Foras na Mara
Marine Institute

CHAPTER 5

PHYTOPLANKTON

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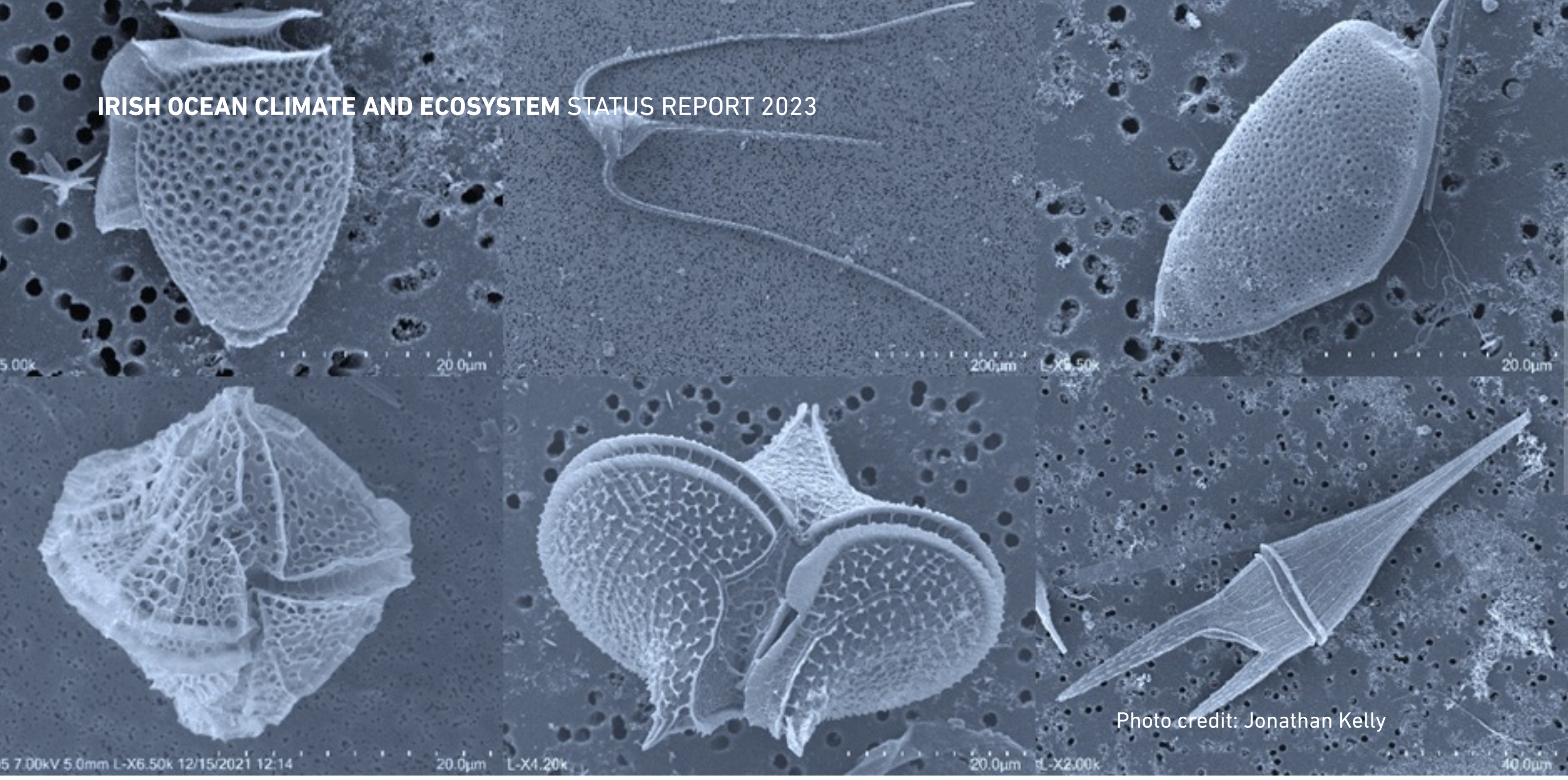

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5.1 INTRODUCTION

Marine phytoplankton are responsible for c. 50% of the primary production on Earth. These microscopic unicellular plant-like organisms are an important food source that sustains marine life and benefits humans who depend on seafood as their primary source of protein. Phytoplankton can be thought of as sensitive indicators of climate change, where changes in community composition can affect and alter marine ecosystems.

A phytoplankton group known as harmful algae with ~200 species know globally. Harmful algae are broadly split into two sub-groups; toxin and non-toxin producing species that can cause harmful effects to marine ecosystems and/or cause seafood safety issues. Toxins produced include Phycotoxins (which can cause harm and impact human health if contaminated shellfish are consumed) and Icthyotoxins (responsible for fish kills). Non-toxin producing high biomass phytoplankton bloom species can result in negative marine ecosystem effects including anoxia, water discolouration, mucilage, and mechanical damage to fish gills.

This chapter presents the observed national and regional phytoplankton results (composition, abundance and peak growth from a seasonal and annual perspective) with data collated from the Marine Institute's National Monitoring Programme for Phytoplankton from 2001 to 2020.

The impacts of climate change on the seafood sector through Harmful Algal Bloom (HAB) events are expected to occur more frequently. An expansion of the phytoplankton growth season (for some species) has already been observed. Changing environmental conditions driven in part by climate change can result in multiple environmental stressors influencing HABs.

5.2 STATUS AND TRENDS OF PHYTOPLANKTON – A GLOBAL PERSPECTIVE

The IOC–UNESCO Global Harmful Algal Bloom Status Report (Hallegraeff *et al*., 2021a) concluded that the perceived idea that HAB trends and events are increasing globally is unsupported by meta–analyses. For a true assessment, research is required at a regional basis focused on individual species and associated biotoxins. This conclusion was also reached after an intensive review of international datasets (Hallegraeff *et al*., 2021b) showing there are no statistically significant trends of increasing distribution and abundances of HAB species. Increased awareness, technology

Monthly cell abundance of diatoms has increased throughout the year nationally, with noticeable increases between October to January, outside the expected growth season.

and monitoring efforts have resulted in increased reports of HAB events, rather than due to increases in the actual occurrence of HAB events.

Climate change impacts on HAB species are of a global concern with many unknowns and scientific questions on how phytoplankton and HAB species will adapt to future changes in the marine environment (Wells *et al.*, 2021). Physical and biogeochemical changes that influence water column stratification, temperature, ocean acidification, and salinity could lead to changes in phytoplankton distributional ranges and an extension of the growth season in some regions (Edwards *et al.*, 2020). In a world with an increasing human population and a demand for increased global food production from aquaculture, there is uncertainty around climate change impacts on shellfish species settlement and growth, the carrying capacity of bays and physical processes such as flooding, coastal erosion and storms affecting coastal and intertidal habitats.

