From Reefs to Risks: Ecological Insights and Distribution of *Gambierdiscus* and Associated Benthic Ciguateric Dinoflagellates in Indonesia

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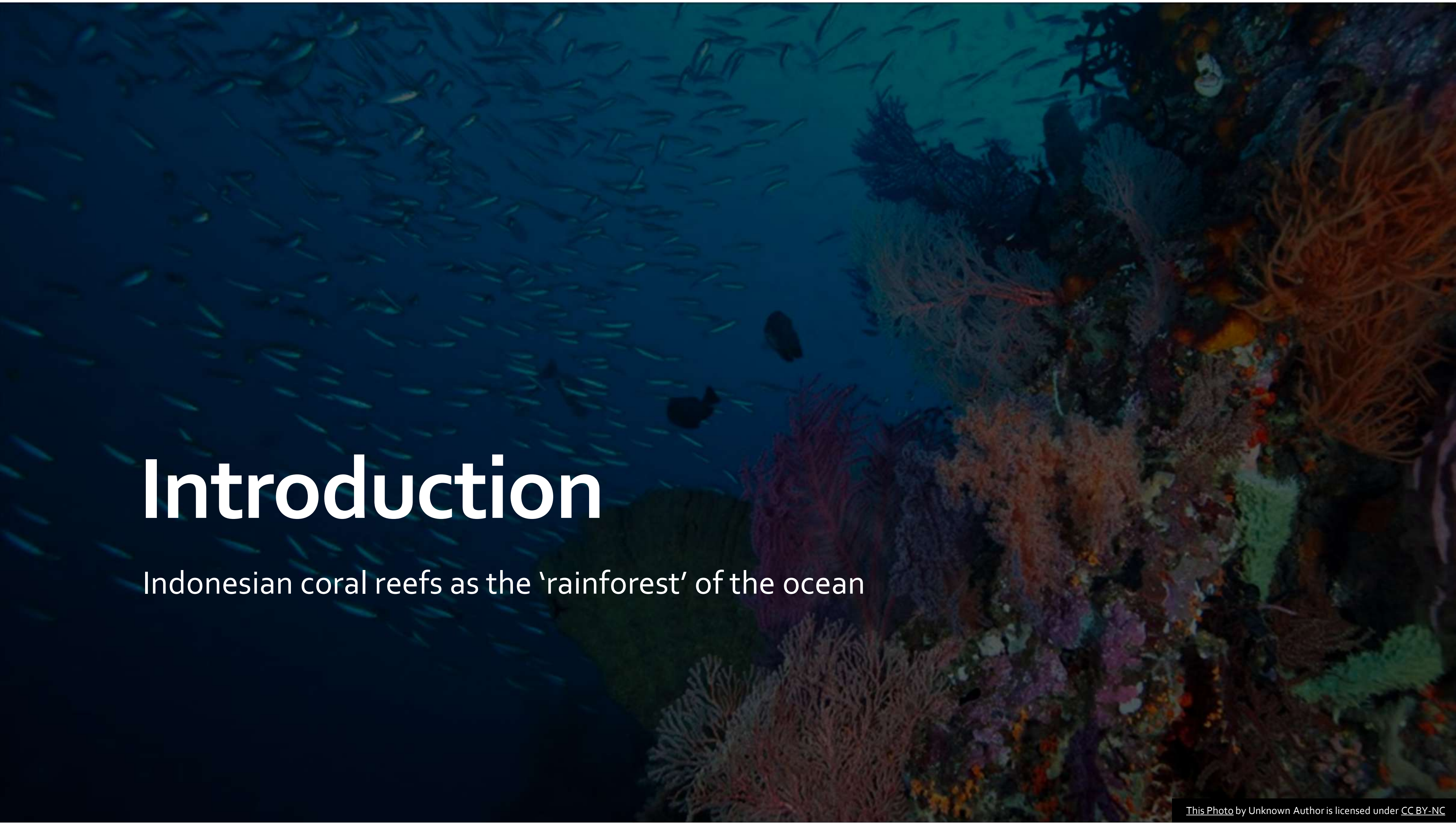
GENERAL LECTURE & SCIENTIFIC MEETING:

FISHPHYTO AND MARINE INVIRONMENTAL MONITORING FOR DISASTER MITIGATION OF HARMFUL ALGAL BLOOMS (HAB) AND CIGUATERA FISH POISONING (CFP)

Dissemination of Technology to Increase the Human Resource Capacity of Indonesian Coastal and Small Islands Communities

28th May 2025
Indonesia



Introduction

Indonesian coral reefs as the ‘rainforest’ of the ocean

Indonesian coral reefs as the **‘rainforest’ of the ocean** and hotspot for marine biodiversity

- **Coral Triangle** contain > 500 species of corals with 3 centres of endemism
- The highest diversity of coral reef species found in the **“Bird Head” peninsula of Papua** → 574 species of corals with species density of 280 species/ha of coastal area → four times higher than the total number of coral species in the entire Atlantic Ocean
- Indonesian coral triangle region also serve as hotspot zones for reef fish diversity → over 2100 species/km² and at least 78 known endemic species → **the “world’s richest country of fish biodiversity”**

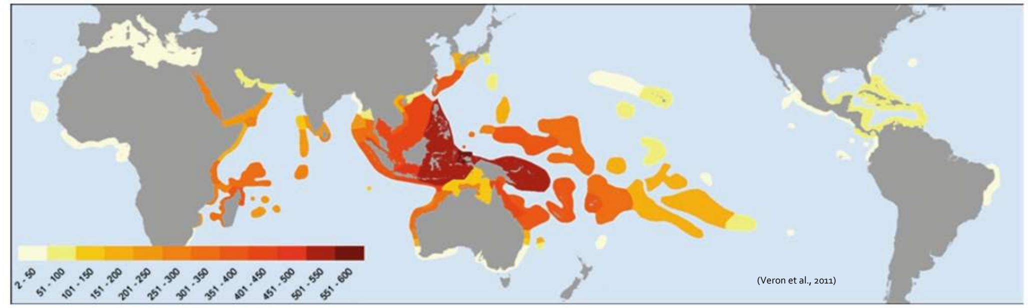
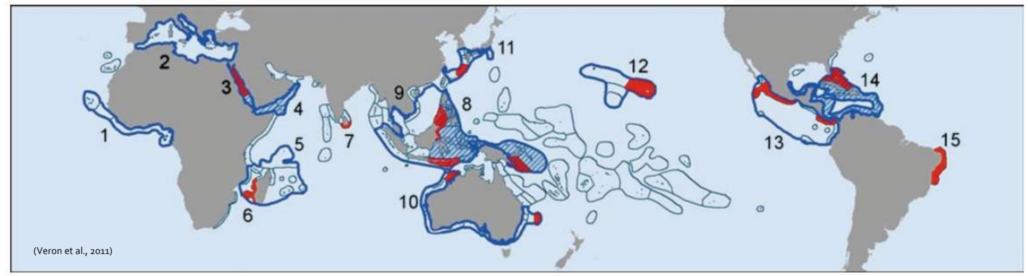


Fig. 2 Global biodiversity of zooxanthellate corals. Colors indicate total species richness of the world’s 141 coral biogeographic “ecoregions” (From the spatial database Coral Geographic, see text)



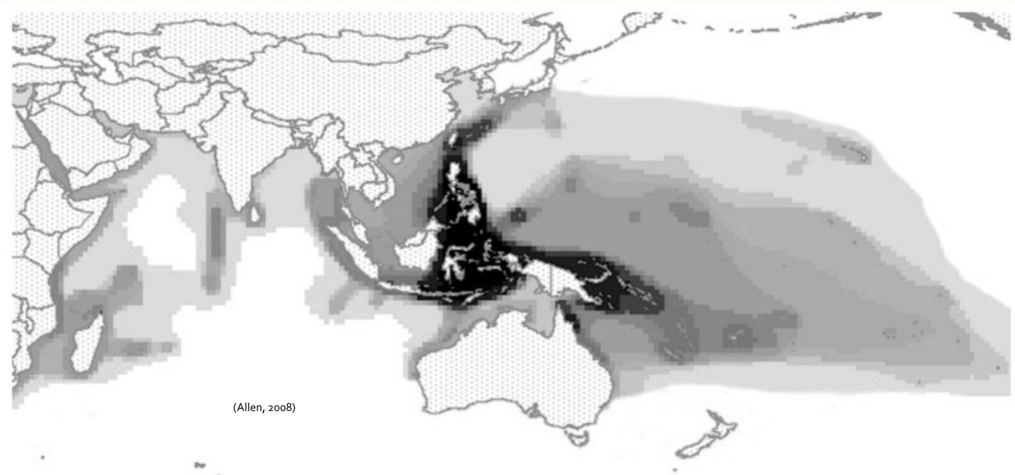


Figure 3. Map of the Indo-Pacific region showing diversity isopleths for tropical reef fishes. The lightest shade represents between 200 and 400 species and the darkest shade between 1300 and 1700 species.

https://www.greenpeace.org/philippines/story/1378/hope-amid-devastation-in-one-of-the-worlds-best-marine-sanctuaries/

Threats to Indonesian coral reef ecosystems

Acute threats
Causing significant damages over short period of time

- Destructive fishing practices, ex. blast fishing
- Anchor damages or ship groundings
- Cyclones, storms, or tsunami

(Edinger et al., 1998)

Chronic threats
Changing the physical and/or biological components of the ecosystem and causing long-term damage

- Sewage and/or industrial pollution
- Increased sedimentation
- Nearshore eutrophication
- Ocean acidification
- Ocean warming

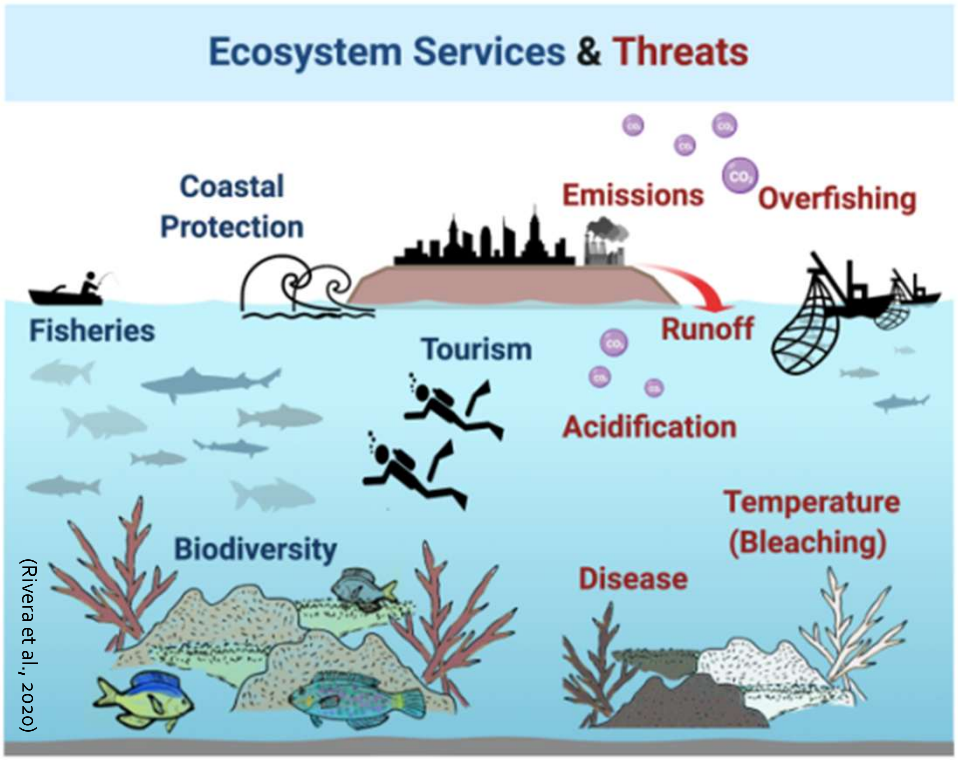
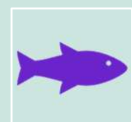


Figure 2: Coral reef ecosystem services (blue) and threats (red). Reefs offer valuable services to humans. Unfortunately, corals are impacted by multiple threats, many of which act to compound each other. Image was created on biorender.com. Icon credits to Lluisa Iborra (skyline), Ifki Rianto (small fishing boat and fisherman), Ruliani (wave), Nikita Kozin (diver), and Luis Prado (large fishing boats), all available from The Noun Project. Reef and associated fish are original artwork by author H.E.R.

