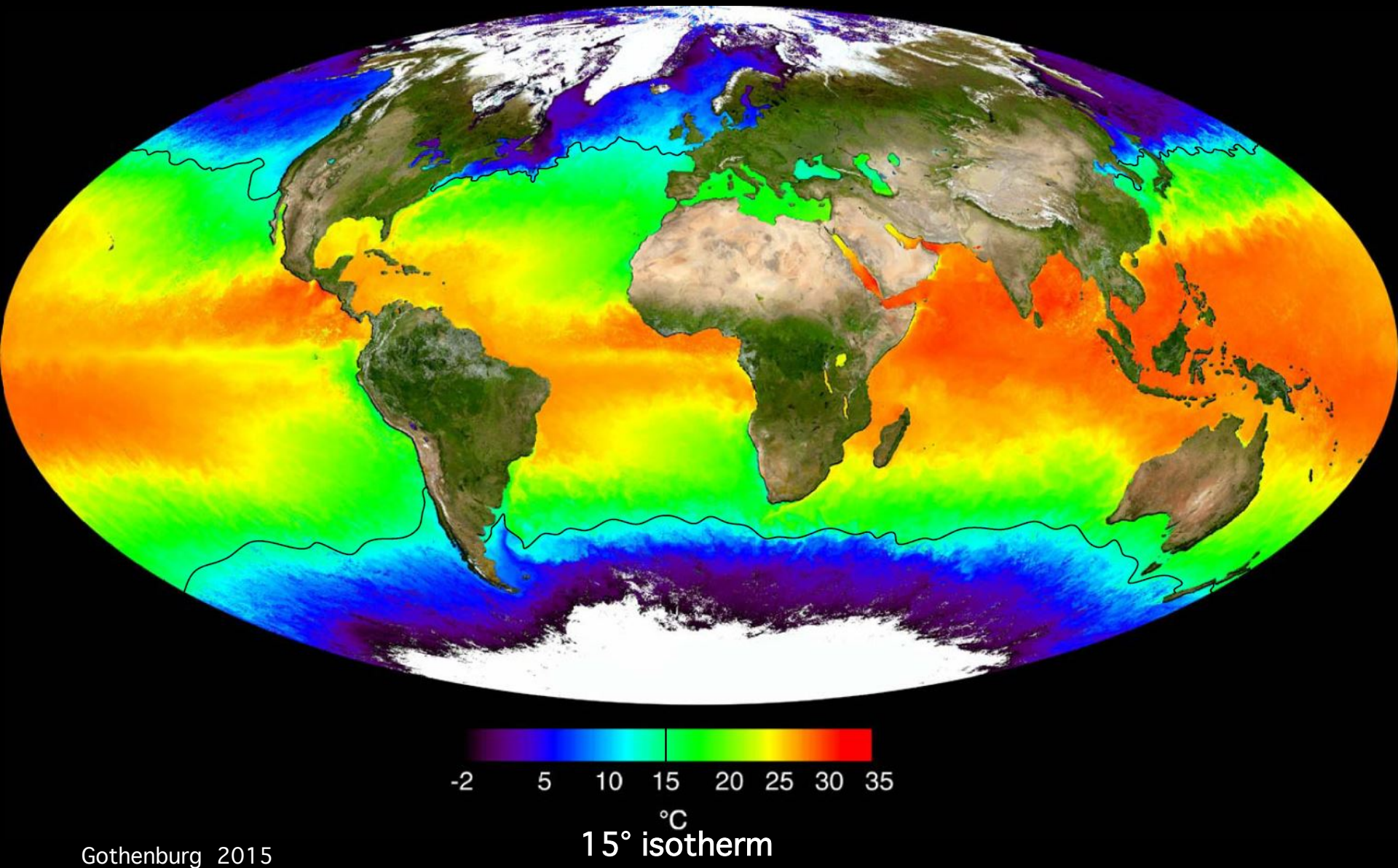
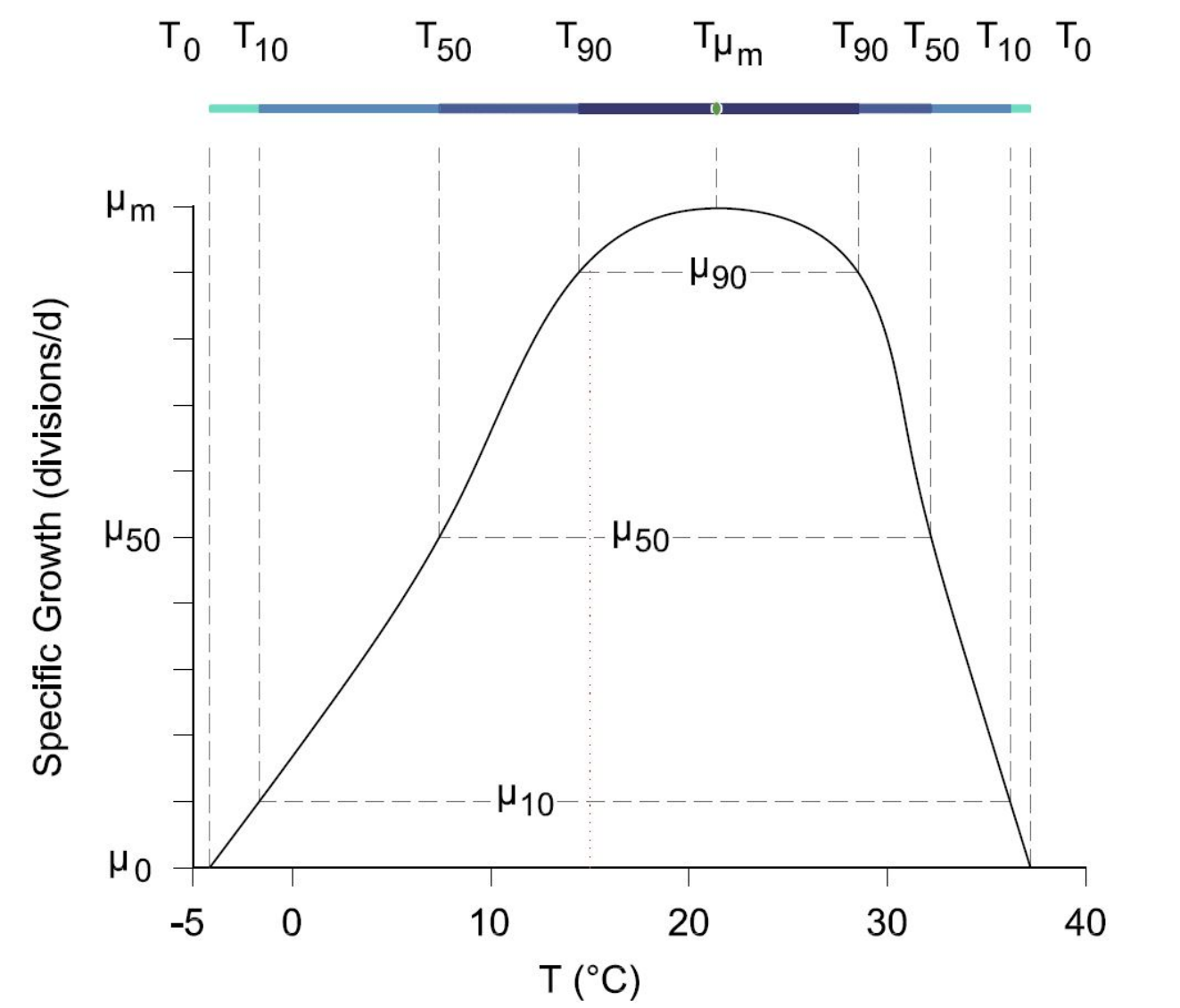
CLIMATE WARMING AND HARMFUL BLOOMS