It is generally concluded that more comprehensive time series data are required, on environmental parameters surrounding HAB events, to improve HAB modelling and predictive forecasts (Wells *et al.*, 2020). Such datasets are essential to improve our understanding of the observed effects and changes in phytoplankton communities and HAB events attributed to climate change.

5.3 STATUS AND TRENDS OF PHYTOPLANKTON IN IRISH WATERS

The phytoplankton community composition in Irish coastal waters is influenced by ocean current circulation patterns and seasonal changes of light availability, nutrients, salinity, temperature and other variables. Inshore marine areas, remain relatively well mixed in winter with intermittent water column stratification due to freshwater runoff from land. In the warmer months, thermal stratification influences phytoplankton growth from March to September. Offshore, in shelf waters, the transport of phytoplankton is associated with the Irish Coastal Current with bottom density fronts playing an important role for the development and transport of blooms in summer and autumn. The transport of phytoplankton and HABs into the bays of southwest Ireland are primarily driven by wind. For a detailed review on the biophysical drivers of HABs in Irish waters please refer to Raine (2014).

Results presented here indicate a noticeable extension of the growth season and an increased average abundance of some phytoplankton in the last decade. In addition, the previous *Irish Ocean Climate & Ecosystem Status report* (Nolan *et al.*, 2010) observed that during the growth season there was an increased phytoplankton abundance (particularly for diatoms) in the early months of the year (from 1998 to 2002), a trend that is also observed in this review. The dinoflagellate group are typically at their highest cell densities from June to August, with the growth season commencing in May and continuing through to August on an annual basis.

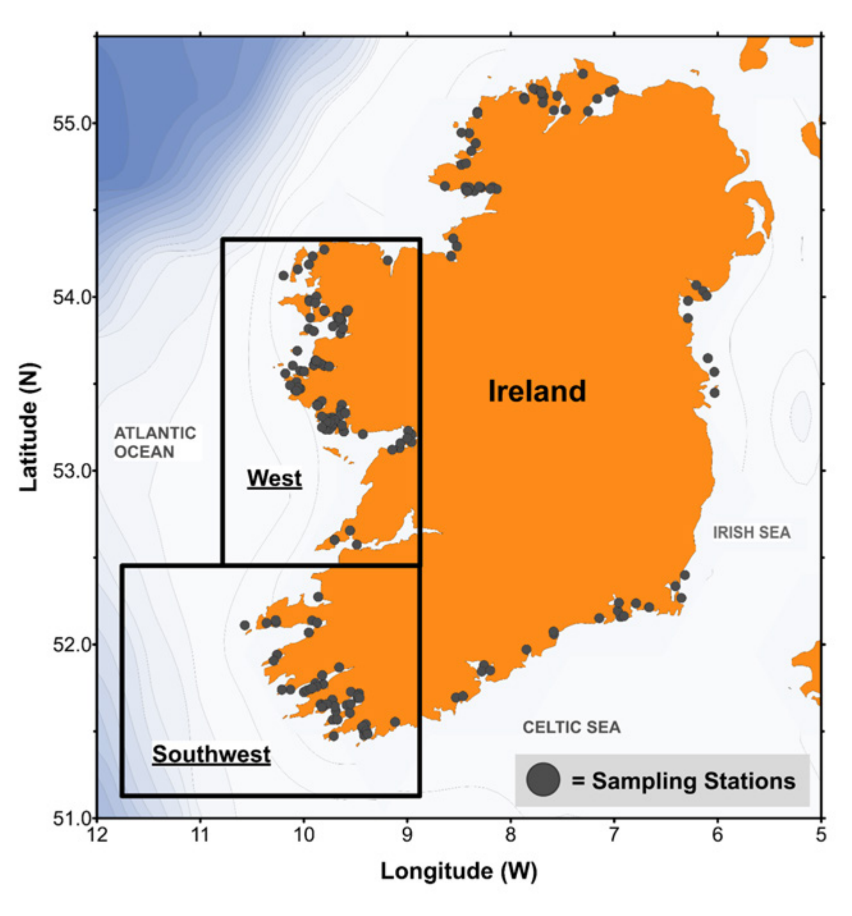


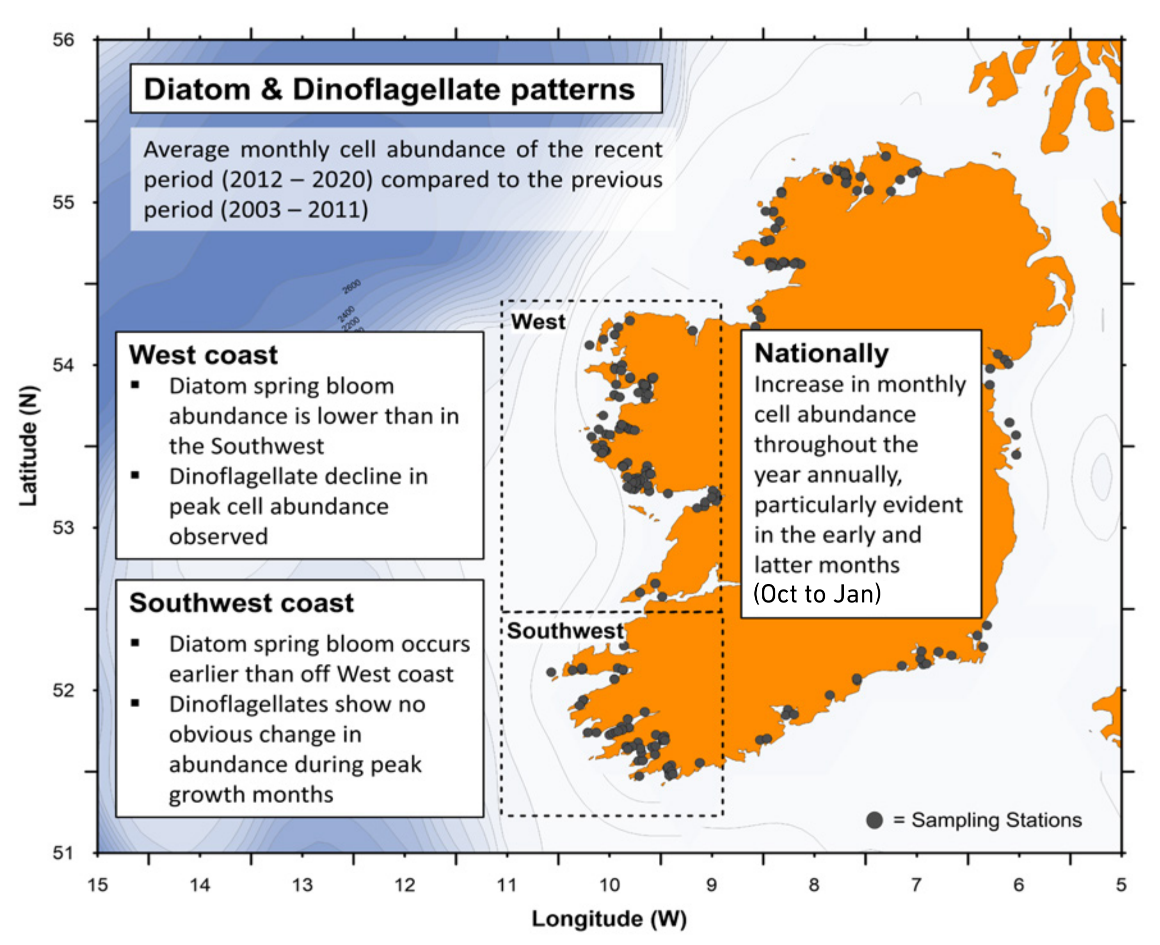
Figure 5.1 Map of aquaculture site locations in Ireland where *in situ* water samples are collected, represented by grey circles. The west and southwest regions are specific focus areas in this review and are defined by the boxes in the map.