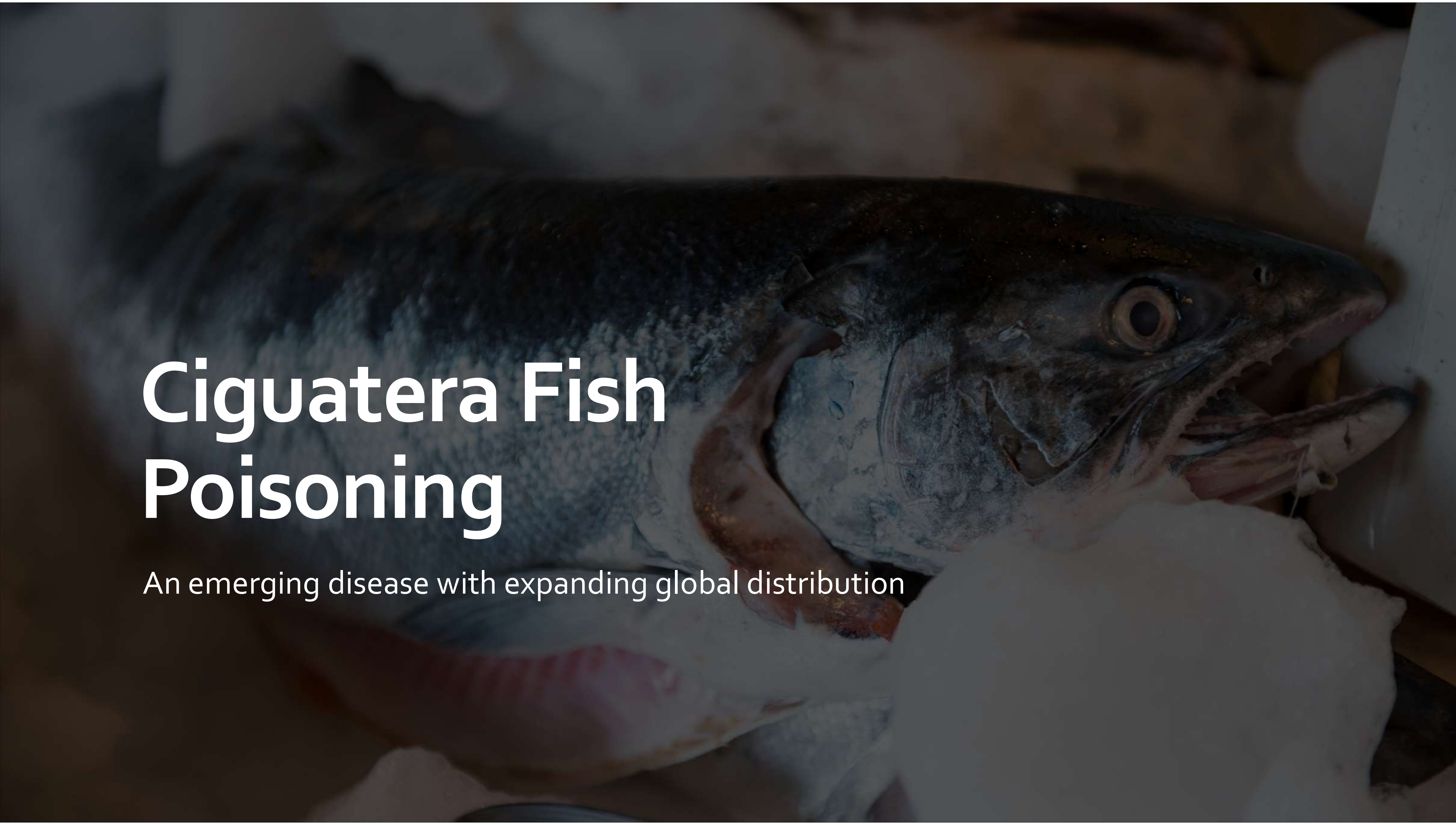
Effects of coral reef degradation

Reduced or loss of key ecosystem services → as coastal protection, habitat for fish, aesthetic value for tourism, support for fisheries



Loss of biodiversity → related to the reduced/loss of complex habitat and ecological function of coral reef in the ecosystem

Increased case of diseases, including in human → one of the most frequently reported and rising diseases → **Ciguatera Fish Poisoning (CFP)**



Ciguatera Fish Poisoning

An emerging disease with expanding global distribution

Ciguatera Fish Poisoning (CFP)

One of the most reported seafood-borne and harmful algal related disease in tropical countries → emerging disease with expanding global distribution

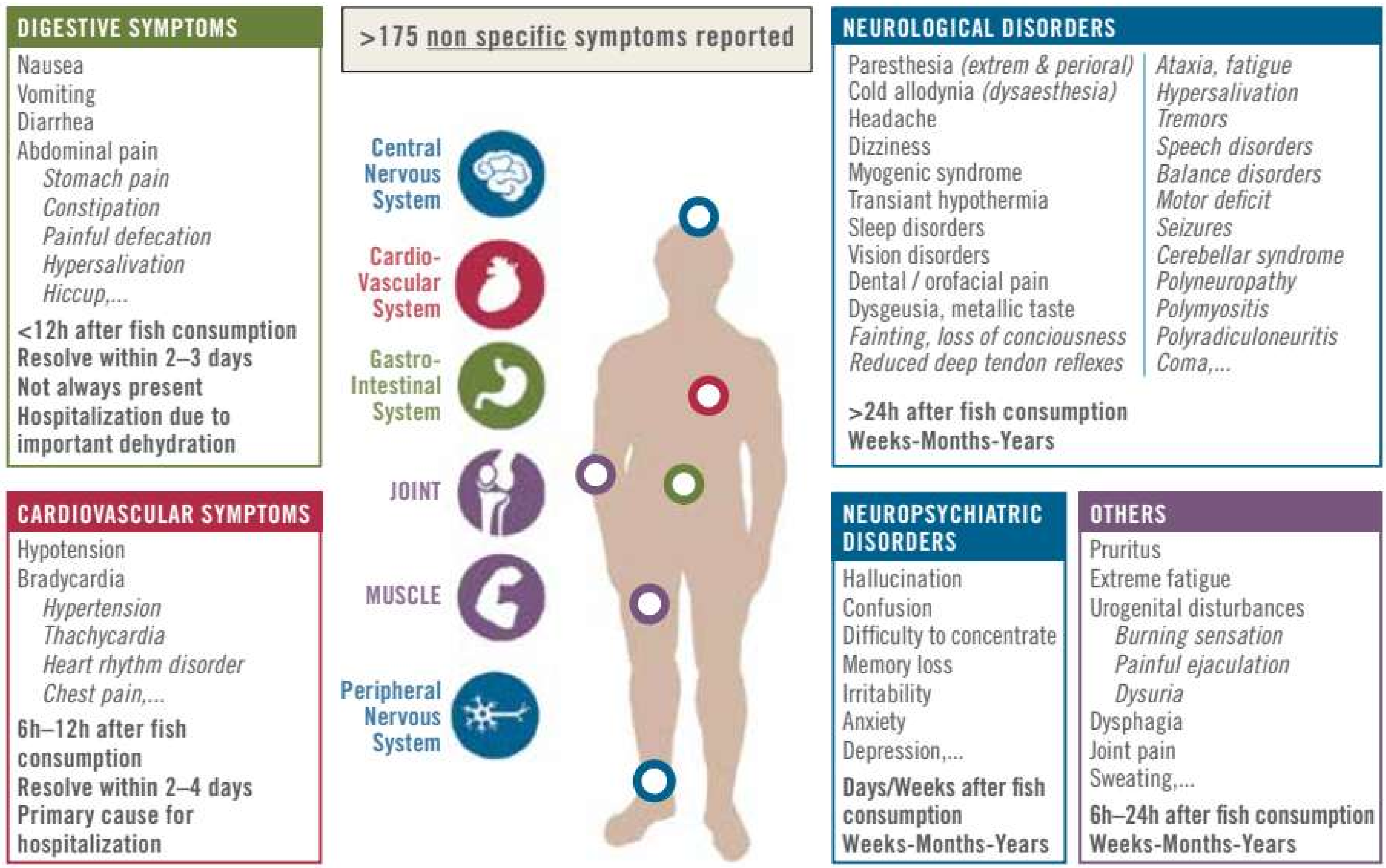
Caused by ingestion of **ciguatoxin**-contaminated reef fish which caused many symptoms within 12 hours of ingesting the contaminated fish (Chinain et al. 2023)

Symptoms: diarrhea, nausea, vomiting, stomachache, reversal of cold-hot sensation, muscles and joints pain, tingling (often painful), numbness on lips and tongue, itch, hypotension (low blood pressure) (de Sylva, 1994; Lehane and Lewis, 2000)

Approximately 10,000 – 50,000 CFP cases per year → World Health Organization estimated the actual number of people affected by CFP could be much higher up to 10 million people per year

CFP is a complex disease with >100 symptoms that have been reported → very difficult to diagnose

FIGURE 10 **EXAMPLE OF REPORTED ACUTE SYMPTOMS OF CIGUATERA POISONING**



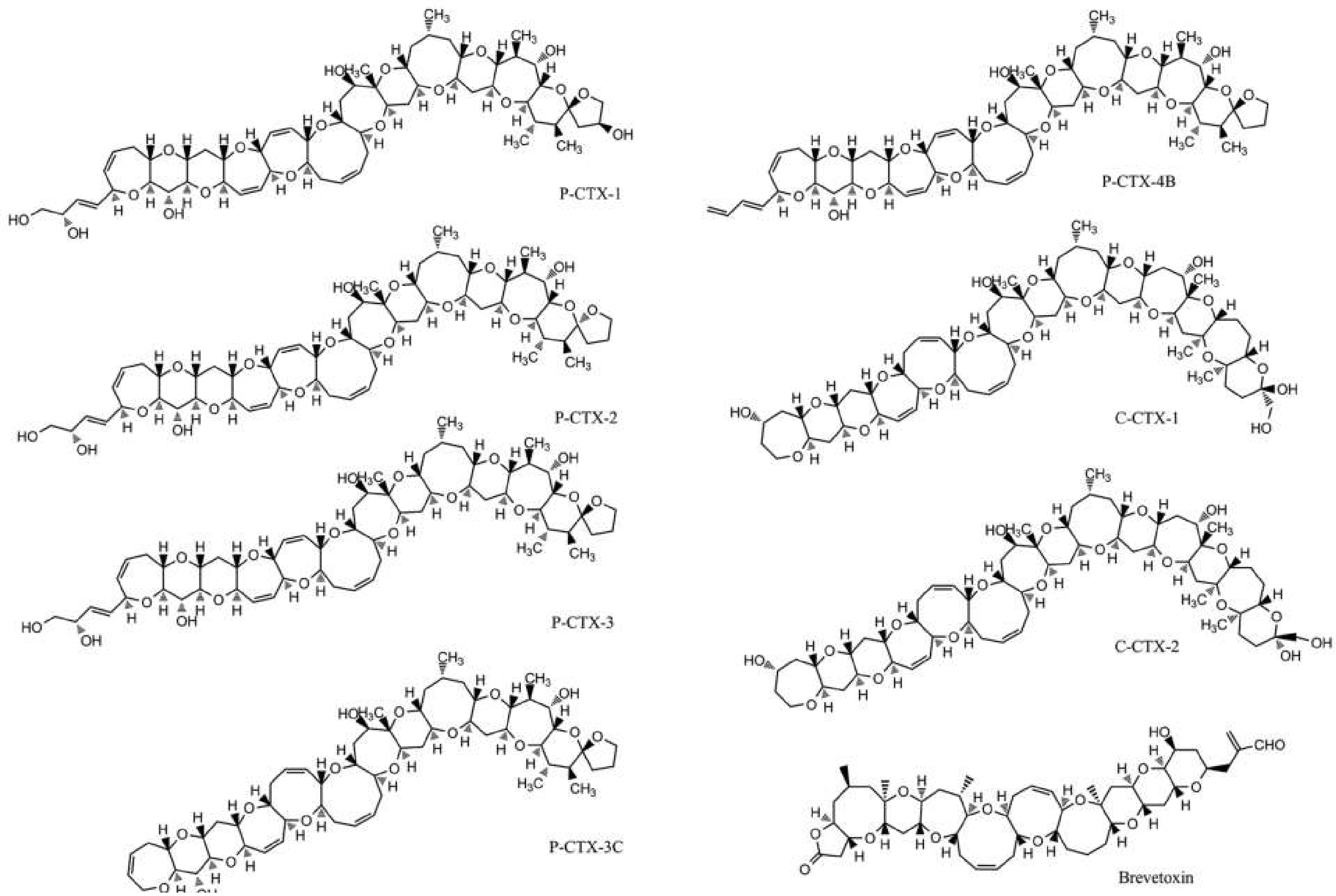
Source: FAO/WHO.