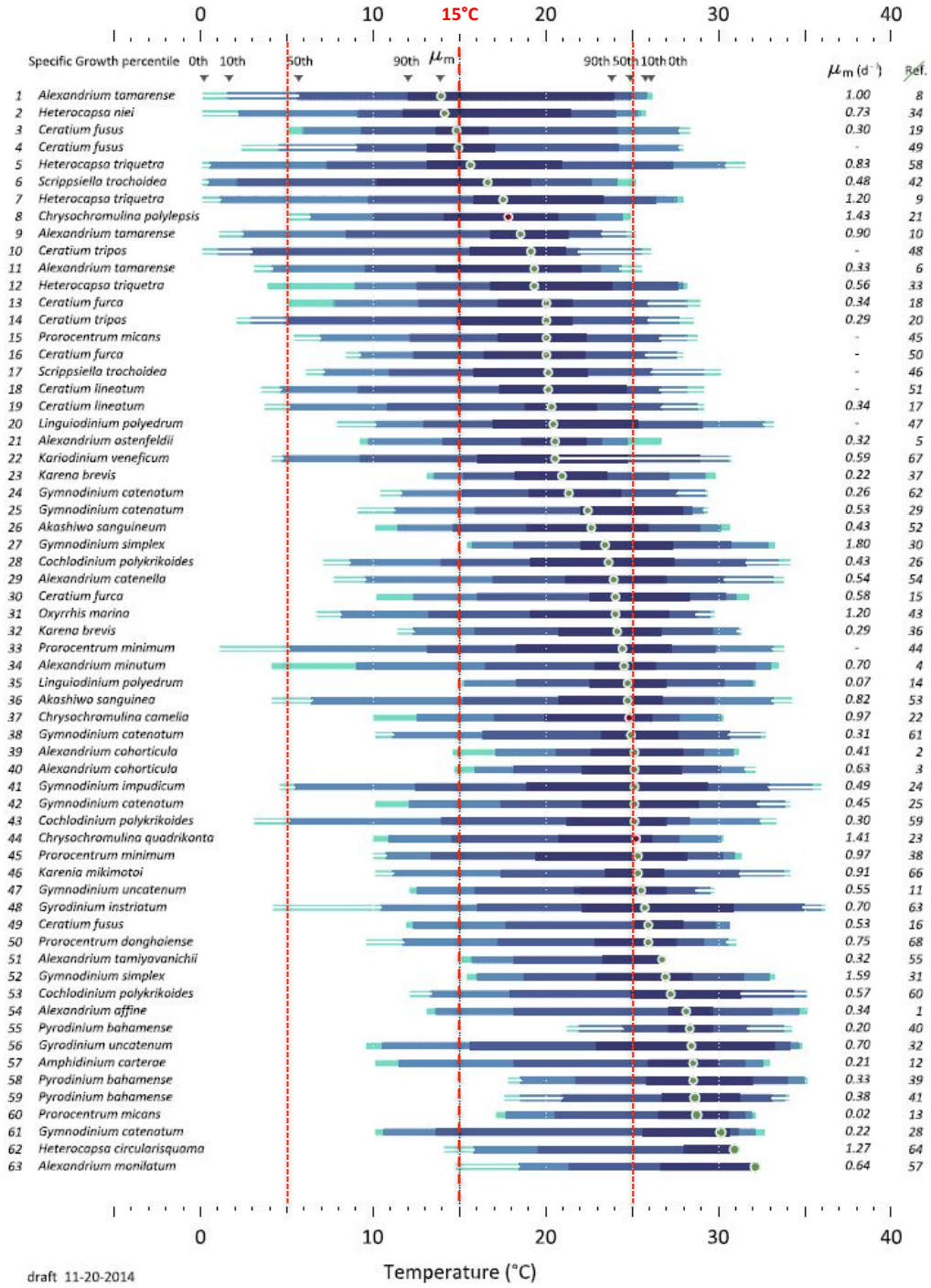
Ted Smayda and Tom Smayda



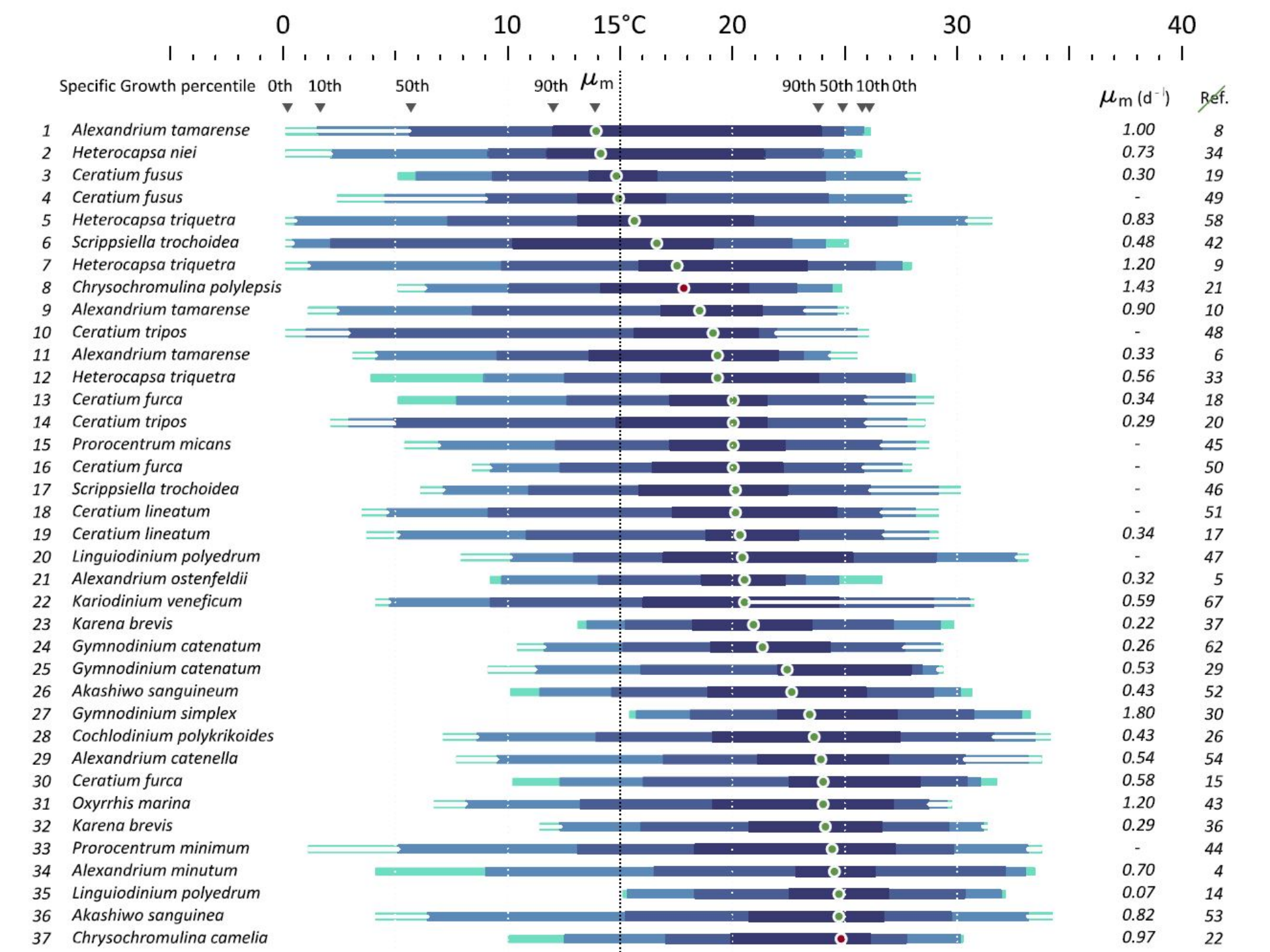
Gothenburg 2015

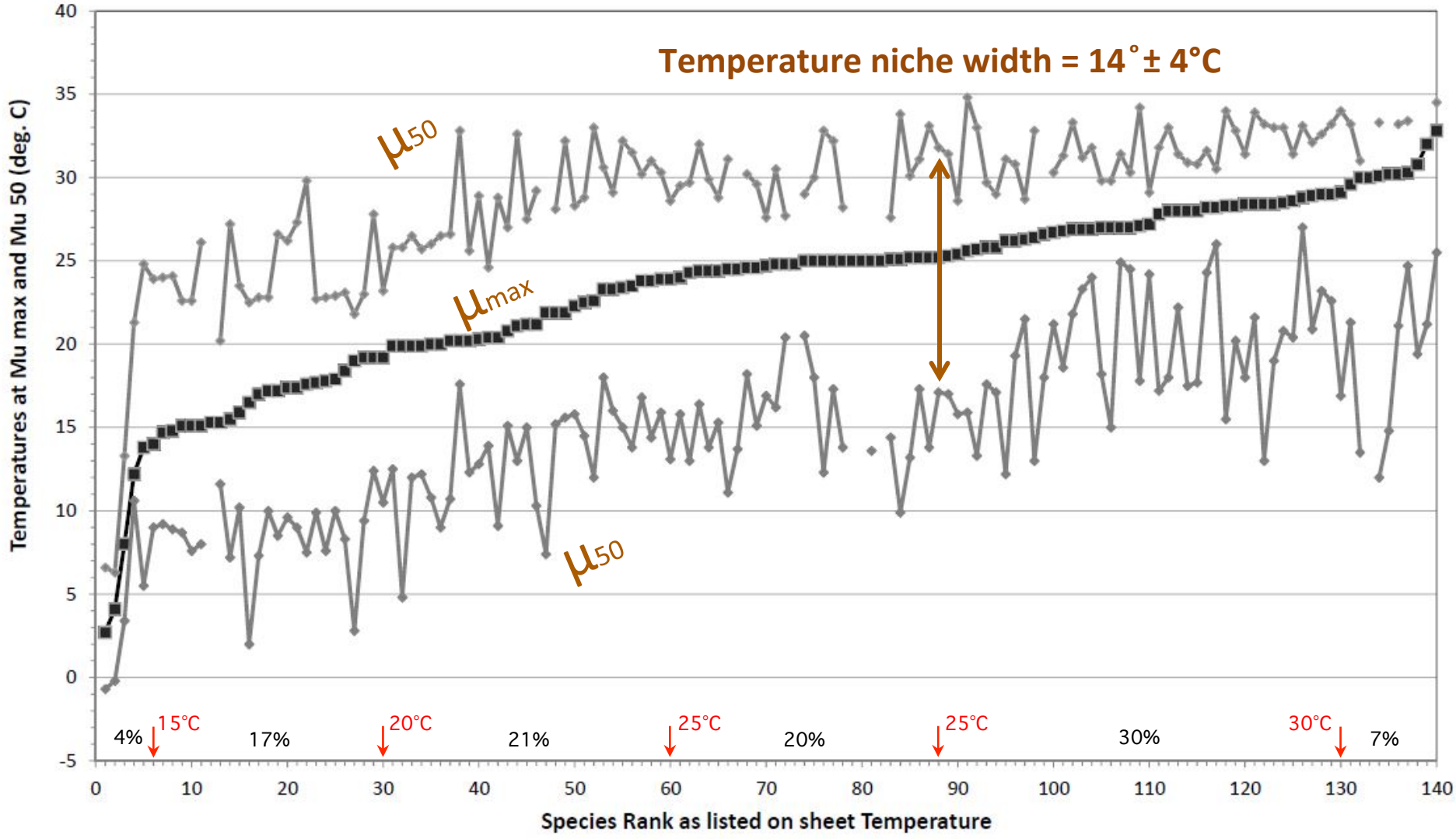
Key


T0 T10 T50 T90 Tμm T90 T50 T10 T0
μm
μ90
μ50
μ50
μ10
μ0
Specific Growth (divisions/d)
-5 0 10 20 30 40
T (°C)



Gothenburg 2015


0
10
15°C
20
30
40
Specific Growth percentile
0th
10th
50th
90th
μ_m
90th
50th
10th
0th
μ_m (d^{-1})
Ref.
1 Alexandrium tamarense 1.00 8
2 Heterocapsa niei 0.73 34
3 Ceratium fusus 0.30 19
4 Ceratium fusus - 49
5 Heterocapsa triquetra 0.83 58
6 Scrippsiella trochoidea 0.48 42
7 Heterocapsa triquetra 1.20 9
8 Chrysochromulina polylepsis 1.43 21
9 Alexandrium tamarense 0.90 10
10 Ceratium tripos - 48
11 Alexandrium tamarense 0.33 6
12 Heterocapsa triquetra 0.56 33
13 Ceratium furca 0.34 18
14 Ceratium tripos 0.29 20
15 Prorocentrum micans - 45
16 Ceratium furca - 50
17 Scrippsiella trochoidea - 46
18 Ceratium lineatum - 51
19 Ceratium lineatum 0.34 17
20 Linguiodinium polyedrum - 47
21 Alexandrium ostenfeldii 0.32 5
22 Kariodinium veneficum 0.59 67
23 Karena brevis 0.22 37
24 Gymnodinium catenatum 0.26 62
25 Gymnodinium catenatum 0.53 29
26 Akashiwo sanguineum 0.43 52
27 Gymnodinium simplex 1.80 30
28 Cochlodinium polykrikoides 0.43 26
29 Alexandrium catenella 0.54 54
30 Ceratium furca 0.58 15
31 Oxyrrhis marina 1.20 43
32 Karena brevis 0.29 36
33 Prorocentrum minimum - 44
34 Alexandrium minutum 0.70 4
35 Linguiodinium polyedrum 0.07 14
36 Akashiwo sanguinea 0.82 53
37 Chrysochromulina camelia 0.97 22