5.4 PHYTOPLANKTON DATASETS

The Irish National Monitoring Programme (NMP) for Phytoplankton commenced in the mid–1980s and was setup to identify and enumerate phytoplankton species (with a particular emphasis on harmful algae) in coastal areas where licensed finfish and shellfish aquaculture operations take place. In the early 2000s, the programme was improved and expanded, and from 2014 onwards, circa 70 samples were collected and analysed weekly in actively harvesting production areas.

Since 2003, phytoplankton data are stored in the Marine Institute's Harmful Algal Blooms (HABs) database (Microsoft SQL Server) with all NMP data publicly available at https://webapps.marine.ie/habs. Prior to this, the Marine Institute's Phytobase (Microsoft Access) database was used to store phytoplankton data.

Phytoplankton data (average monthly cell abundance) used in this chapter covers the time period from 2003 to 2020 for three main phytoplankton groups: diatoms, dinoflagellates and 'all community' species. For the HAB species detailed in this review, a slightly expanded dataset from 2001 to 2020 was used. For both data sets, results were compiled into three areas, referred to as the 'whole Ireland' where all NMP coastal site data was included, and for two specific regions where intensified aquaculture production activities occur, i.e., the "west" and the "southwest" (Figure 5.1).



Diatom & Dinoflagellate patterns

Average monthly cell abundance of the recent period (2012 – 2020) compared to the previous period (2003 – 2011)

West coast

- Diatom spring bloom abundance is lower than in the Southwest
- Dinoflagellate decline in peak cell abundance observed

Southwest coast

- Diatom spring bloom occurs earlier than off West coast
- Dinoflagellates show no obvious change in abundance during peak growth months

Nationally

Increase in monthly cell abundance throughout the year annually, particularly evident in the early and latter months (Oct to Jan)

Figure 5.2 Overview of the key observations and changes observed for Diatom and Dinoflagellate average monthly cell abundance and occurrence from 2003 to 2020

Additional phytoplankton abundance datasets for Irish coastal and estuarine waters exist. These programmes include (a) the annual offshore phytoplankton oceanographic survey and (b) the Water Framework Directive (WFD) monitoring programme that began in 2011. The Environmental Protection Agency and the Marine Institute are responsible for WFD phytoplankton monitoring, one of the many parameters used in the assessment of water quality. Due to different consistencies in timeframes, sampling protocols and analytical methodologies, data from the two programmes mentioned above are excluded from the current review.

5.5 PHYTOPLANKTON IN COASTAL BAYS

The key observations and changes observed for diatom and dinoflagellate average monthly cell abundance and occurrence from 2003 to 2020, with comparisons between the two time periods 2003–2011 and 2012–2020 are presented in Figure 5.2.

In coastal waters, phytoplankton are relatively abundant throughout the year from February to October. Diatom blooms occur in both spring and autumn, and as expected, spring bloom abundances are higher than those observed in autumn. From a national perspective, the overall observation for the total phytoplankton community

Photo credit: Andrew Downes

was an increased cell abundance on a monthly basis throughout the year for the period 2012–2020 when compared to 2003–2011 (Figure 5.3(a)). While high phytoplankton productivity is expected at inshore coastal sites throughout the growth season (March to September), the recent elevated levels of phytoplankton in late autumn and winter (October to January) is surprising.

The recent monthly average cell abundance increase throughout the year is particularly noticeable off the west coast of Ireland. For the period 2012–2020, average cell concentrations were higher and the growth season extended in the latter part of the year.

Since 2008, phytoplankton average numerical abundance has increased in winter. Off the southwest coast (Figure 5.3(b)), from 2003 to 2011 the highest average cell concentration was in June; however, this was not observed in the recent period, 2012–2020. The overall observations from the west and nationally, 2012–2020 show a higher average cell abundance with a more prolonged growth period throughout the year. Of interest in the southwest, was a change from a bi–modal seasonal distribution (2003–2011) to a tri–modal distribution (2012–2020).

For diatoms, nationally, there were increases of average cell abundances throughout the year in the recent period (2012–2020) when compared to the period 2003–2011 (Figure 5.3(c)). The spring bloom duration increased from March to April (2003–2011) to March to May (2012–2020). Slightly different patterns emerge in the west and southwest regions, e.g., the spring bloom off the southwest coast occurs earlier in the year by approximately one month. Spring bloom cell abundances are also lower in the west when compared to the southwest, and this is particularly evident in the 2012–2020 period (Figure 5.3(d)).

For dinoflagellates, nationally, average cell abundance for the time period 2003–2011 increased from May with maximum abundances in July and August while the maximum for the period 2012–2020 were confined to August (Figure 5.3(e)). In recent years (2012–2020), dinoflagellates have shown an increased abundance in the early and latter months of the year. Slightly different geographic patterns are observed in both periods regionally. For the period 2003–2011 dinoflagellate bloom peak (cell maximum abundance) was in July, while it was August in the southwest. For the period 2012–2020 the bloom peak in both the west and southwest was lower than that observed in 2003–2011 (Figure 5.3(f)).