Ciguatoxin chemical structure

- **Ciguatoxin (CTX) →** one of the most complex marine toxin molecules
- Lipid-soluble and heat-stable-compounds of neurotoxin
- Odorless and tasteless
- No antidotes available

(Perkins et al., 2024)

Fig. 1. Structures of common ciguatoxins and brevetoxin. (Yang et al., 2016)



Complexity, chemical variations (up to 30 CTX congeners), and transformation during bio-accumulation and bio-magnification process through the marine food web → make it very challenging to study

Ciguatera toxin pathways

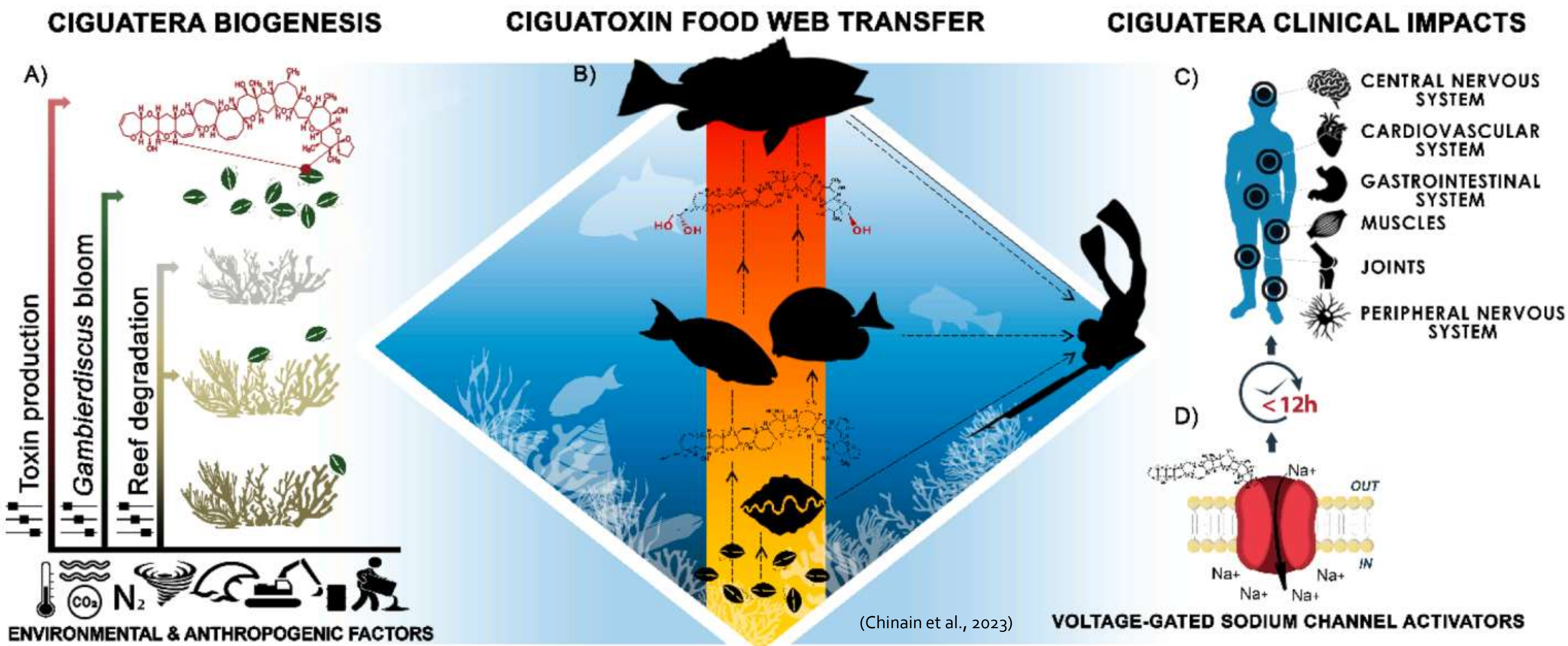


Fig. 1. Ciguatera Poisoning. A) biogenesis in coral reef ecosystems; B) ciguatoxin (CTX) transfer in marine food webs; C) health impacts of CTXs in consumers; D) voltage-gated sodium channels as biological targets of CTXs. © Institut Louis Malardé.

Mechanism of Ciguatera outbreak due to coral reef degradation

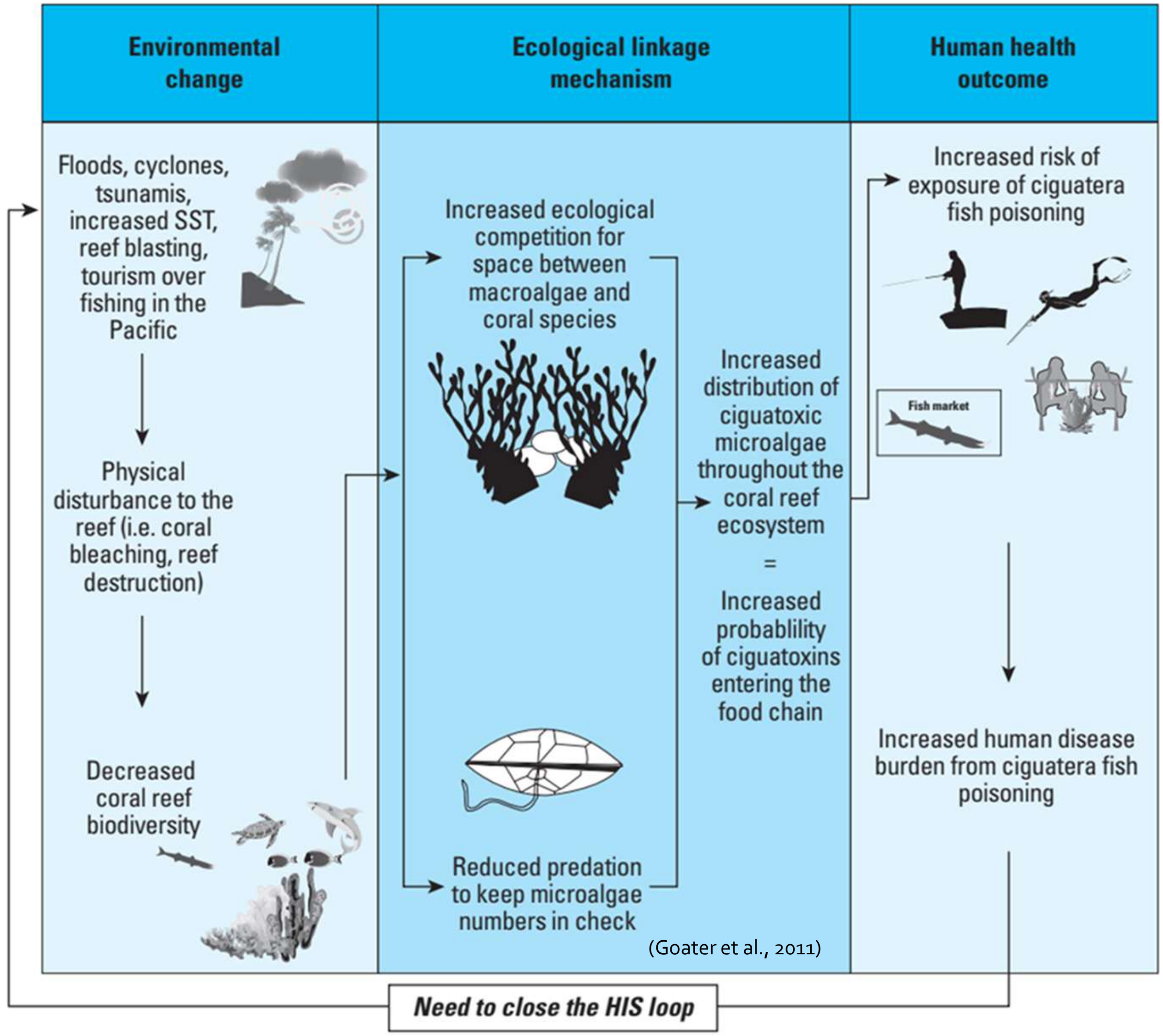
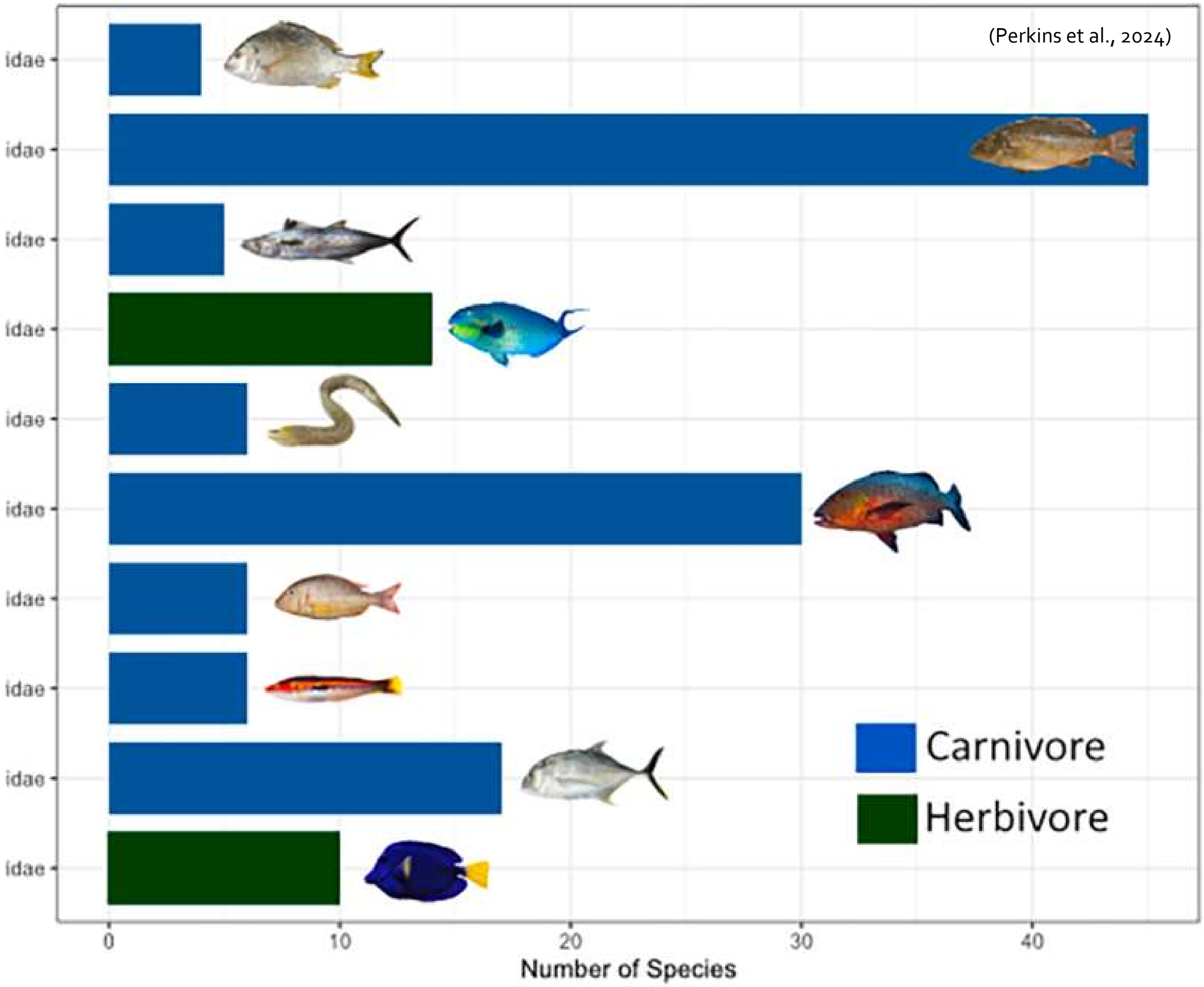