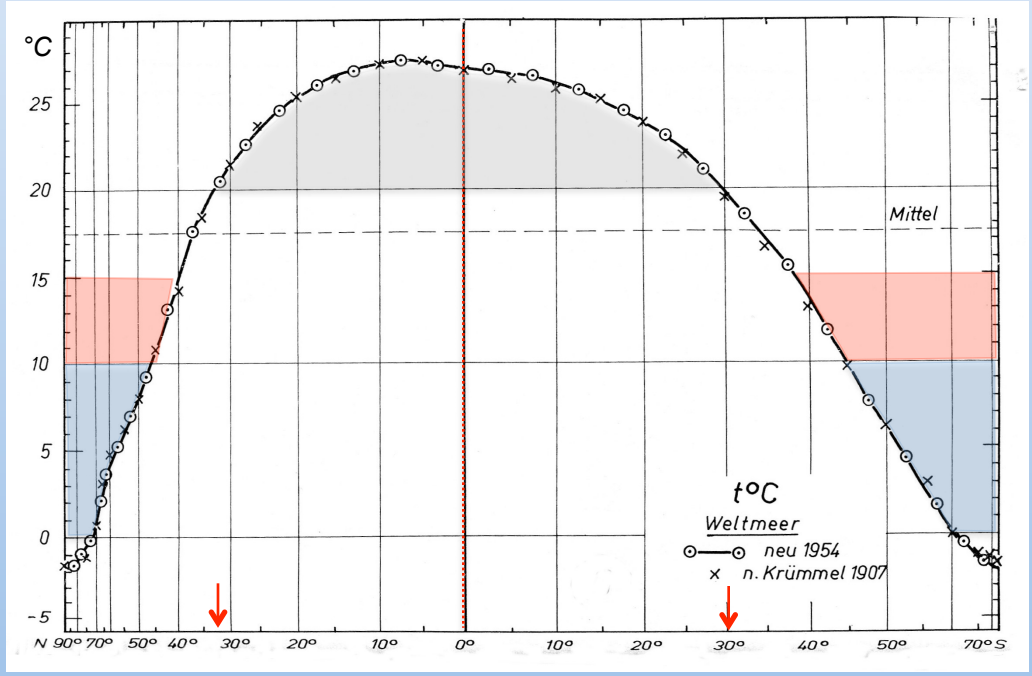


Gothenburg 2015

°N	< 0	0 – 10	10 – 20	15 – 20	20°C
90-70°N	11,680				
70-45		17,541			
45-35			29,246	18,440	
30-0					90,650
0-30°S					97,936
30-45			48,098	32,265	
45-60		40,087			
60-80	20,243				
Σ	31,923	57,628	77,344	50,705	188,586
%	9	16	21	14	52

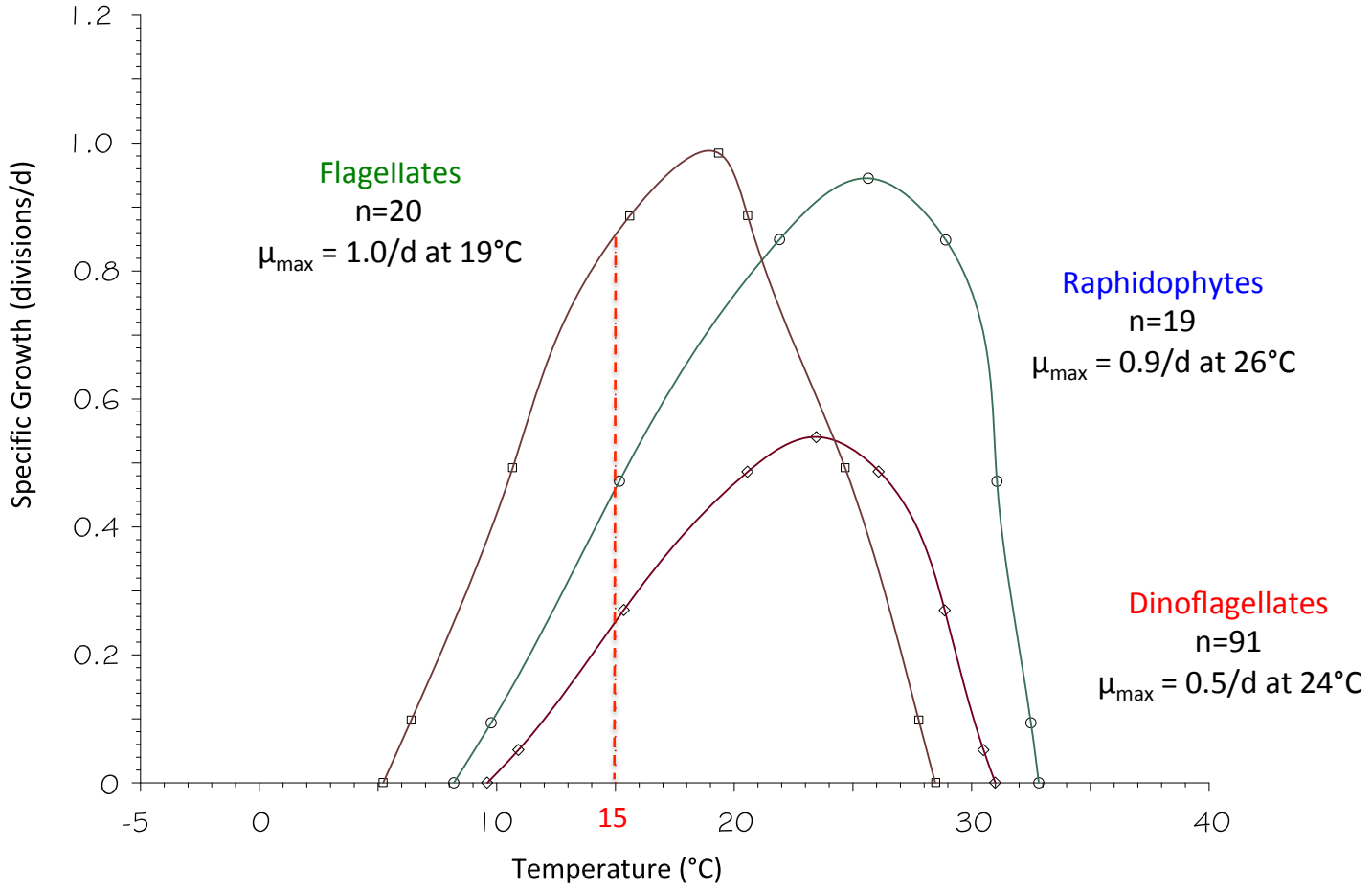
Areas of Ocean (as 10^6 km^2) as % of total area in which temperature < 0°, 0-10°,10-20°, 15-20° and > 20°C [*]

