorophyll a (Chla) concentration versus particulate organic carbon (POC) concentration (2002-2018) for Barbados one degree grid square (a), showing a strong correlation between them (b). As such, only Chla was used in correlation analyses with fishery data. Data are from the open-source Giovanni database (https://giovanni.gsfc.nasa.gov/giovanni/).

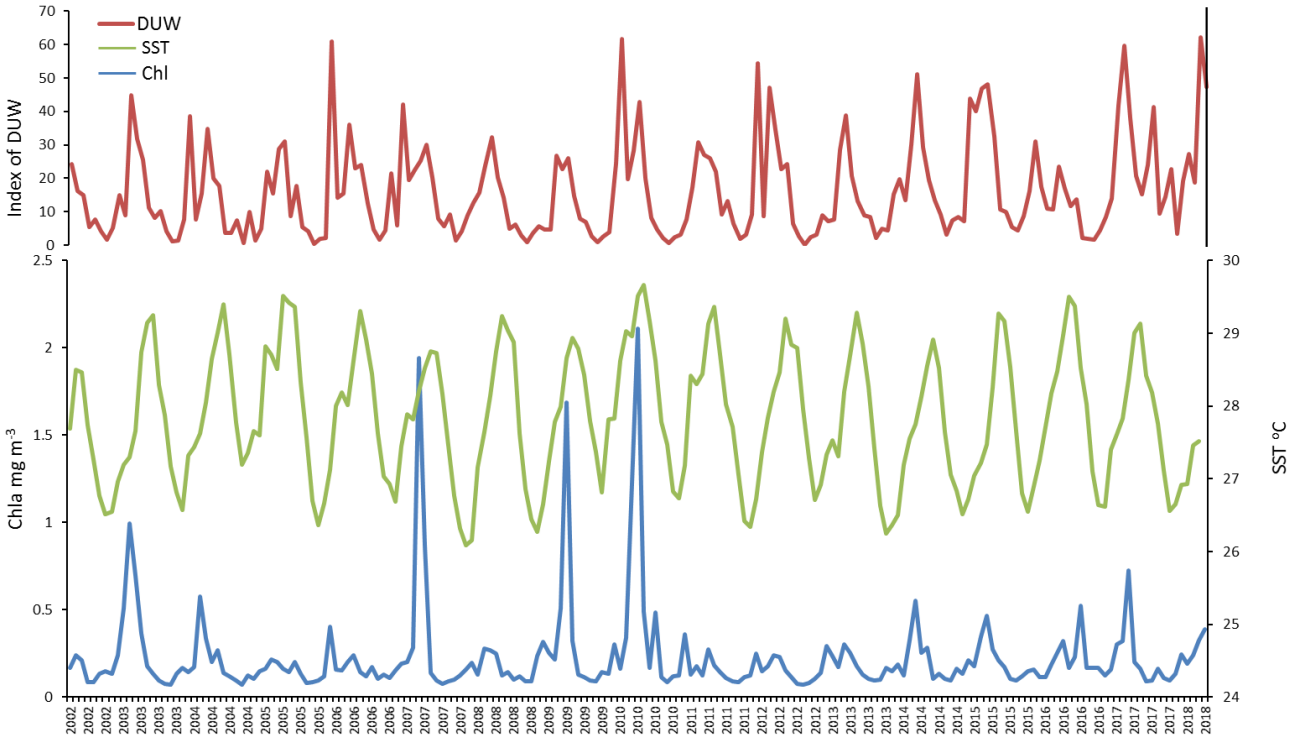

Figure A2-2. Plot of monthly mean oceanic variables (Chla - chlorophyll a concentration, SST - nightime sea surface temperature, DUW - dust wet deposition) over the period 2002-2018 for Barbados one degree grid square. Data are from the open-source Giovanni database (https://giovanni.gsfc.nasa.gov/giovanni/). These were used to explore possible relationships with the fishery data.