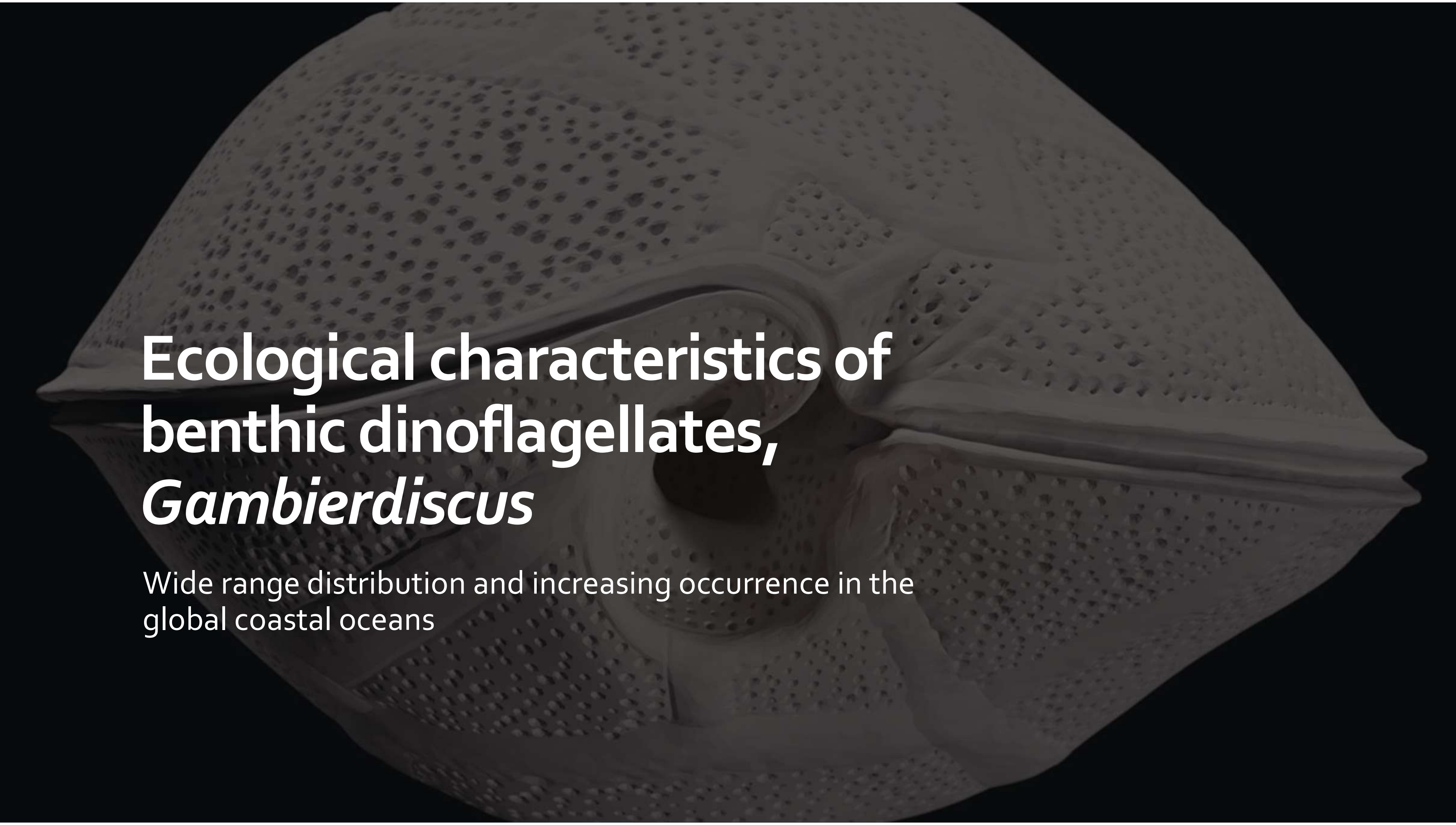
Figure 2. Linking environmental and human health outcome data to close the HIS loop. SST, sea surface temperature. The equal sign (=) indicates that increased distribution leads to increased probability.



A bar chart showing the ten most common fish families associated with CP occurrences in alphabetical order along the y-axis. The x-axis represents the number of different species that have been implicated in CP occurrences within each family

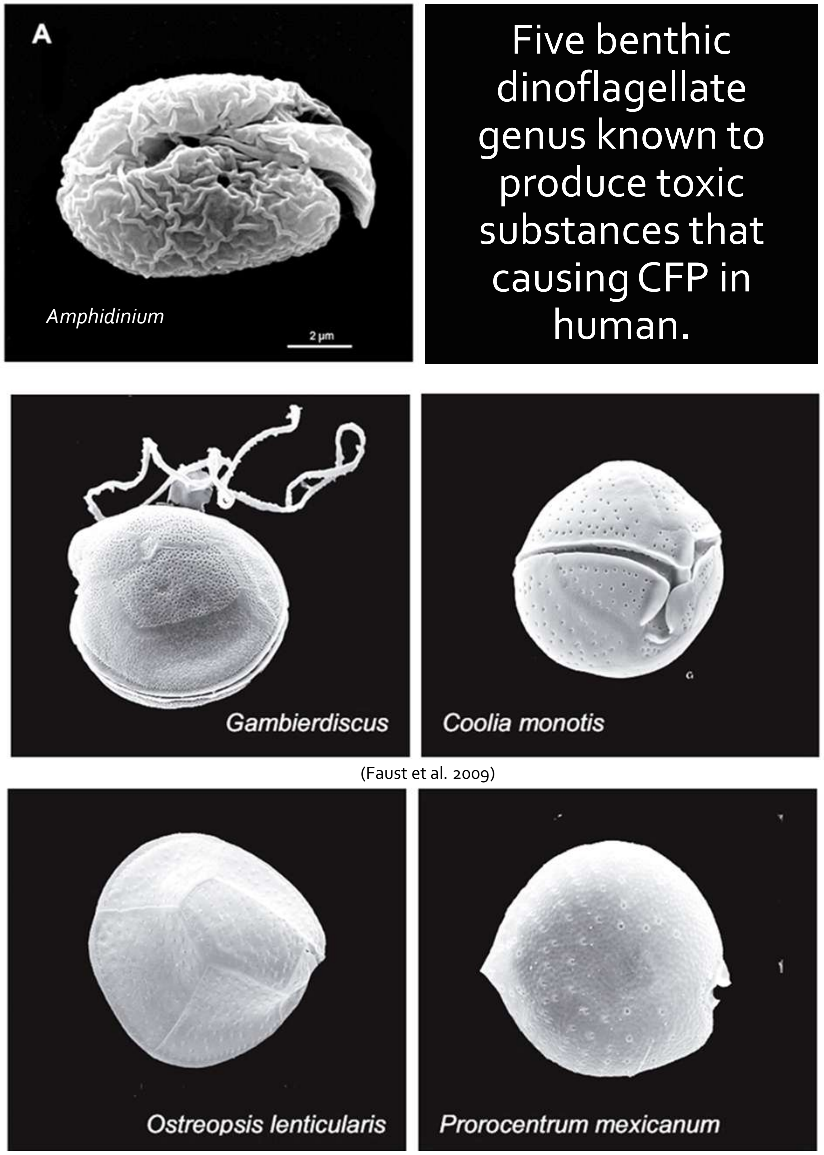
Reef fish as vector for CFP

- Ciguatoxin → undergo process of **bio-accumulation** and **bio-magnification** through the marine food-web
- The carnivorous fish and the top predators → high risk to accumulate high concentration of CTX to cause CFP in human



Ecological characteristics of benthic dinoflagellates, *Gambierdiscus*

Wide range distribution and increasing occurrence in the global coastal oceans



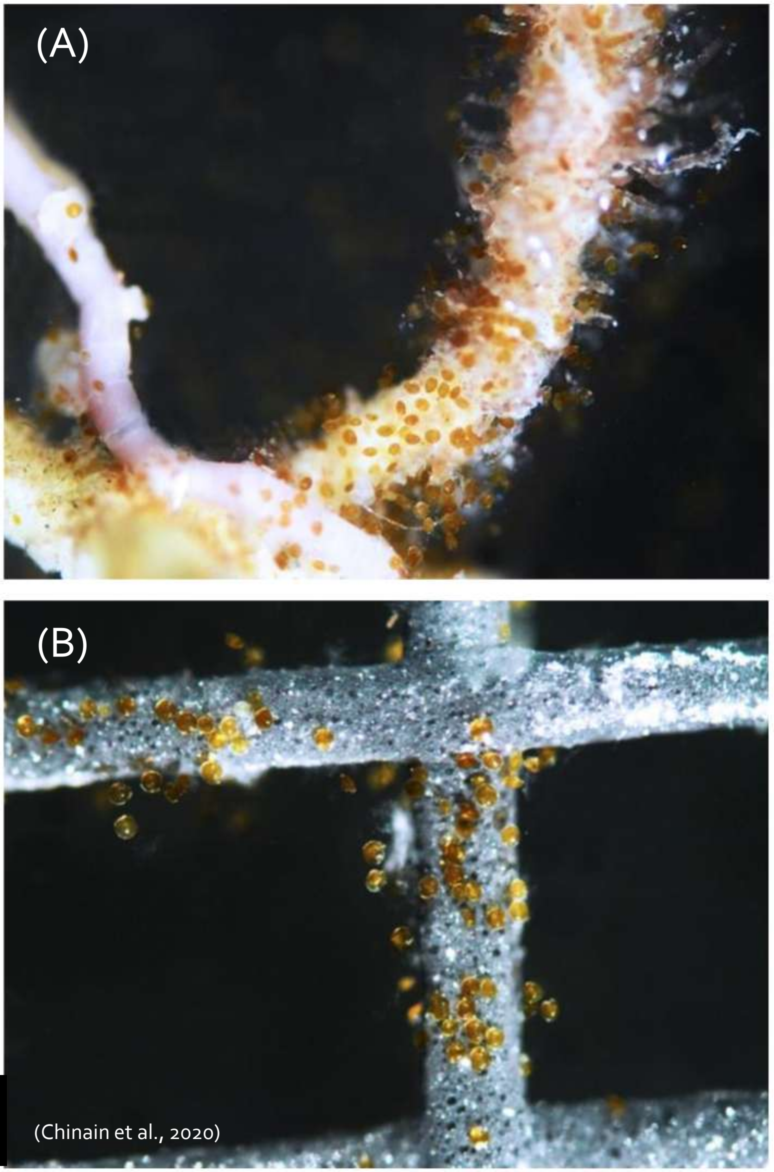
(Faust et al. 2009)

Ciguateric benthic dinoflagellates

- Benthic epiphytic dinoflagellates living attached to substrates → macroalgae, dead corals, or macroplastic
- Could produce toxic substances, such as **ciguatoxin** (CTX) → causing **Ciguatera Fish Poisoning** (CFP) → **Benthic harmful algae (BHA)** → species belongs to genus *Gambierdiscus* (and *Fukuyoa*), *Prorocentrum*, *Amphidinium*, *Ostreopsis*, and *Coolia*
- Ciguatoxin (CTX) → well known to be produced by ***Gambierdiscus toxicus*** → first discovered from a coral reef ecosystem of Gambier Island, French