*compiled from Tabelle 1 and 8 in Wüst et al. (1954); total area 361,059 X 10^6 km^2



Wüst et al. (1954)

Average TvK of the various groups



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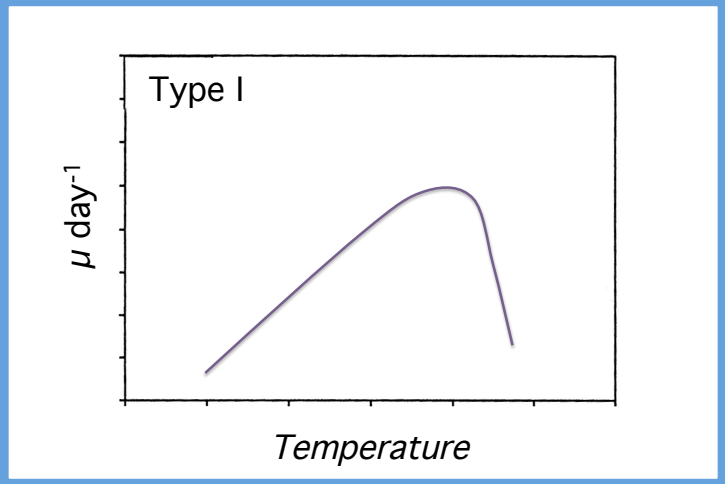
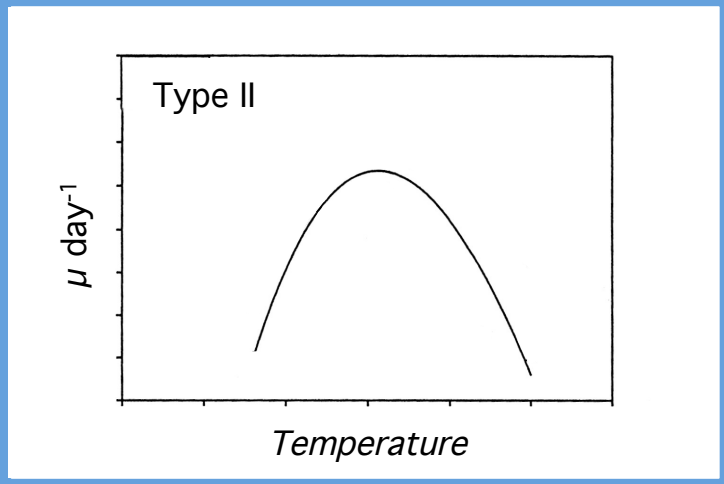
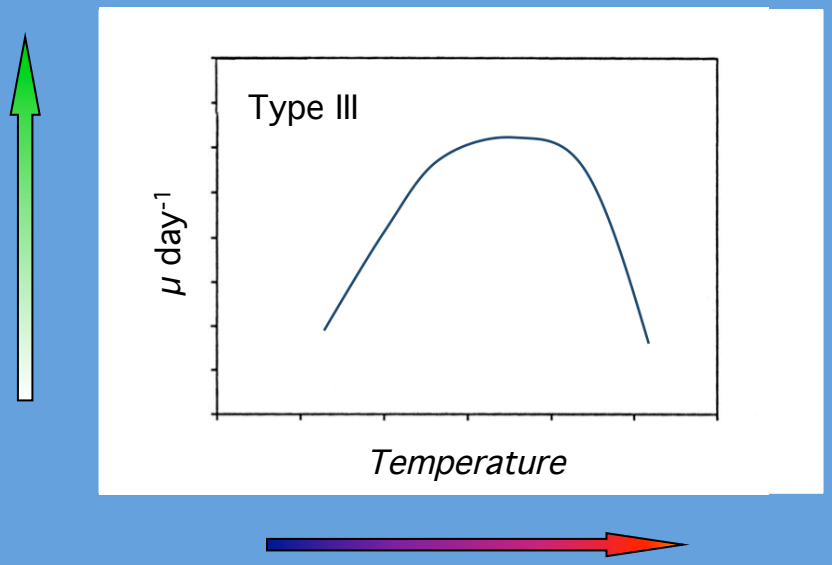
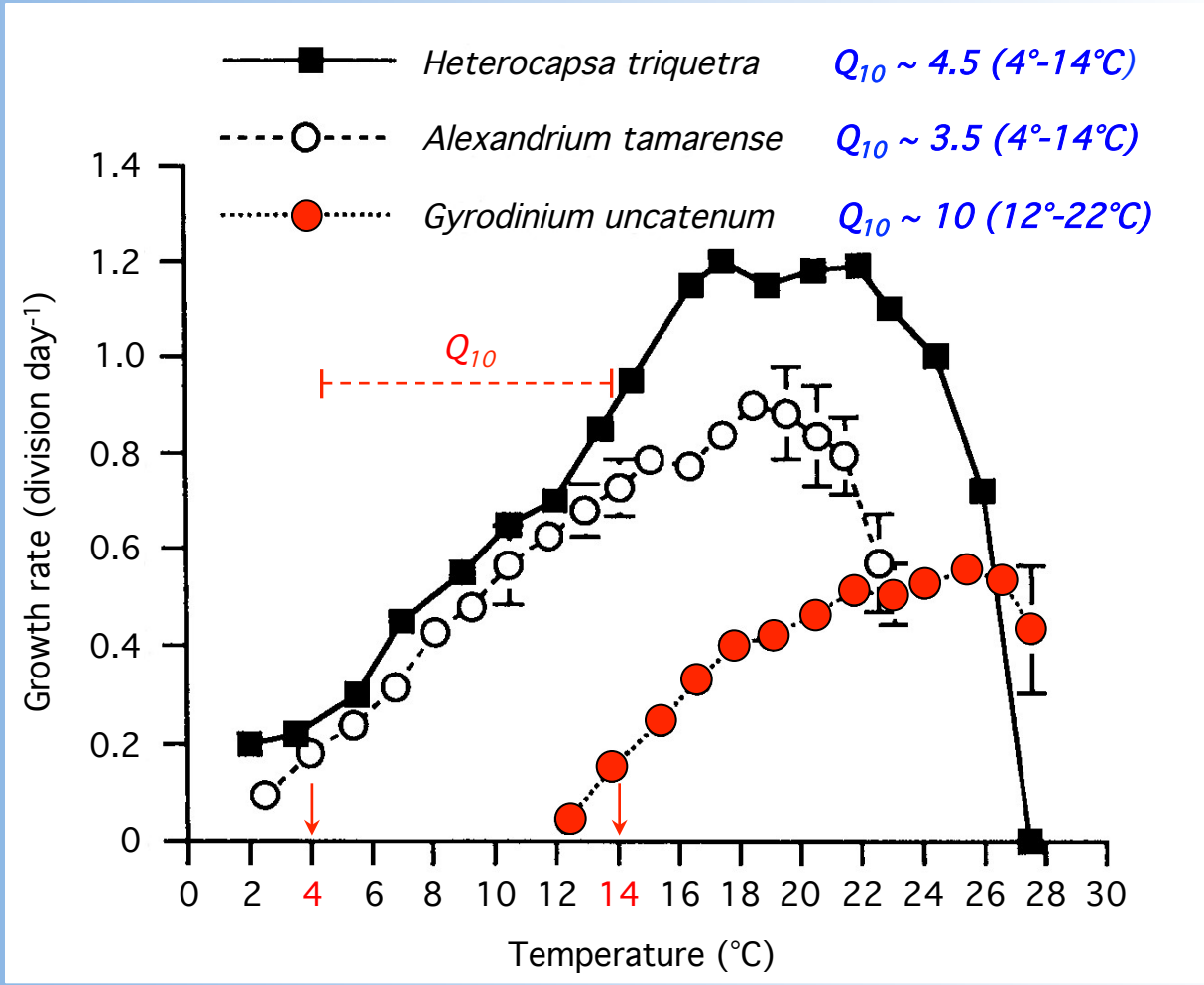