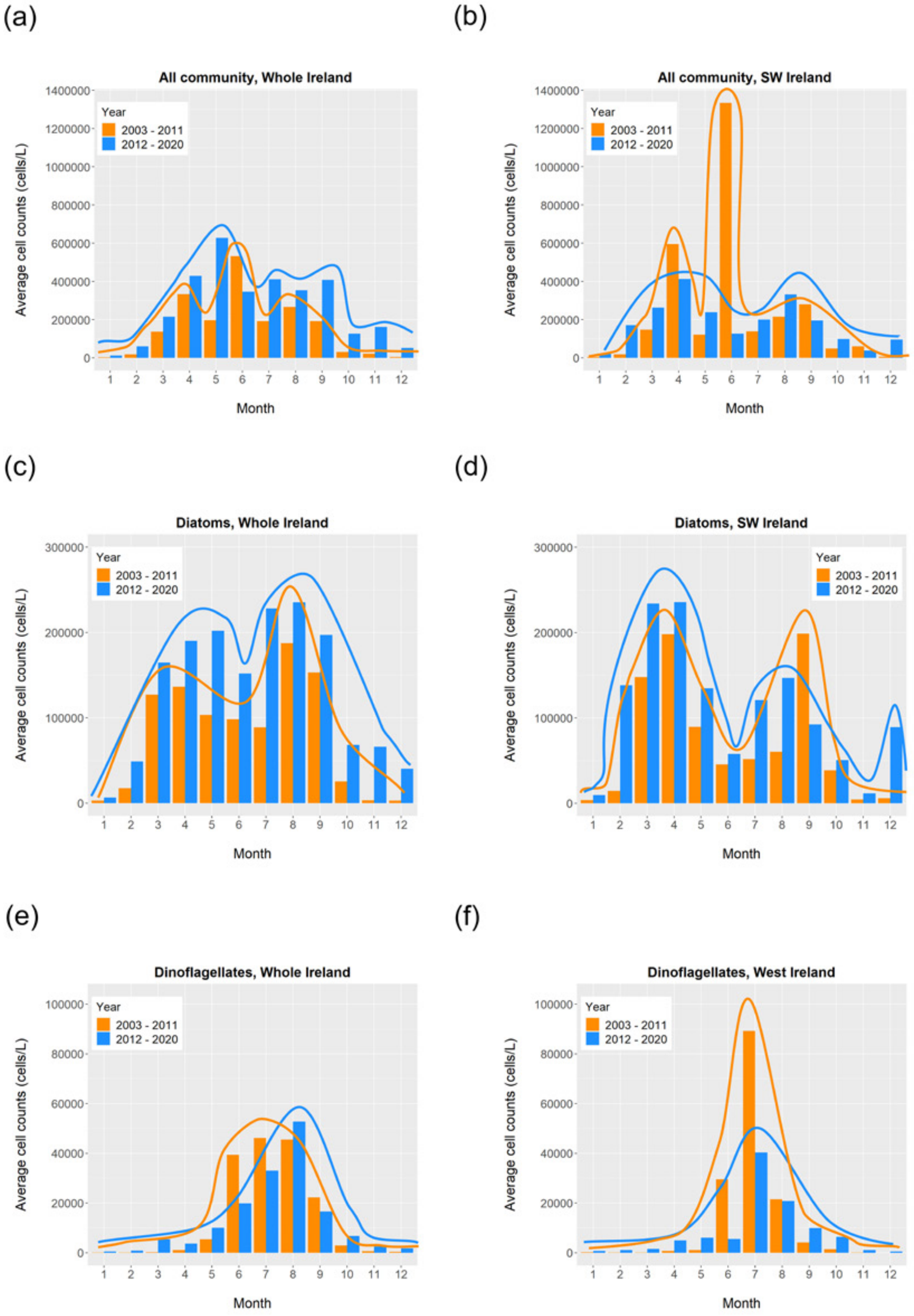


Figure 5.3 Average monthly cell counts (cells/L) for two time periods, 2003–2011 (orange) and 2012–2020 (blue). X–axis=month; Y–axis=numerical abundance. Phytoplankton community (a) whole Ireland and (b) southwest Ireland. Diatoms (c) whole Ireland and (d) southwest Ireland. Dinoflagellates (e) whole Ireland and (f) west Ireland. *Orange/Blue distribution lines are free hand drawn and are for visual purposes only to demonstrate seasonal changes in abundance between the two time periods and not statistically derived.*

5.6 POTENTIALLY TOXIC AND/OR HARMFUL ALGAL BLOOMS (HABS)

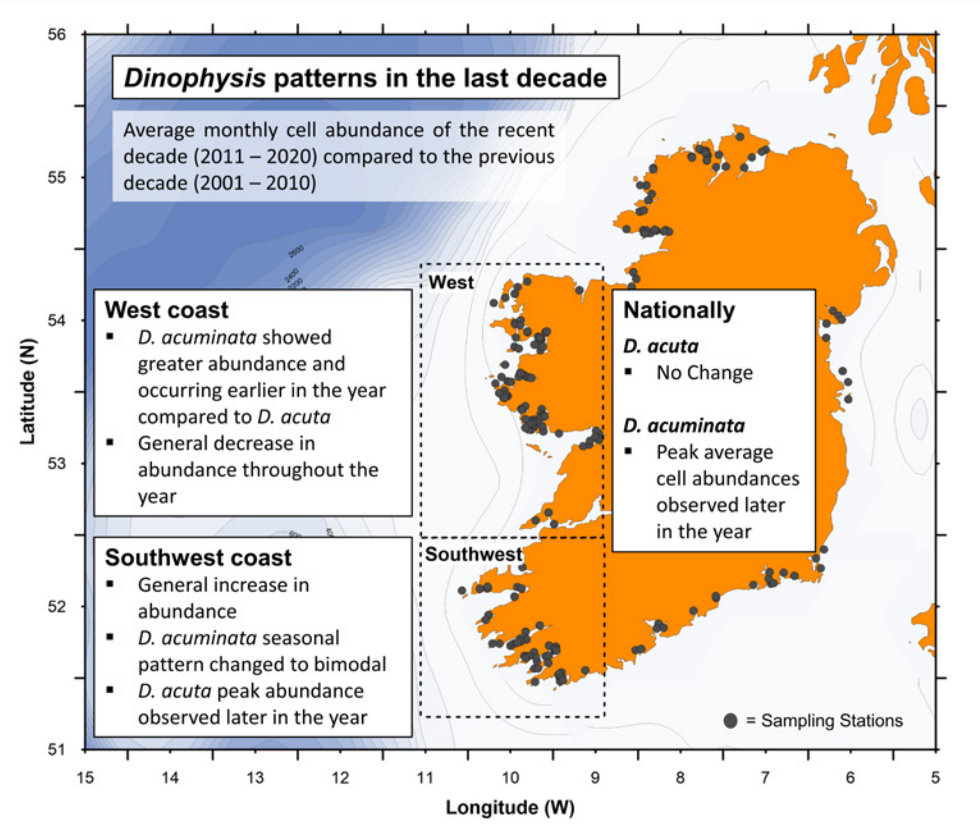
In this study, five phytoplankton taxa, each with the potential to cause a harmful algal event are examined over two decades between 2001 and 2010 and 2011 and 2020 (see Figures 5.4 – 5.8). These taxa include *Dinophysis acuminata*, *Dinophysis acuta, Karenia mikimotoi, Alexandrium* species and *Pseudo–nitzschia* species from the "*P. seriata*" complex. The HAB taxa exhibited large inter–annual variability.