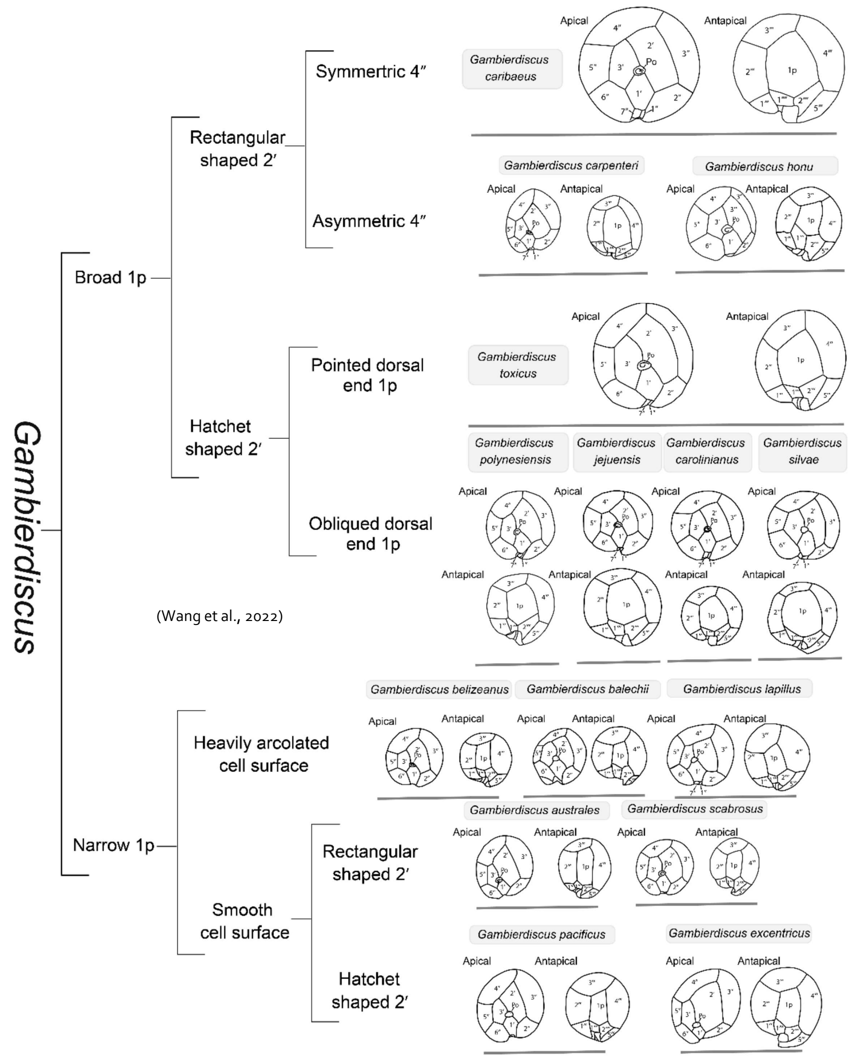
Gambierdiscus spp

- One of the main cause of CFP cases → particularly species of *Gambierdiscus toxicus*
- *Gambierdiscus* → produces two types of toxins → ciguatoxin (CTXs) and maitotoxin (MTXs)
- Naturally found attached to the surface of macrophytes, corals, and sand grains → via mucous filaments → also can easily attached to man-made surfaces and floating debris (plastic, wood, etc)
- Commonly found in coastal areas of Indian Seas, Carribean Seas, and tropical belt of Pacific Ocean → recently found expanding to sub-tropical waters of Australia, Japan, and Meditteranean

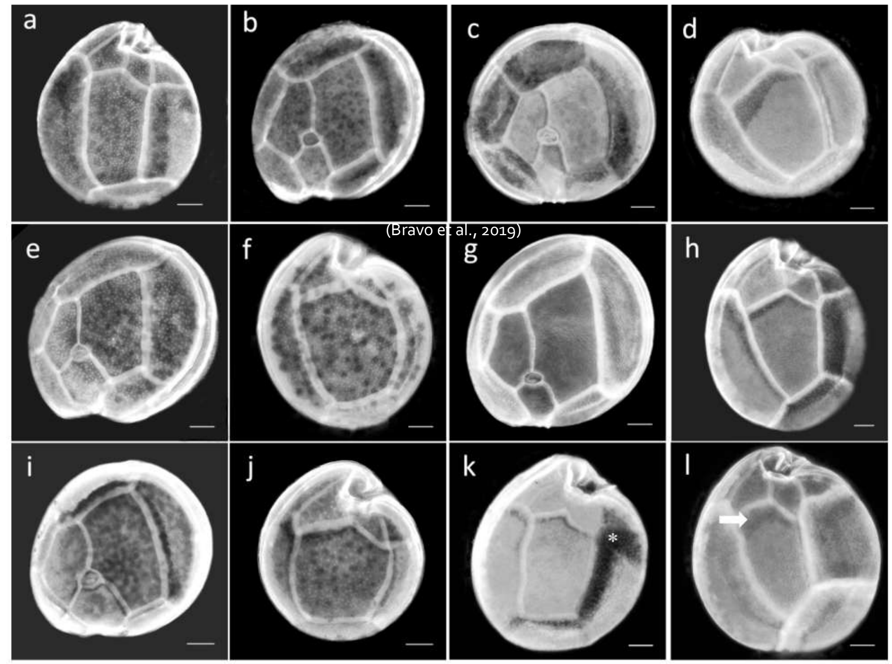


Cells of *Gambierdiscus* sp. attached to natural and artificial substrates. (A) on the thallus of *Jania* sp. (Rhodophyte); (B) on the grilling of a window-screen device (© ILM).

Example of Gambierdiscus morphological features for classification



Schematic diagram of the identification of different species of Gambierdiscus according to their morphology. Because of the wide variability in Gambierdiscus cell size, the size of the line drawings does not reflect the true differences in cell sizes.



Photographs of cultured cells of the five species of *Gambierdiscus* reported from the Canary Islands and including their thecal plates. Hypotheca (a) and epitheca (b) of *G. australes*. Epitheca (c) and hypotheca (d) of *G. caribaeus*. Epitheca (e) and hypotheca (f) of *G. carolinianus*. Epitheca (g) and hypotheca (h) of *G. excentricus*. Epitheca (i) and hypotheca (j) of *G. silvae*. For the hypothecae of *G. australes* (k), the difference in their staining intensity (asterisk) reveals that they derived from a recently divided cell. The hypotheca of *G. excentricus* (l) has a less dense upper end of the 2″″ plate (arrow). Scale bars = 10 µm.

Table 1. Reported polyether compounds in *Gambierdiscus*. (Wang et al., 2022)

Species	Ciguatoxins (CTXs)	Maitotoxins (MTXs)	Others
Gambierdiscus australes	CTX1B, P-CTX-3C	MTX, MTX-3	P-Gambierone analogue, putative gambieroxide gambierone
Gambierdiscus balechii			
Gambierdiscus belizeanus		MTX-3	
Gambierdiscus cheloniae		MTX-3	gambierone
Gambierdiscus excentricus		MTX-4	
Gambierdiscus honu		MTX-3	
Gambierdiscus pacificus	51-hydroxyCTX-3C, 2,3-dihydroxyCTX-3C	MTX-3	
Gambierdiscus polynesiensis	P-CTX-4A, P-CTX-4B, P-CTX-3C, M-seco-CTX-3C, 49-epiCTX-3C	MTX-1, MTX-3	
Gambierdiscus toxicus	P-CTX-3C, 2,3-dihydroxy P-CTX-3C, P-CTX-4A/B		Gambieric acids, gambierol, gambieroxide

Toxins produced by *Gambierdiscus*

- Many species of *Gambierdiscus* are now known to produced CTXs, MTXs, and some analogous toxins → gambierone, gambieric acid, gambierole, gambieroxide
- Based on the make-up of the structural backbone of each molecule → 30 congeners of CTXs divided into groups → CTX3C, Caribbean Sea CTXs (C-CTXs), Pacific Ocean CTXs (P-CTXs/CTX4A), and Indian Ocean CTXs (I-CTXs)

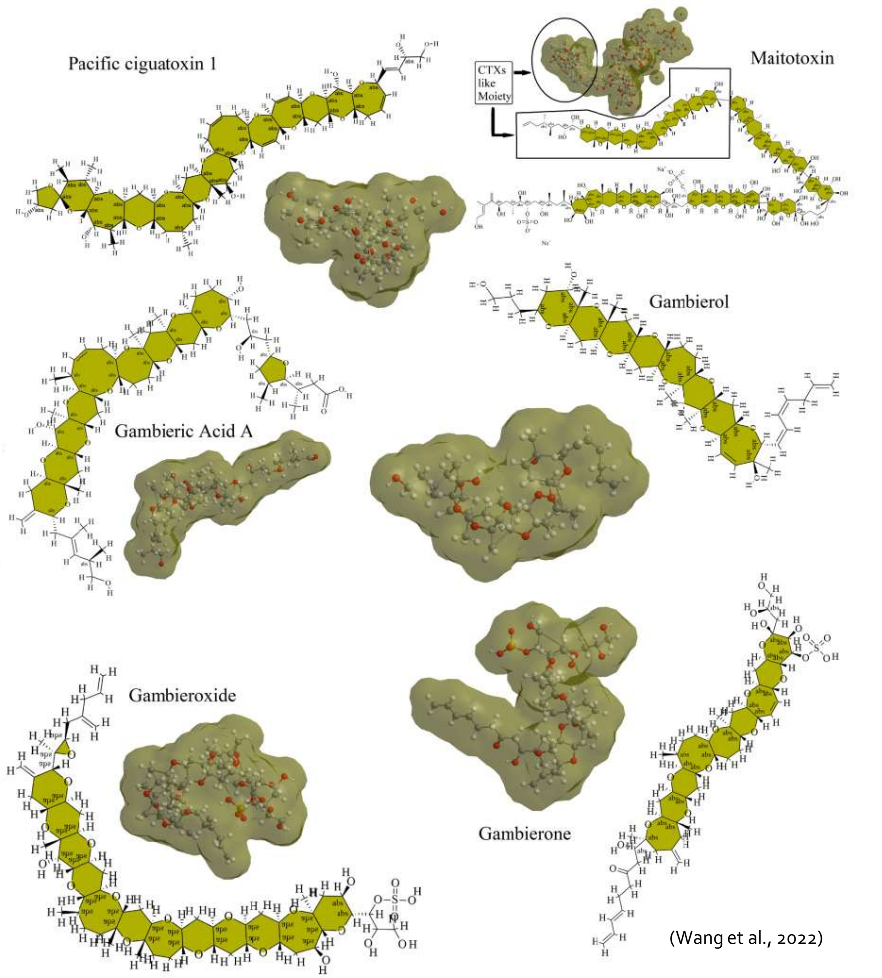
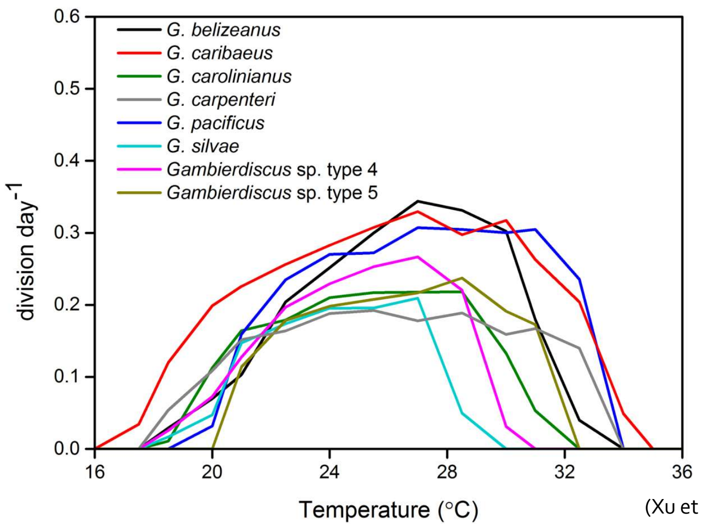


Figure 4. The predicted 2D and 3D structures of Pacific ciguatoxin 1, maitotoxin, and other products of *Gambierdiscus* spp. The framed part indicates the CTX-like moiety, which is the hydrophobic part of the molecule.

Relationship between *Gambierdiscus* and environmental factors



(Xu et al., 2016)

Fig 7. Average growth response of *Gambierdiscus* species to temperatures of 16–36°C. For ease of viewing, error bars shown in Fig 6 are omitted here.