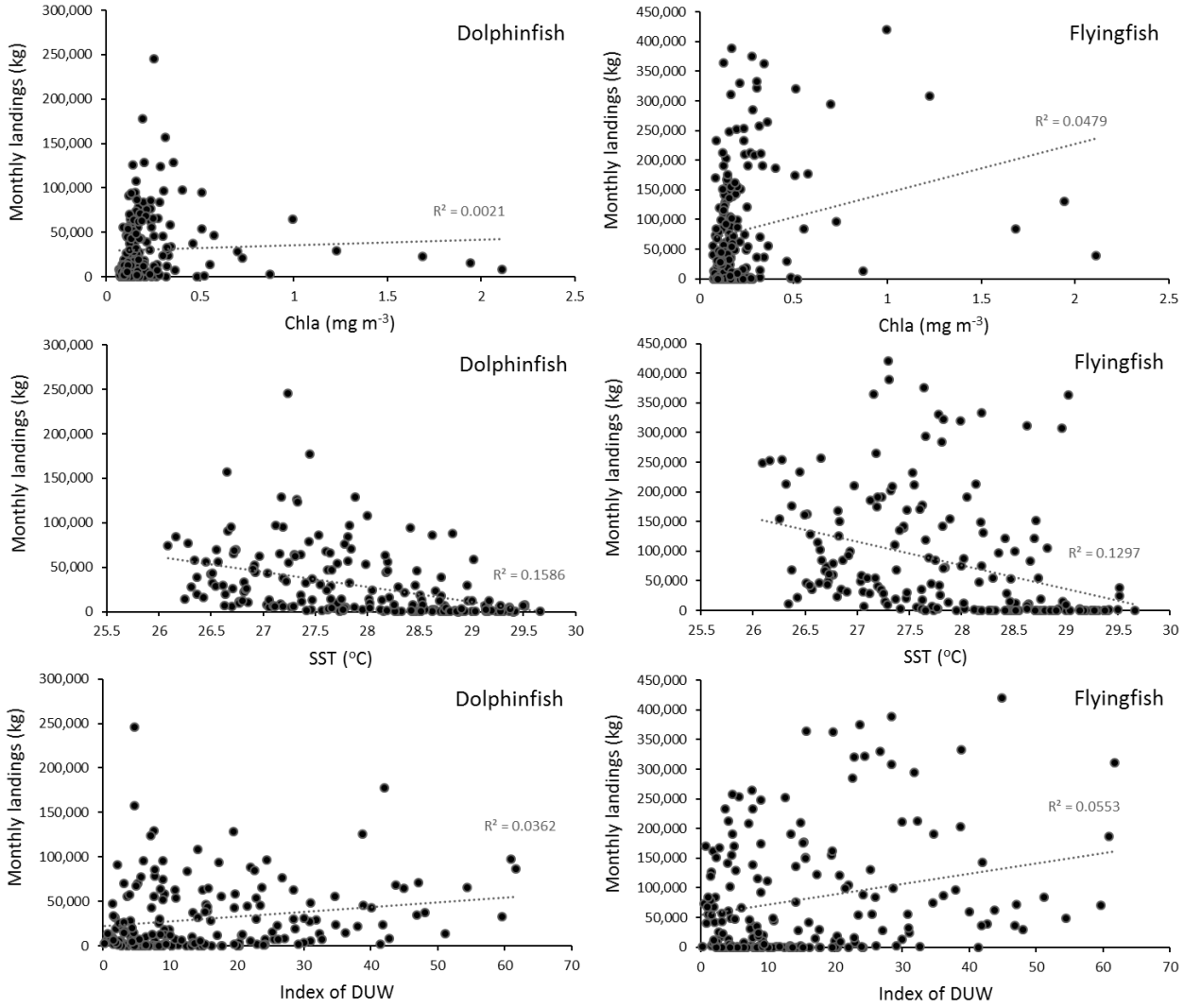

Figure A2-3. Exploratory analyses of fish landings by the Barbados pelagic fishing fleet versus select oceanographic variables over the period July 2002 to December 2017. Landings data are monthly recorded totals for dolphinfish (left panel) and flyingfish (right panel) from the official database of the Barbados Fisheries Division. Oceanographic variables (Chla - chlorophyll concentration, SST - night-time sea surface temperature, DUW - dust wet deposition) are monthly mean values for the selected one degree square to the east of Barbados (shown in Figure 1) and are downloaded from the open-source Giovanni database (https://giovanni.gsfc.nasa.gov/giovanni/). Dashed lines show plotted linear trend between variables and low R^2 values indicate lack of correlation in all cases.