5.6.1 *DINOPHYSIS* SPECIES

Dinophysis acuminata and *Dinophysis acuta* are usually present as low biomass blooms that produce Diarrhetic Shellfish Toxins. An overview of key observations for *Dinophysis* species average monthly cell abundance in the recent decade (2011–2020) compared to the previous decade (2001–2010) are presented in Figure 5.4.

The most abundant *Dinophysis* species in Irish coastal waters, responsible for Diarrhetic Shellfish Toxins in Irish shellfish, are *D. acuminata* and *D. acuta*. Nationally, there was relatively little change in the overall average monthly *Dinophysis* cell abundances. Regionally, however, changes were

An overall decrease in average monthly cell abundance was observed for both *Dinophysis acuta* and *Dinophysis acuminata* off the west coast of Ireland. In the southwest, a general increase in abundance was observed with *D. acuta* maximum abundance peaking later in the year.



***Dinophysis* patterns in the last decade**

Average monthly cell abundance of the recent decade (2011 – 2020) compared to the previous decade (2001 – 2010)

West coast

- *D. acuminata* showed greater abundance and occurring earlier in the year compared to *D. acuta*
- General decrease in abundance throughout the year

Southwest coast

- General increase in abundance
- *D. acuminata* seasonal pattern changed to bimodal
- *D. acuta* peak abundance observed later in the year

Nationally

D. acuta

- No Change

D. acuminata

- Peak average cell abundances observed later in the year

● = Sampling Stations

Figure 5.4 Changes observed for *Dinophysis* species between the period 2003 and 2011 and 2012 and 2020.

observed in the timing of blooms and average monthly cell abundances. In the west, there was a decrease in the average monthly cell abundance for both *D. acuta* and *D. acuminata* during 2011–2020 when compared to 2001–2010. Both *Dinophysis* species are clearly more abundant at aquaculture sites located in southwest Ireland when compared to sites in the west and when combined with the results of sites nationally around the coastline of Ireland. In the southwest, the average monthly cell abundances of *D. acuminata* increased with the maximum abundance occurring earlier in the year (June) in the recent decade (2011–2020) when compared to previous decade (2001–2010; Figure 5.5(a)). For *D. acuta* during 2011–2020, the peak abundance was in September compared to August during 2001–2010 (Figure 5.5(b)). Such changes could have an impact on the timing and length of toxin related shellfish harvesting closures.

5.6.2 *KARENIA MIKIMOTOI*

Karenia mikimotoi is a high biomass bloom forming icthyotoxic (produces chemicals harmful to fish) species that has a negative impact on caged fish and benthic communities. Historically (e.g. in 2005 and 2012) this species formed persistent and geographically extensive large blooms that had devastating effects on Irish marine ecosystems and resulted in extensive mortalities of fish and benthic organisms off the southwest and west coasts of Ireland.

Karenia mikimotoi, has shown a noticeable presence throughout the year, including the winter months since 2000 (Figure 5.6(a)). Average monthly cell abundance of this dinoflagellate in the recent decade (2011–2020) shows this organism is more prevalent than in the previous decade (2001–2010). Blooms (maximum average cell abundance) are occurring later in the year (July to September) with a maximum peak average cell

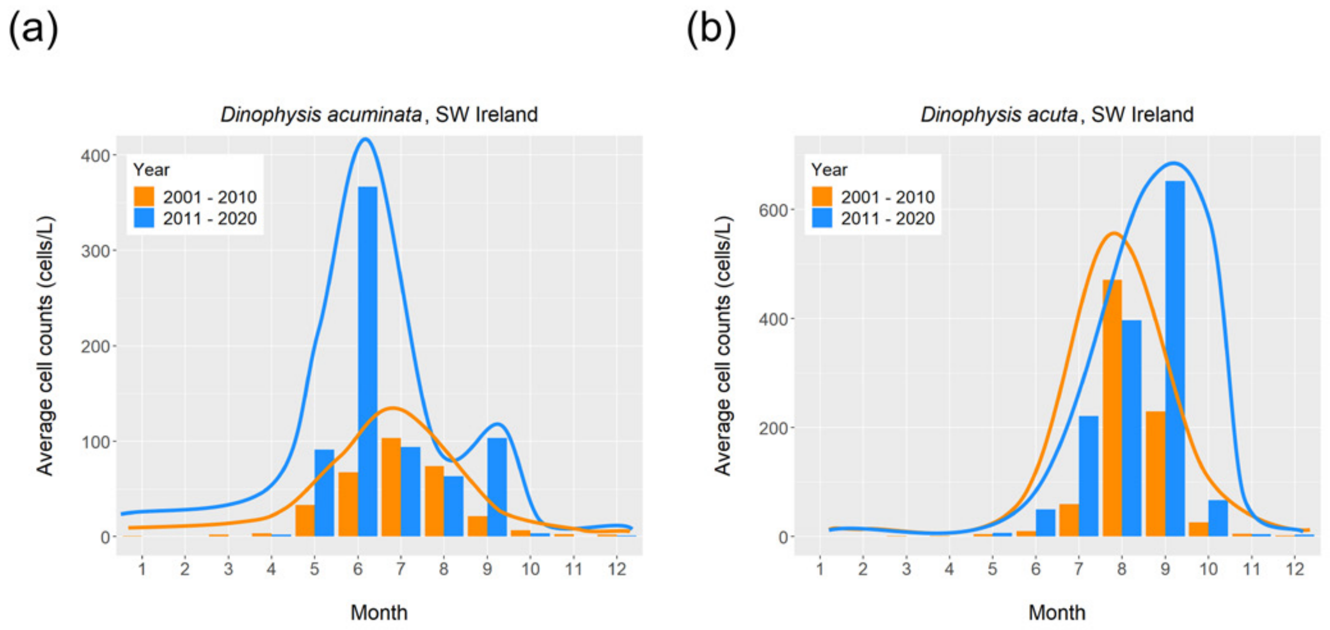


Figure 5.5 Average monthly cell counts (cells/L) for two time periods, 2001–2010 (orange) and 2011–2020 (blue). X–axis=month; Y–axis=numerical abundance. *Dinophysis* species in southwest Ireland (a) *D. acuminata* and (b) *D. acuta. Orange/Blue distribution lines are free hand drawn and are for visual purposes only to demonstrate seasonal changes in abundance between the two time periods and not statistically derived.*

abundance in July compared to June in the previous decade. This pattern is also visible in the west coast region (Figure 5.6(b)) and in the national dataset examined. Maximum average cell abundance off the southwest coast in August/September were higher than in the west (Figure 5.6(b) and 5.6(c)).