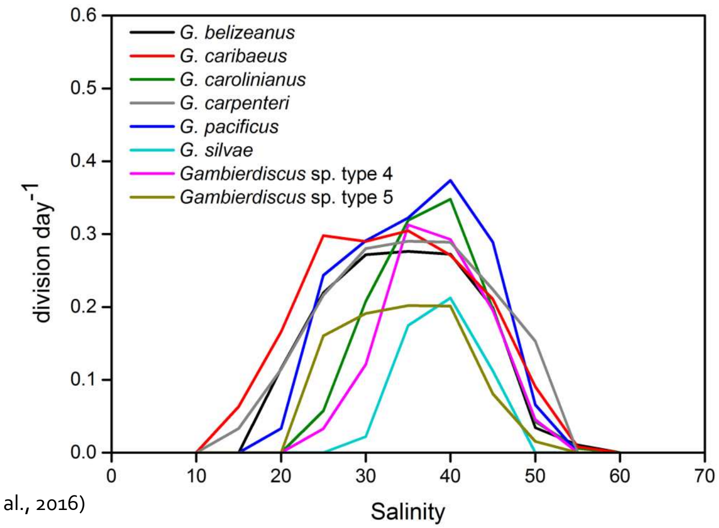


Fig 2. Average growth response of *Gambierdiscus* species to salinity of 10–60. For ease of viewing, error bars shown in Fig 1 are omitted here.

- *Gambierdiscus* → occupy wide range of habitat type due to its relatively wide tolerance to many environmental conditions
- **Temperature** → generally prefer warmer water → optimal range between 19 – 31°C → can sustain growth between 15 – 34°C
- **Salinity** → *Gambierdiscus* is less sensitive to salinity variation than to temperature → species-specific optimal salinity → generally prefer high and stable salinity between 28 – 35 → oceanic salinity between 34 – 38 could sustain growth for many *Gambierdiscus* species
- **Irradiance** → *Gambierdiscus* have good tolerance to low and high irradiance between 11 – 400 μmol photons.m^{-2}.s^{-1} → can survive to the depth < 5m or > 150m depth in tropical waters

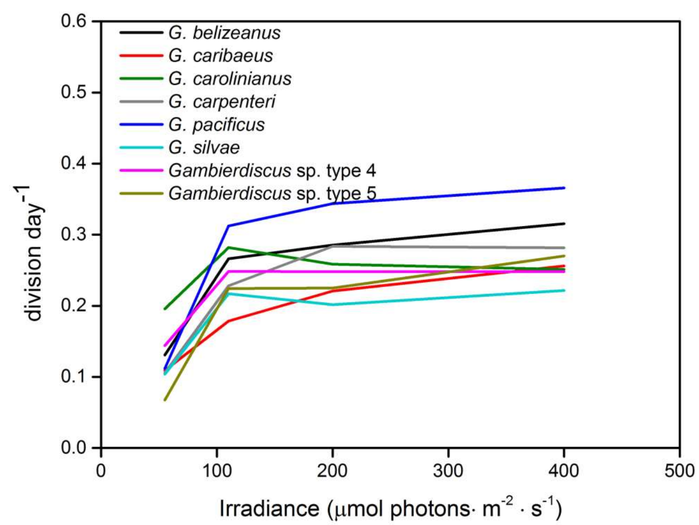
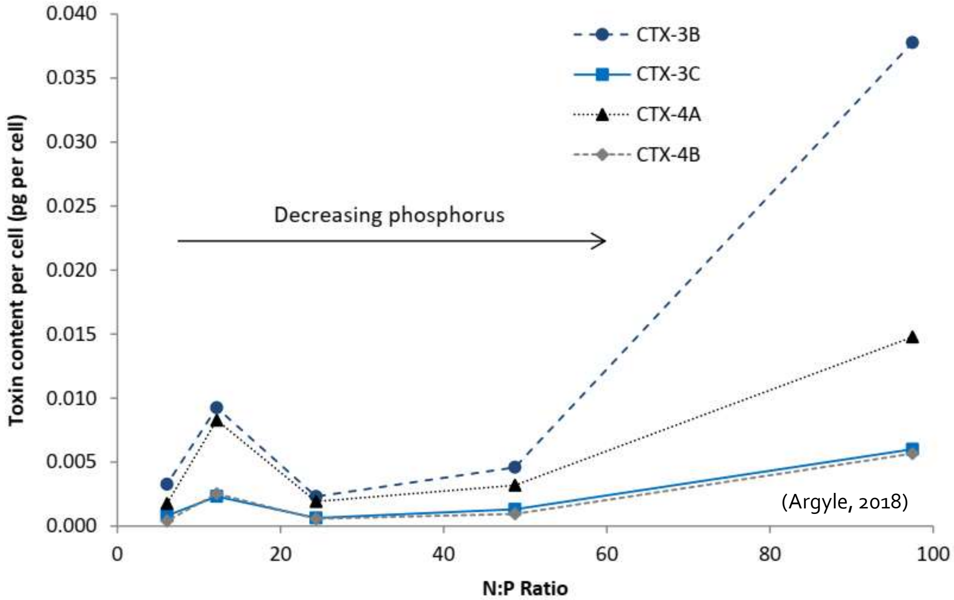
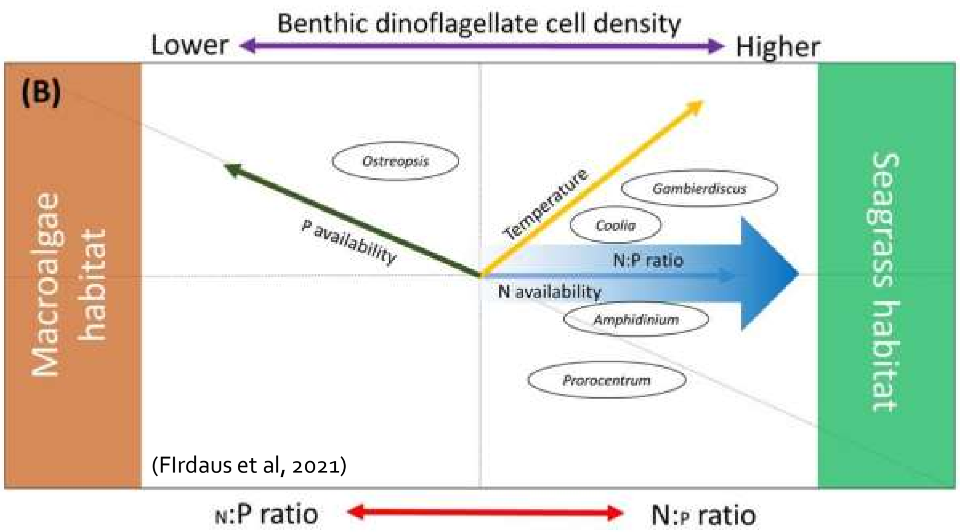


Fig 5. Average growth response of *Gambierdiscus* species to irradiance of 55–400μmol photons · m^{-2} · s^{-1}. For ease of viewing, error bars shown in Fig 4 are omitted here.



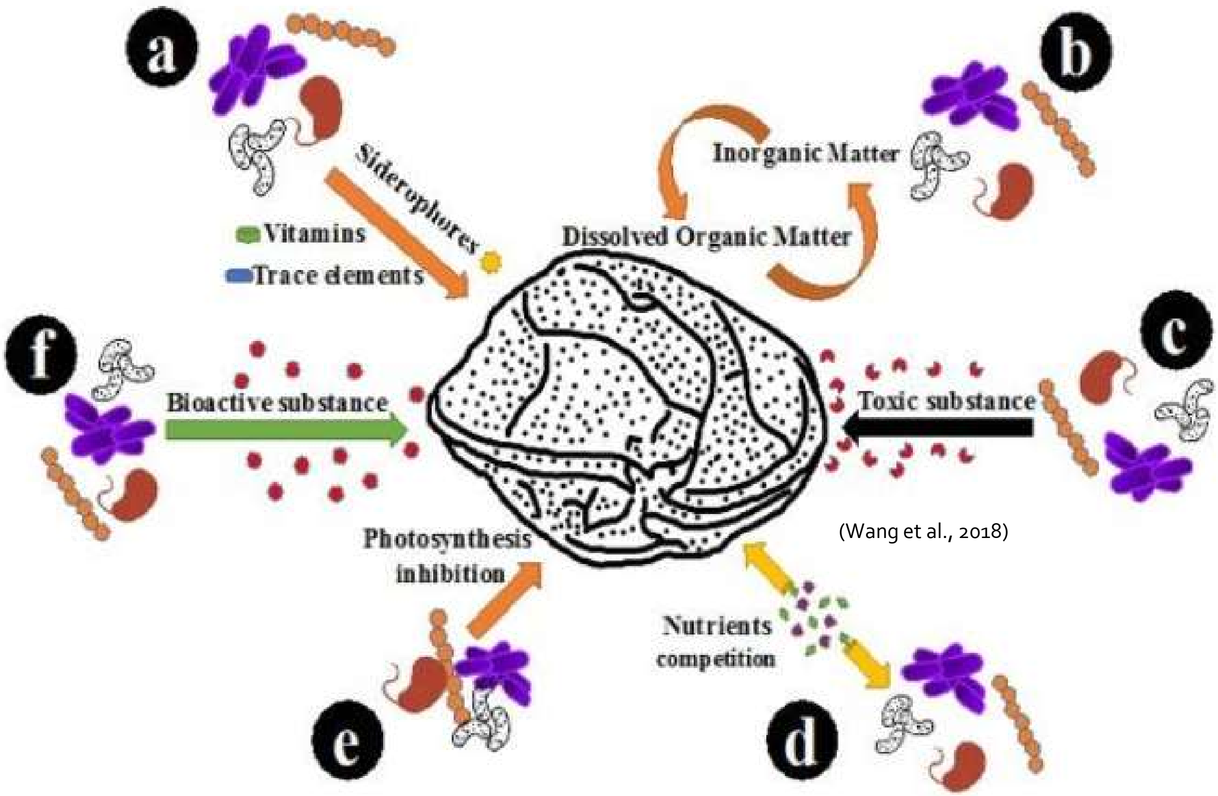


Role of nutrients in *Gambierdiscus* growth and toxin production

- Increasing nutrients (NO2, NO3, NH4+, and PO43-) → generally did not affecting *Gambierdiscus* abundance → nutrients might not growth limiting factors of *Gambierdiscus* at ambient concentrations → any growth restrictions to natural *Gambierdiscus* populations resulting from insufficient resources may be due to other factors (Loeffler et al., 2015):
  - dissolved inorganic carbon
  - interactions with host substrates, or
  - processes that disturb the aqueous boundary layer)
- BUT → the availability and ratios of nutrients affect intercellular activities → increasing toxin production with a higher N:P ratio (N:P ≥ 30:1) (Loeffler et al., 2015; Argyle, 2018) → *Gambierdiscus* toxin production is higher in P-limited condition (Argyle, 2018)

Bacteria and *Gambierdiscus* relationship

- **Marine bacteria** exhibit both positive and negative effect towards *Gambierdiscus* growth and toxin production
- Bacteria roles in promoting *Gambierdiscus* growth:
  - Produce bioactive substance
  - Converting DOM to inorganic matte
  - Produce vitamins and/or trace elements
- However, bacteria also could produce toxin or bioactive substance that inhibit photosynthesis or metabolism → also can act as competitor in nutrient assimilation