Gothenburg (2015)

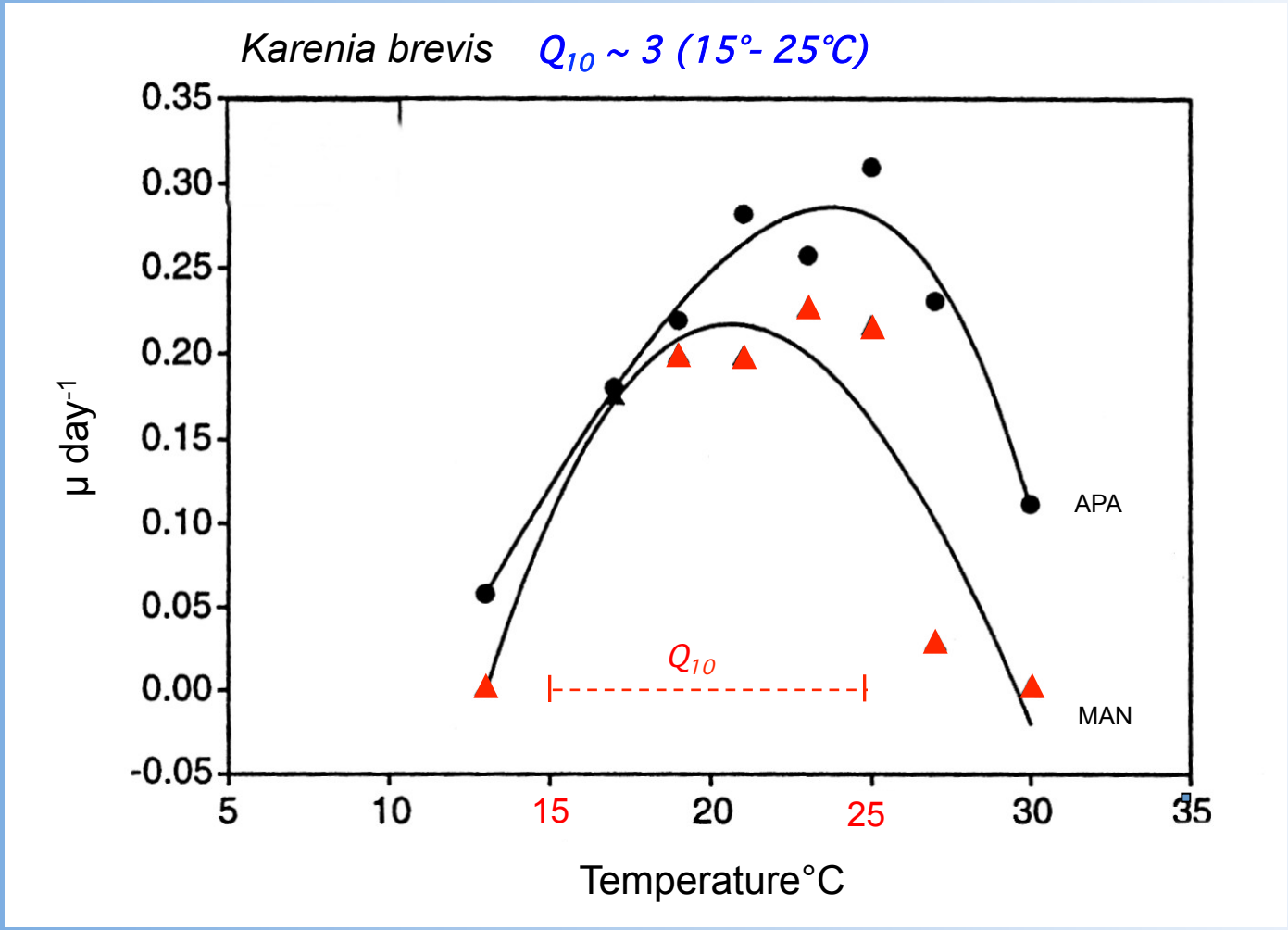
Type I



Anderson & Rengefors (2006)

Gothenburg (2015)