5.6.3 *PSEUDO-NITZSCHIA* SPECIES

Pseudo–nitzschia species from the "*P. seriata*" complex represent a mix of difficult to identify species, some of which produce Amnesic Shellfish Toxins. In the recent decade, the abundance of diatoms in the "*P. seriata*" complex have declined with a significant decline observed off the west coast. Nationally, blooms in spring and autumn for the period 2001–2010 are not as obvious in the most recent decade 2011–2020, where average cell abundance is consistent from April to September.

5.6.4 *ALEXANDRIUM* SPECIES

Some *Alexandrium* species cause a serious illness in humans if shellfish contaminated with Paralytic Shellfish Toxins (PST) are consumed resulting in the human syndrome referred to as Paralytic Shellfish Poisoning (PSP).

> ***Karenia mikimotoi* was more abundant in recent years (2011-2020) with blooms occurring later in the year (July to September), and maximum cell abundance is occurring in late July in the most recent decade compared to June in the previous decade (2001-2010) both nationally and in the southwest.**

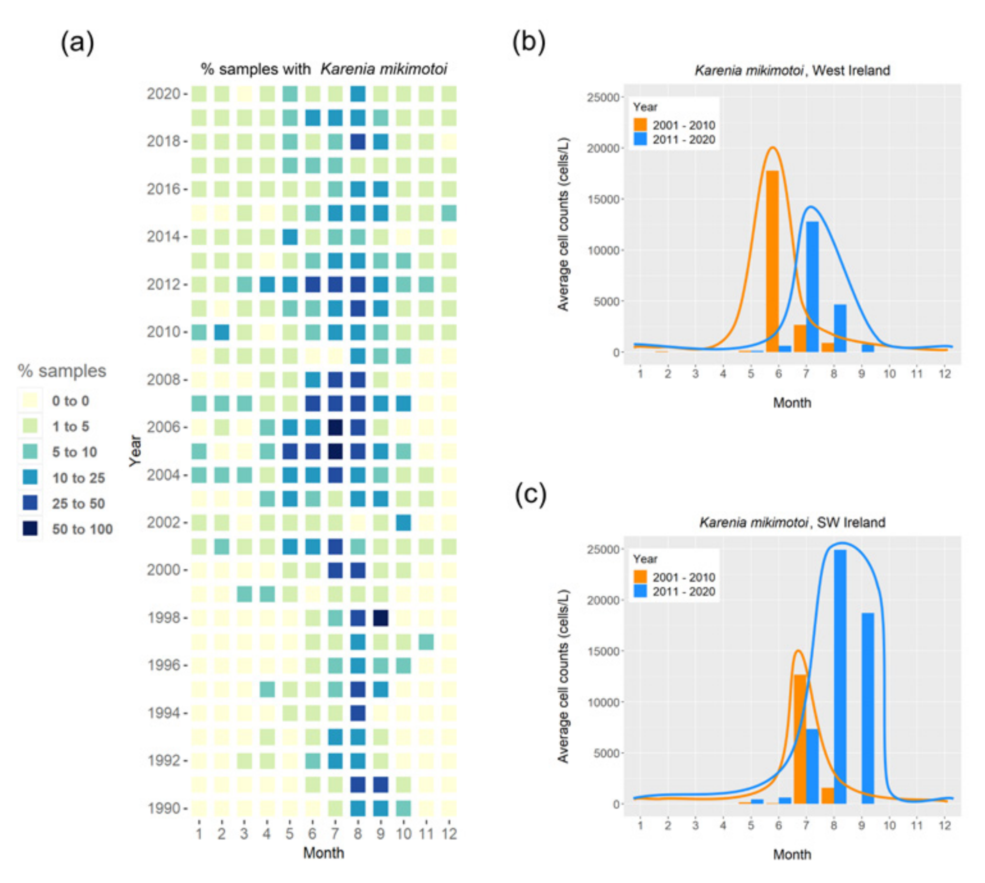


Figure 5.6 (a) Percentage of samples with *Karenia mikimotoi* cell counts (cells/L) observed from 1990 to 2020, X–axis=month; Y–axis=% of samples. Average monthly *K. mikimotoi* cell counts (cells/L); (b) west coast Ireland and (c) southwest coast of Ireland; for two time periods, 2001–2010 (orange) and 2011–2020 (blue). X–axis=month; Y–axis=numerical abundance. *Orange/Blue distribution lines are free hand drawn and are for visual purposes only to demonstrate seasonal changes in abundance between the two time periods and not statistically derived.*

Monthly cell abundance of *Alexandrium* species has increased from June to August, with a noticeable shift in the cell abundance pattern. Substantial increases in cell abundance are now observed, particularly in the southwest since 2018. Paralytic Shellfish Toxins were reported above EU regulatory levels in shellfish from the southwest for the first time in 2018, and this is now observed annually.

Alexandrium cell abundances between 2001 and 2020 were examined in this review. Key observations between two decades 2001–2010 and 2011–2020 are presented in Figure 5.7.

The geographic distribution and abundance of *Alexandrium* has changed in recent years off southwest Ireland (Figure 5.8(a)). Historically, PSTs above regulatory levels were confined to one location on the south coast, however, since 2018, PSTs above EU regulatory levels in shellfish have occurred on a near annual basis at one additional location off the southwest. This increased risk for potential Paralytic Shellfish Poisoning events is a concern to the shellfish industry and regulatory authorities. To address this, a recently funded project called PSPSafe (2021–2025) by the Department of Agriculture, Food and the Marine is working to determine the geographical extent of this issue (distribution of PSTs and associated *Alexandrium* species diversity).

Nationally, the bloom frequency and abundance of *Alexandrium* has increased in the recent decade (2011–2020). In the west, small decadal average cell abundance increases occurred in June and July (Figure 5.8(b)). In the southwest, significant increases in cell abundance occurred in the last decade between June and August, where blooms peaked in August (Figure 5.8(c)). The significant cell abundance increases off southwest Ireland include both toxic and non–toxic *Alexandrium* species, with larger bloom densities observed since 2018.