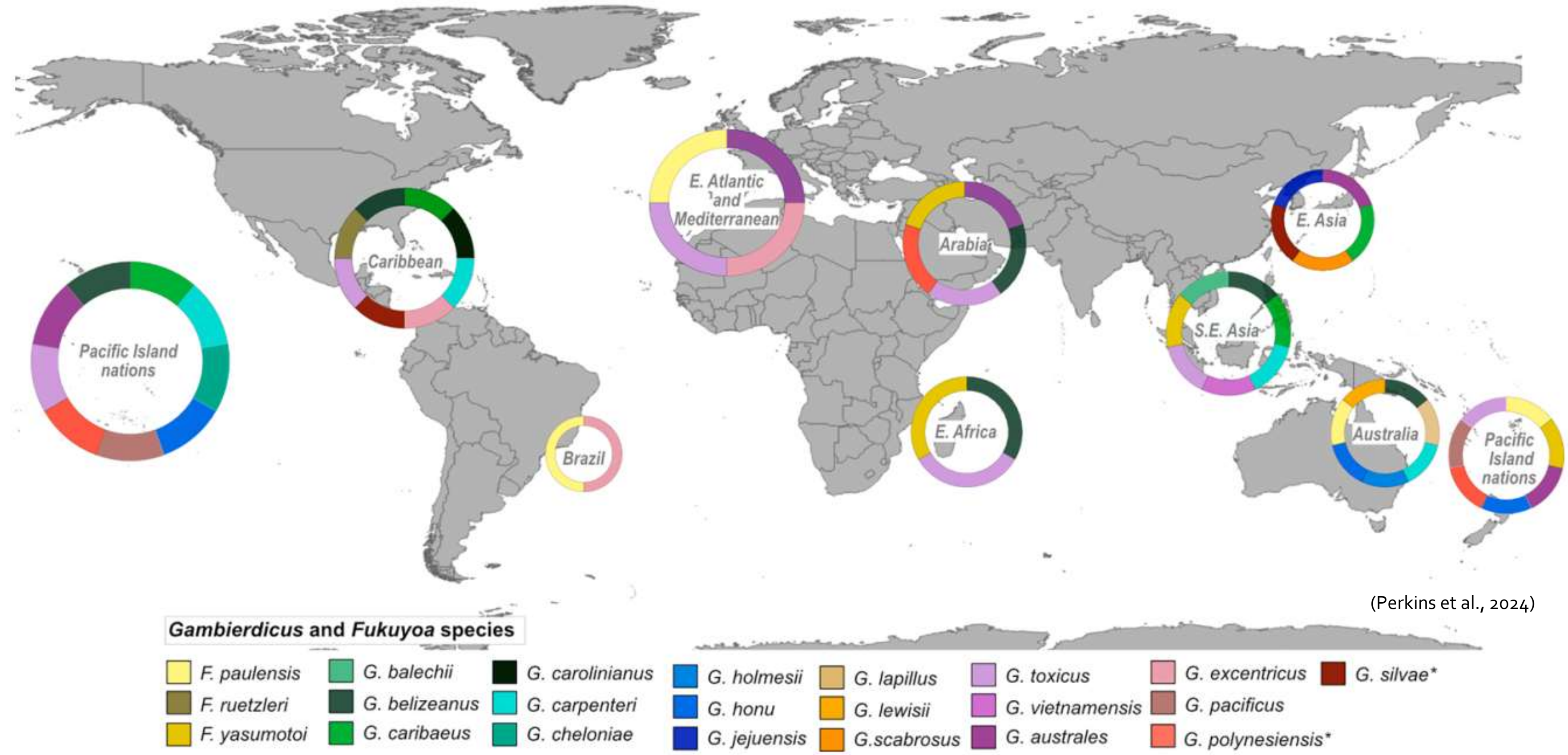


(Wang et al., 2018)

Figure 7. Scheme of the interactions between QS bacteria and *Gambierdiscus*.

Distribution pattern of *Gambierdiscus* and CFP

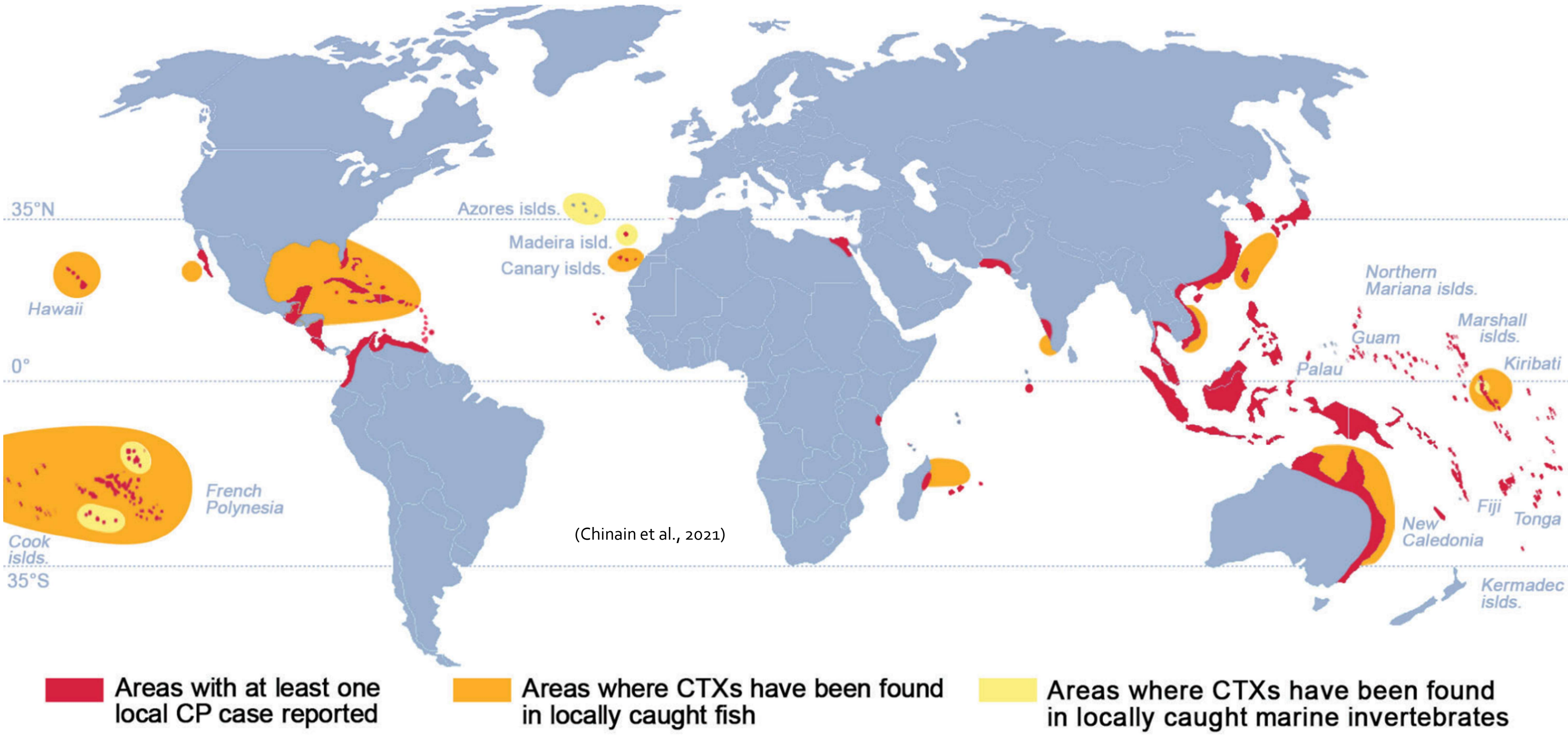
Increasing global range and performing jump dispersals to temperate countries

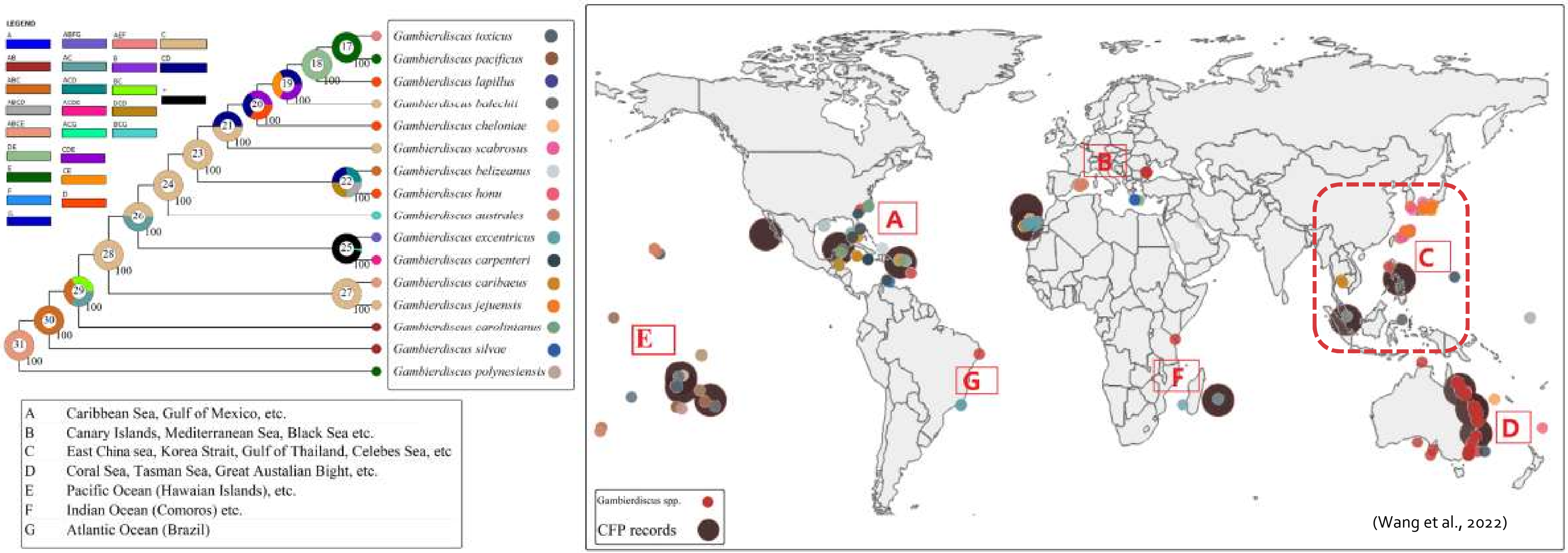


(Perkins et al., 2024)

Global distribution of the 22 known *Gambierdiscus* and *Fukuyoa* dinoflagellate species from multiple global studies. Note: *Species with confirmed ciguatoxin production.

Global occurrence of CFP





Global distribution of ciguatera food poisoning (CFP) records and *Gambierdiscus* spp.The locations where *Gambierdiscus* are present are classified into six regions (A–G), and the pie charts in the phylogenetic tree show the probability of the locations at each node. The colors of the point on the right side of the phylogenetic tree are used to distinguish different *Gambierdiscus* species in the global ocean. Distribution information is obtained from the Ocean Biodiversity Information System and the IOC Harmful Algal Bloom Programme (Searched on 23 August 2021)

Records of benthic dinoflagellate species associated with CFP

Benthic dinoflagellates which could potentially caused CFP → *Amphidinium* sp., *G. toxicus*, *O. ovata*, *O. siamensis*, *P. lima*, *P. concavum*, dan *P. rhathymum*, *Gambierdiscus sp.*, *Ostreopsis sp* → have been reported and studied from several places in Indonesia:

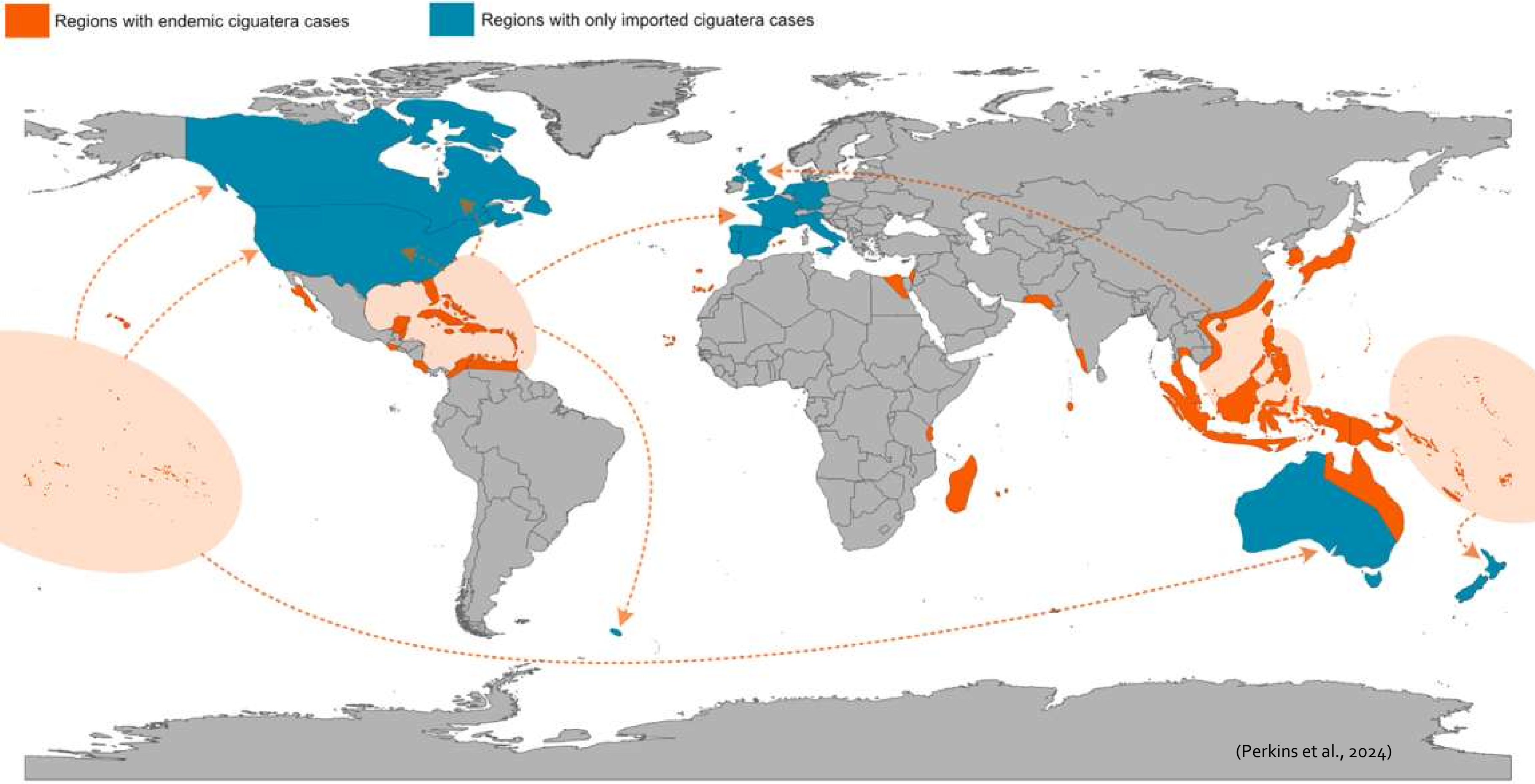
- Seribu Island
- Belitung Island
- Bali coastal waters
- West coast of South Sumatera
- Bintan Island
- Padang coastal waters
- Lampung Bay
- Weh Island coastal waters
- Gili Matra