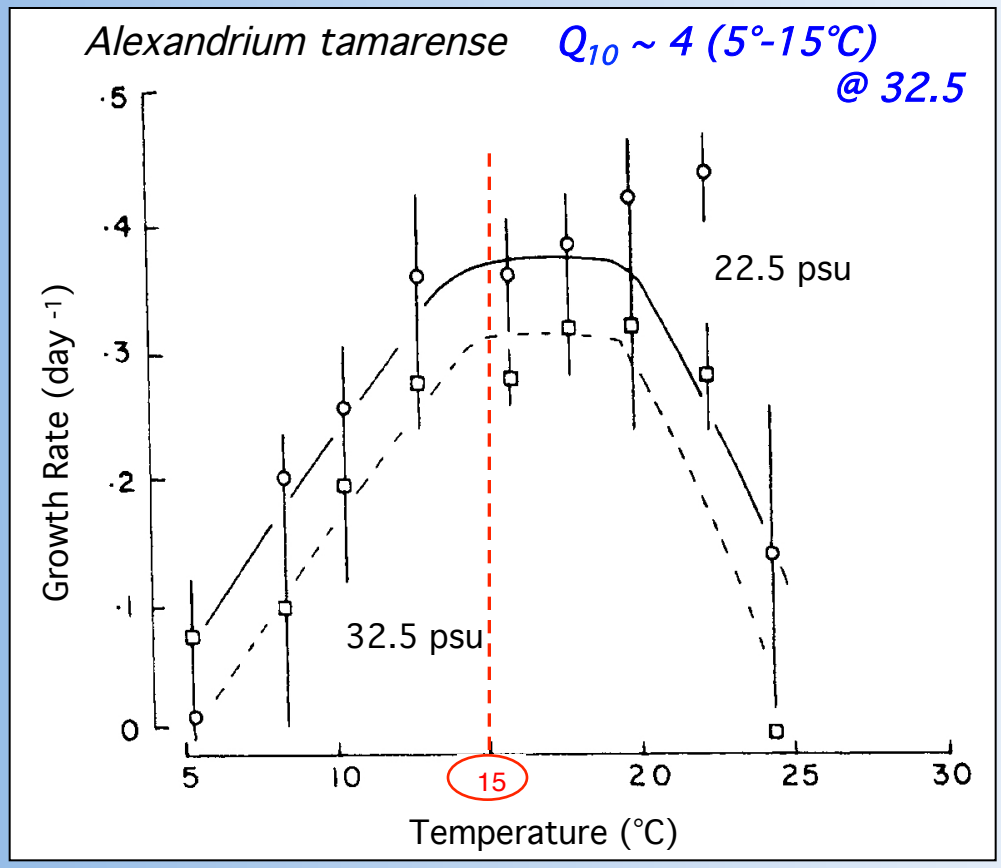
Type II



McKay et al. (2006) F10

Gothenburg (2015)