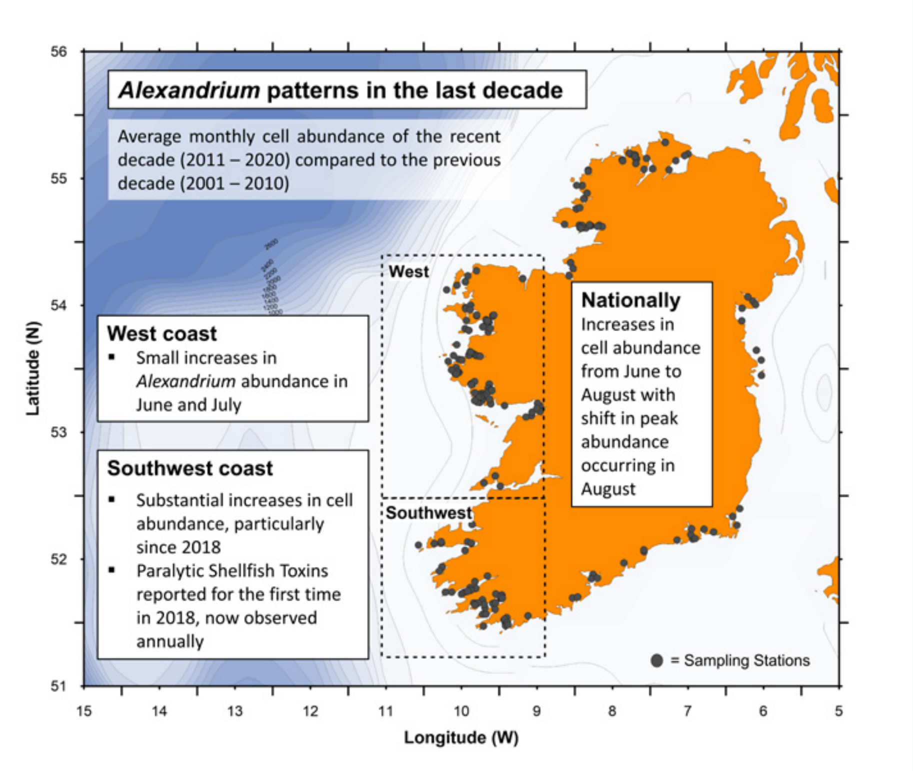


Figure 5.7 Changes observed for *Alexandrium* between the period 2003 and 2011 and 2012 and 2020.

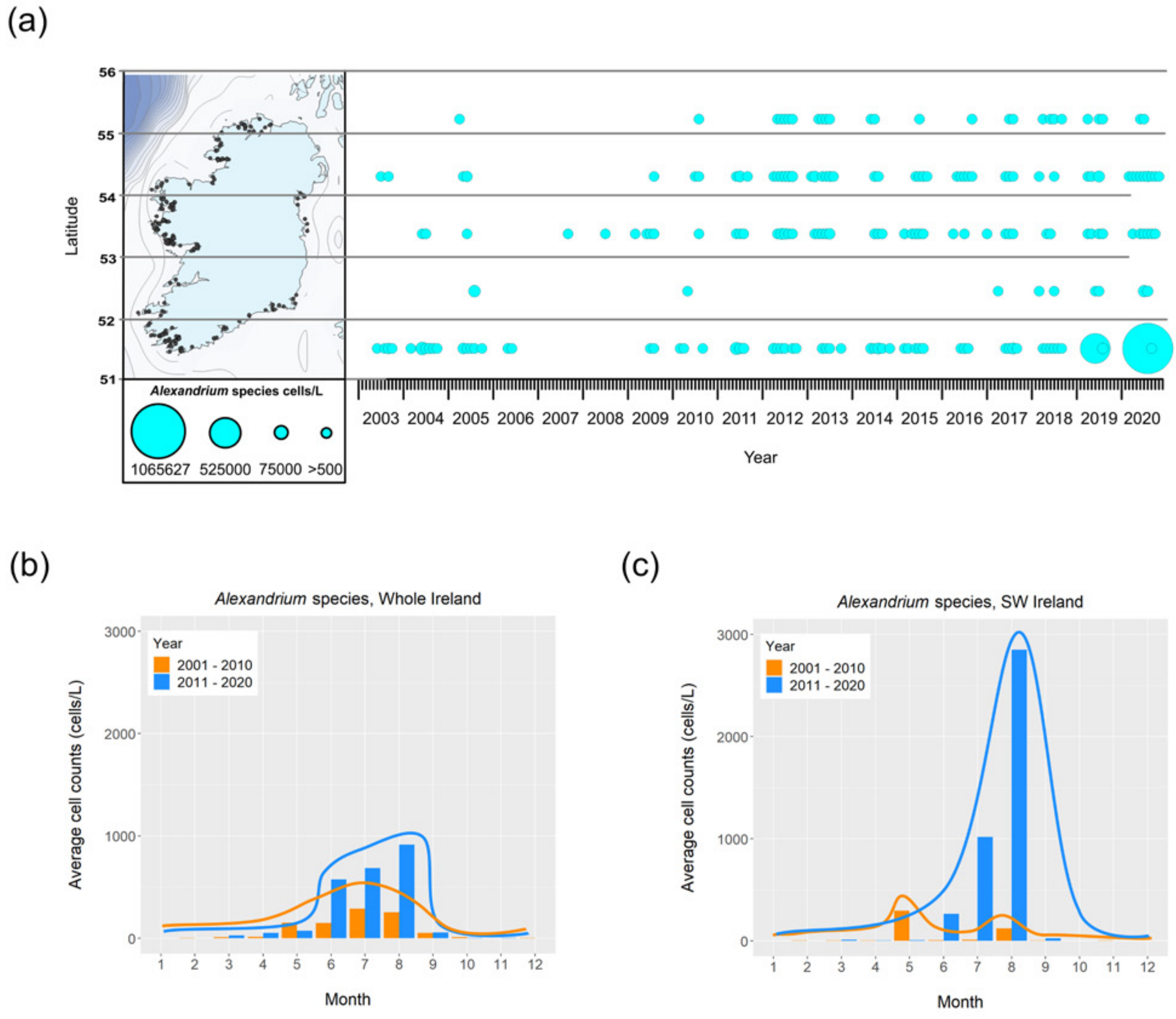


Figure 5.8 *Alexandrium* abundances and distributional patterns off the Irish coast. (a) Temporal and spatial distribution of *Alexandrium* species cells counts (>500 cells/L) from 2003 to 2021 where the X–axis=month/year and Y–axis=Latitude. Average monthly *Alexandrium* species cell counts (cells/L), (b) whole Ireland and (c) southwest coast of Ireland; for two time periods, 2001–2010 (orange) and 2011–2020 (blue). X–axis=month; Y–axis=numerical abundance. *Orange/Blue distribution lines are free hand drawn and are for visual purposes only to demonstrate seasonal changes in abundance between the two time periods and not statistically derived.*