Widiarti 2002, Widiarti 2010, Skinner et al. 2011, Widiarti 2011, Thamrin 2014, Dwivayana 2015, Eboni et al. 2015, Oktavian et al. 2015, Seygita et al. 2015, Widiarti & Pudjiarto 2015, Widiarti et al. 2016a, Widiarti et al. 2016b, Widiarti & Adi 2016, Widiarti et al. 2019

bHABs and CFP → not yet considered as a major threat to Indonesian coastal communities or ecosystems (no formal report or huge cases) → lack of awareness and studies

Global dispersal pattern of CFP

Jump dispersal



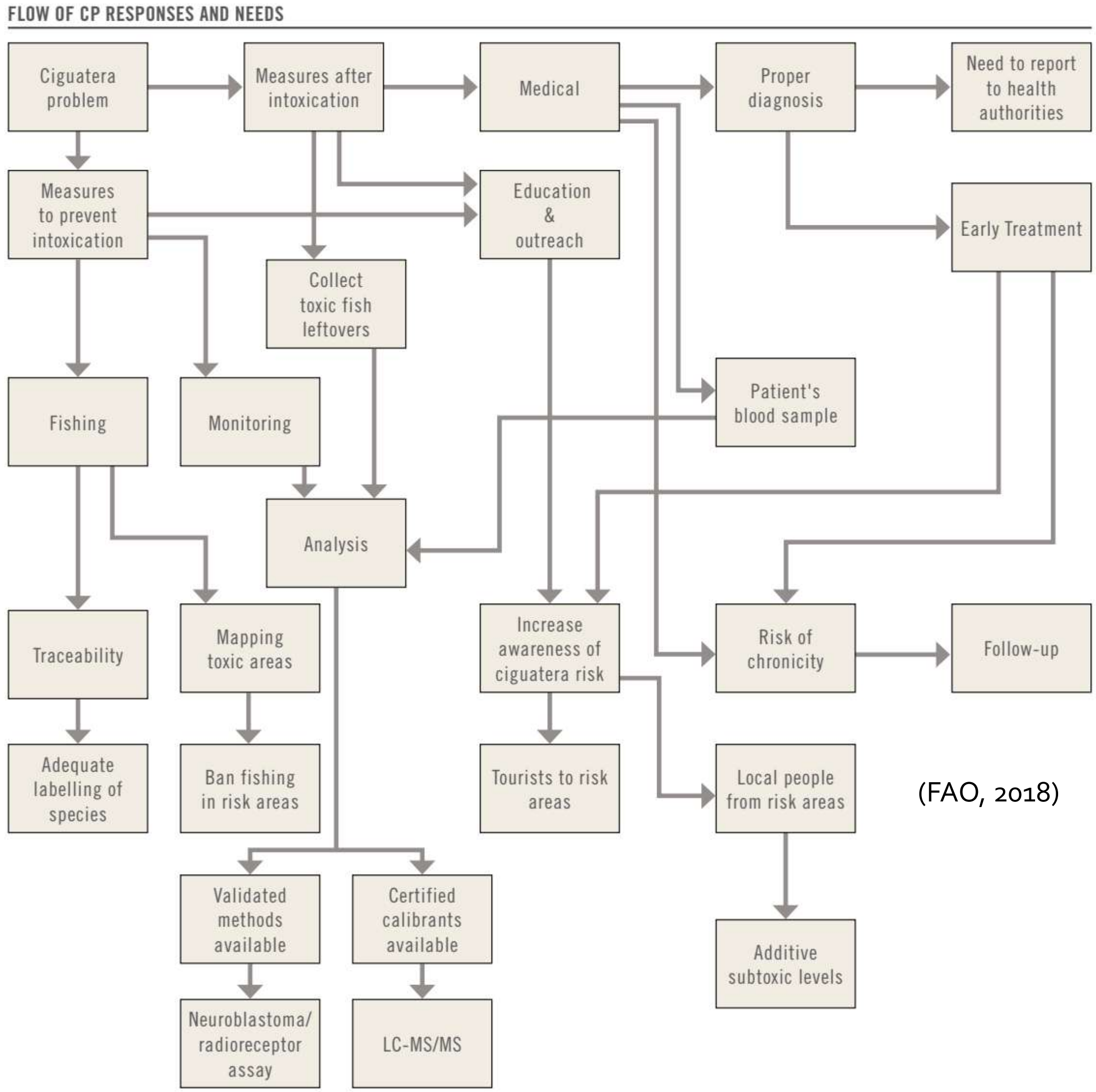
Global map of endemic ciguatera areas (orange) and imported ciguatera areas (blue). The orange arrows indicate examples of areas in which imported fish have originated and caused CP cases in another location

Mitigating CFP in Indonesia

A collaborative initiative between researchers, government entities, and local communities.

Ciguatera response model based on FAO 2018

- **CFP** → complex issue that underreported in many countries → particularly in Indonesia where there are **NO official reports**
- **Seafood safety** → became an issue for seafood export product → mainly because fish from Indonesia has record to cause outbreak in another country (Germany)

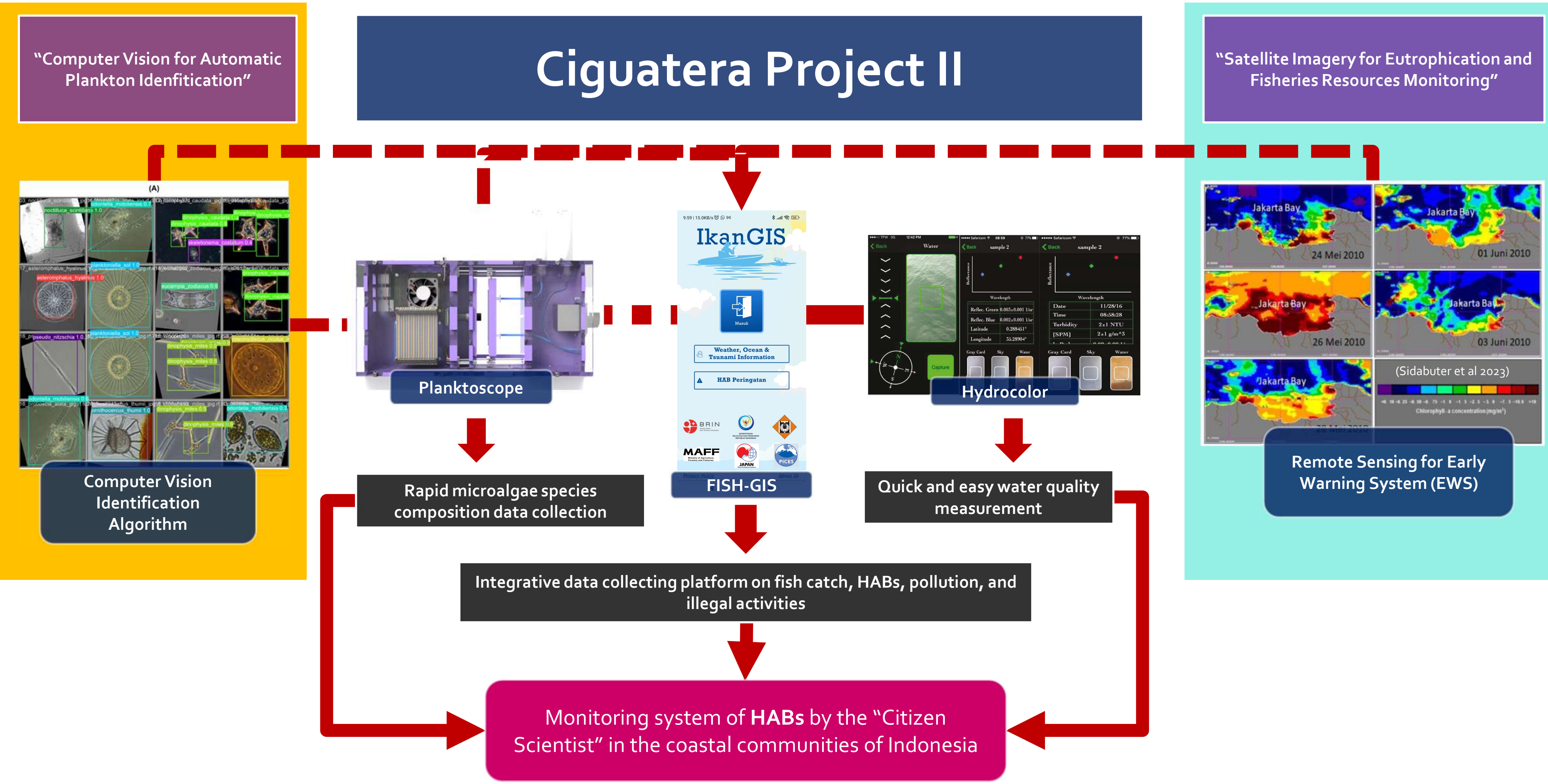


(FAO, 2018)

Effective CFP mitigation requires a multi-faceted approach, integrating **research**, **community action**, and **policy**

Improve	Improve national surveillance, research, and data collection
Invest and develop	Invest and develop strategies and rapid detection tools to detect the presence of ciguatoxin
Integrate	Integrate CFP management into marine conservation and climate adaptation policy
Scale up	Scale up community-based monitoring (e.g. **Ciguatera** and **FishPhyTO PICES project**) and public education
Promote	Promote sustainable and diversified fisheries practices (e.g. shift to pelagic species)
Foster	Foster a better interdisciplinary and international collaboration

The three elements of CFP mitigation must operate in unison.



PICES Projects like Ciguatera Indonesia and FishPhytO were an international collaborative effort to build and improve the ability to detect the presence of harmful microalgae and changes in water quality, including algal blooms, in Indonesian waters

Summary

- **Ciguatera Fish Poisoning** → is a hidden but increasing threat in national seafood safety in Indonesia → due to its complex symptom and hard-to-detect toxin
- **Coral reef degradation** → promotes the rapid and uncontrolled growth of ciguateric benthic dinoflagellates → produces toxin that undergo bio-magnification and bio-accumulation → increased risk of CFP exposure due to consuming fish at higher trophic level
- ***Gambierdiscus*** → one of the main cause of CFP → have strong tolerance against many environmental condition → wide global distribution with increasing range towards the sub-tropical waters due to warming ocean
- **CFP mitigation is complex** → especially in large country in Indonesia where CFP case were not reported or ignored → but collaborative effort to develop mitigation strategy has been done

Thank you

Scribbo ergo sum