CASE STUDY

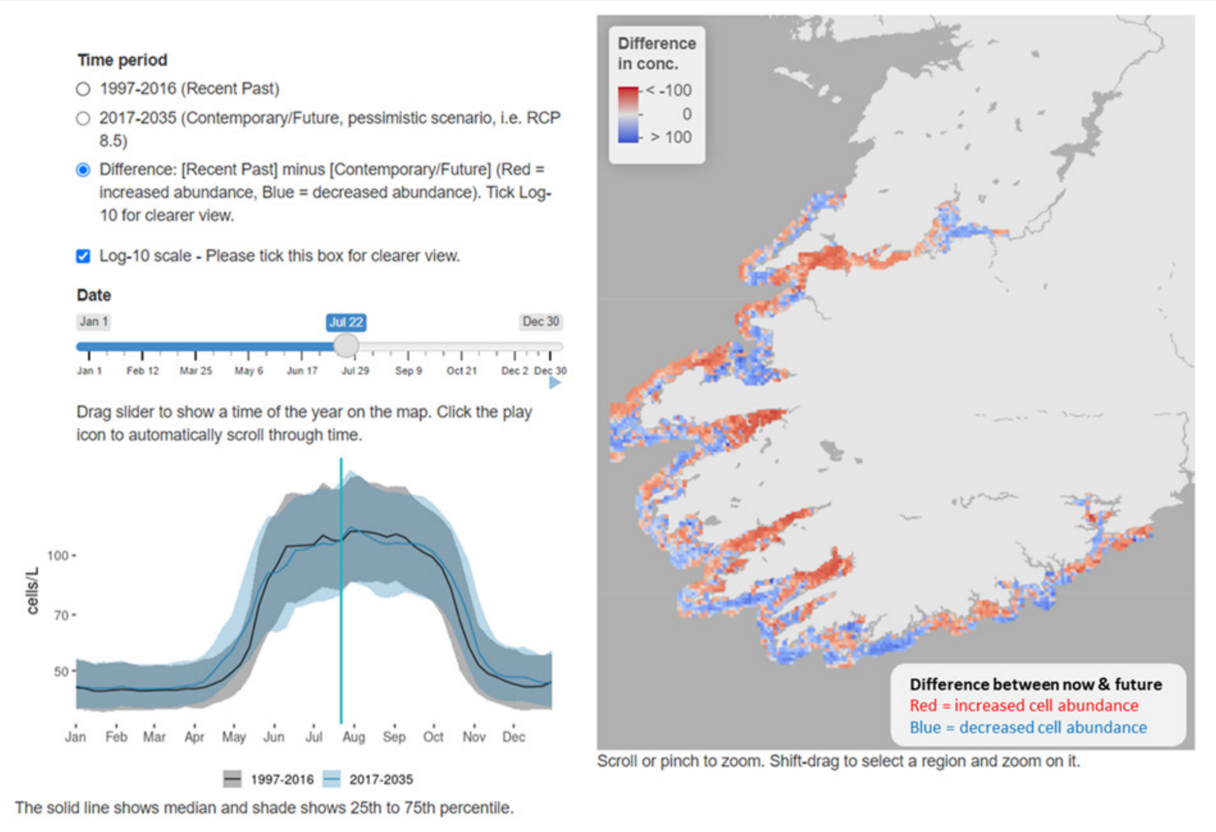
HARMFUL ALGAL BLOOM SPECIES IN IRELAND – FUTURE PREDICTIONS

ESTIMATING HARMFUL ALGAL BLOOMS IN A FUTURE OCEAN – CASE STUDY TO DEVELOP HAB CLIMATE SERVICE (PROTOTYPE)

A downscaled Irish ocean climate model was developed in 2020 (Nagy *et al*., 2021; Chapter 9). Using data from this numerical model combined with the National Monitoring Programme HAB data, a machine learning approach was carried out to estimate future distributions and occurrences of key Harmful Algal Bloom (HAB) taxa in Irish waters.

Most HAB taxa examined showed a slight probability of presence increase in spring, summer and autumn, and an increased bloom period in the contemporary/future ocean (2017–2035) when compared to the recent past ocean (1997–2016). The abundance model for *Dinophysis acuminata* showed similar trends. However, "*Pseudo–nitzschia seriata*" complex was an exception and only showed an increased presence in spring.

The climate service application (Figure CS5.1) was developed for *Dinophysis acuminata*. Abundance estimates in the application allows the user to view the modelled estimates under "recent past ocean conditions" (i.e. 1997–2016) and "contemporary/future ocean conditions" (i.e. 2017–2035). An option is available to view the difference between the two time periods and to watch the distributional changes with time.



Time period

○ 1997-2016 (Recent Past)

○ 2017-2035 (Contemporary/Future, pessimistic scenario, i.e. RCP 8.5)

● Difference: [Recent Past] minus [Contemporary/Future] (Red = increased abundance, Blue = decreased abundance). Tick Log-10 for clearer view.

☑ Log-10 scale - Please tick this box for clearer view.

Date

Drag slider to show a time of the year on the map. Click the play icon to automatically scroll through time.

The solid line shows median and shade shows 25th to 75th percentile.

Scroll or pinch to zoom. Shift-drag to select a region and zoom on it.

Figure CS5.1 Harmful Algal Bloom Climate Service with applications developed for *Dinophysis acuminata* presence probability and abundance estimates. The applications are also available for *Dinophysis acuta* presence and abundance, *Karenia mikimotoi* presence, "*Pseudo-nitzschia seriata*" complex presence and abundance, and *Alexandrium* species presence.

Photo credit: Caroline Cusack

5.7 RECOMMENDATIONS

1. Develop new and improved risk-management decision tools to include an operational HAB forecast system and biophysical models (including the development of HAB seasonal forecasts and HAB and phytoplankton community climate predictions) that can provide support to the seafood sector adaptation plan.
2. Establish a long-term climate network of sentinel sites (collecting biological, chemical and physical data) to detect invasive plankton species and novel/emerging biotoxins produced by these species.
3. Develop appropriate spatial scale models to estimate the future likely change in biological processes, e.g., prevalence of harmful algae.
4. Extend phytoplankton sampling offshore to improve knowledge of plankton shelf dynamics, and augment the existing alert system (HABs).

LIST OF FIGURES

LIST OF CASE STUDY FIGURES

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