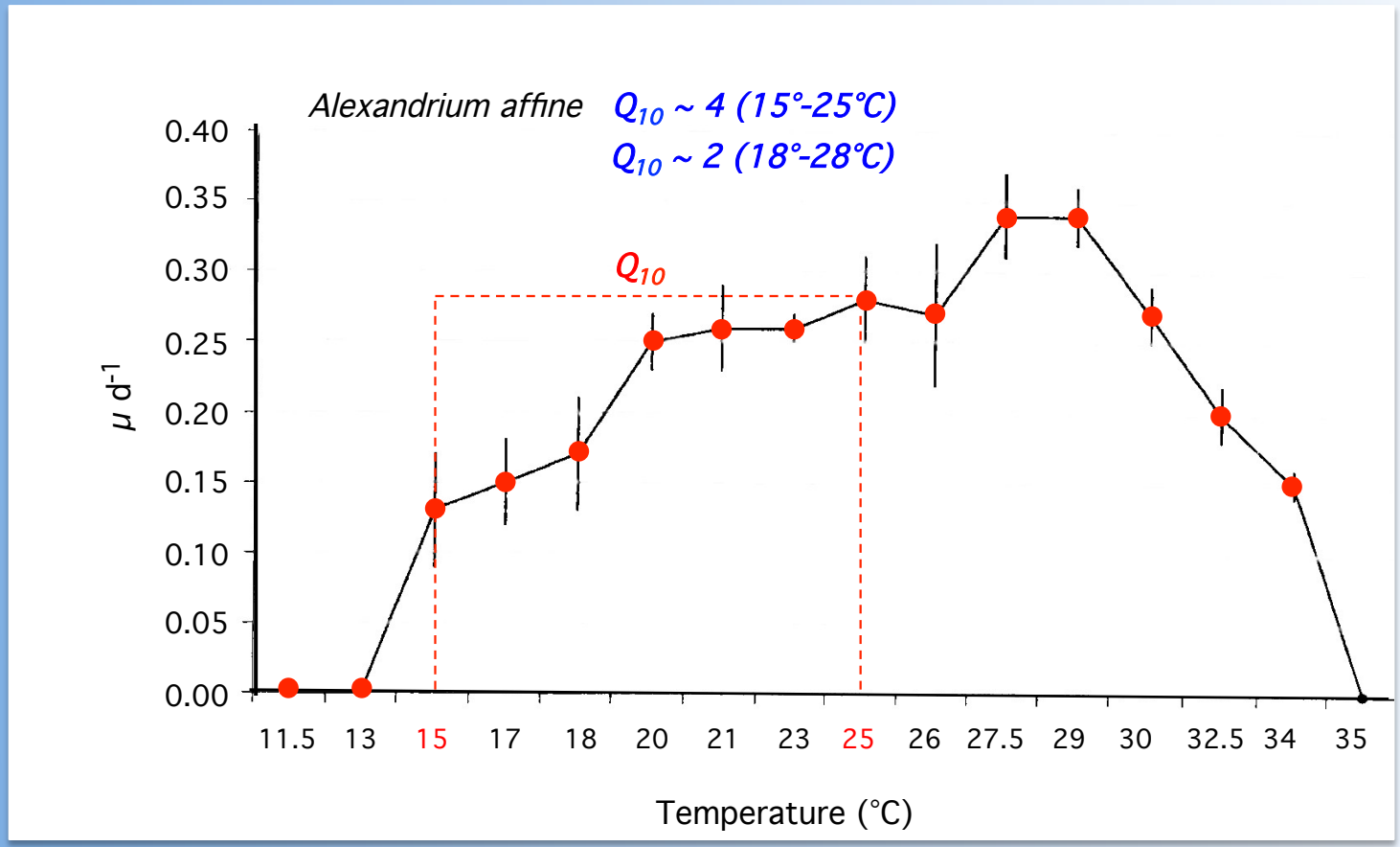
Type III



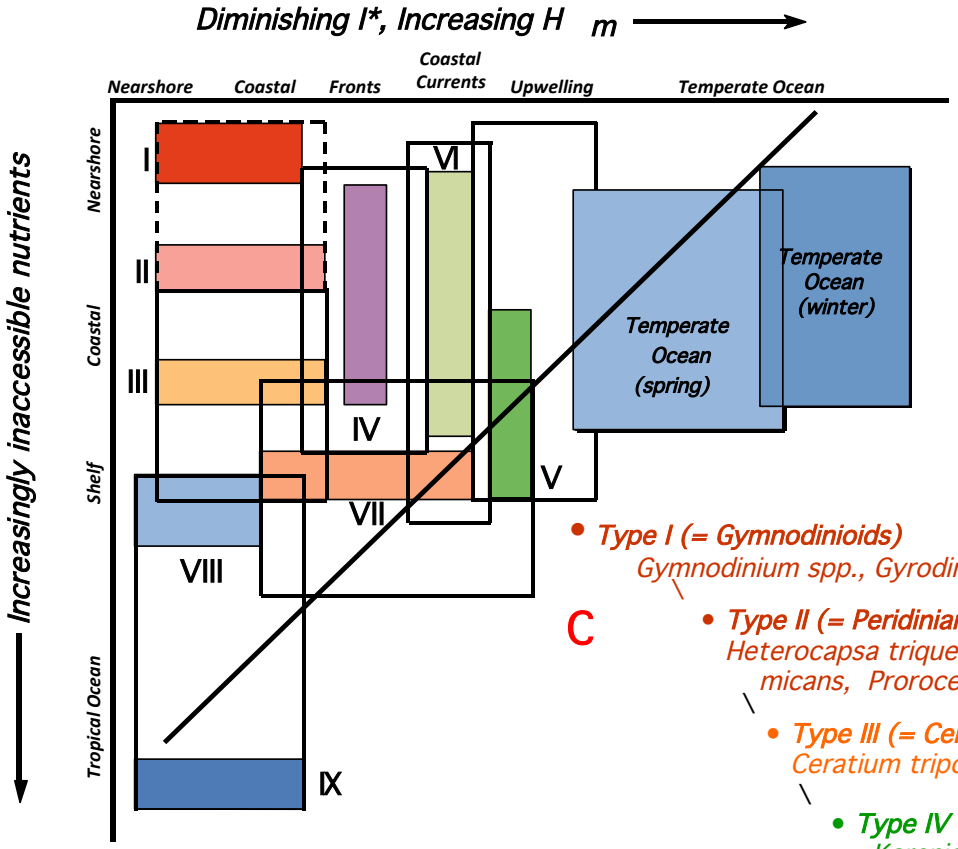
Watras et al. (1982) F4

Gothenburg (2015)

Type III



Band-Schmidt et al. (2003)
Gothenburg (2015)



- **Type I (= Gymnodinioids)**
  Gymnodinium spp., Gyrodinium instriatum, Heterocapsa rotundata

C

- **Type II (= Peridinians/Prorocentroids)**
  Heterocapsa triquetra, Scrippsiella trochoidea, Prorocentrum micans, Prorocentrum minimum, Prorocentrum triestinum
- **Type III (= Ceratians)**
  Ceratium tripos, C. fusus, C. lineatum, C. longipes
- **Type IV (= Frontal Zone Taxa)**
  Karenia mikimotoi, Alexandrium tamarense)

R

- **Type V (= Upwelling Relaxation Taxa)**
  Gymnodinium catenatum, Lingulodinium polyedrum
- **Type VI (= Coastal Current Entrained Taxa)**
  Alexandrium fundyense, Pyrodinium bahamense var. compressum, Karenia brevis, Ceratium spp.
- **Type VII (= Dinophysoids)**
  Dinophysis spp.

S

- **Type VIII (= Tropical Oceanic Flora)**
  Amphisolenia, Histioneis, Ornithocercus, Ceratium spp.
- **Type IX (= Tropical Shade Flora)**
  Pyrocystis noctiluca, Pyrocystis pyriformis

Modified from Smayda & Reynolds (2001)
Gothenburg, 2015

TENTATIVE CONCLUSION

- "COOL WATER" FLAGELLATES, i.e. THOSE THAT TOLERATE AND GROW AT ca. 5° TO 15°C, PREDOMINATE IN LIFE FORM TYPES I TO III
- THESE LIFE FORMS GENERALLY HAVE MUTED OR NO TOXIC EFFECTS
- THESE GENERALLY ARE THE "RED TIDE" SPECIES

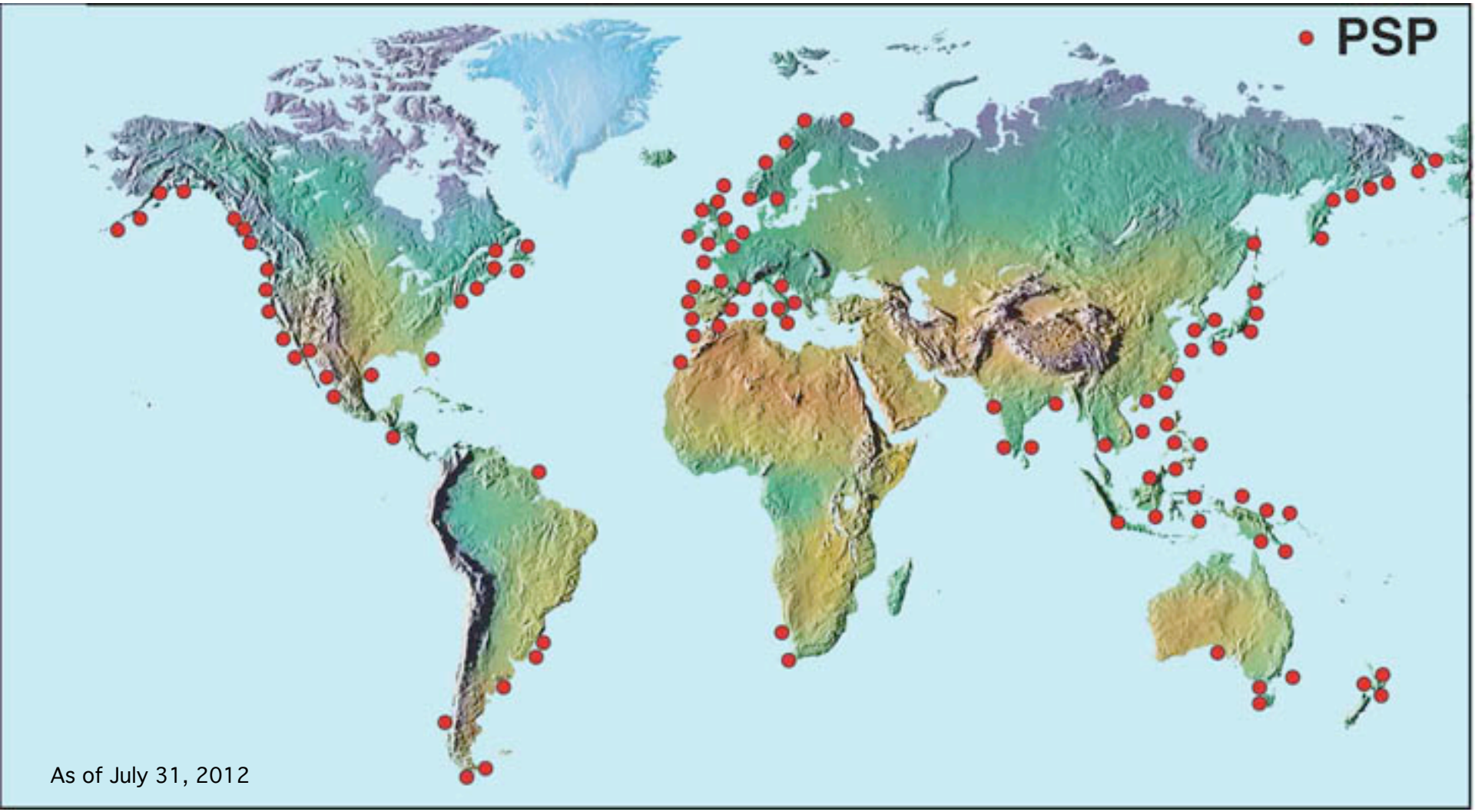
Examples:

Ceratium spp.; Heterocapsa triquetra; Prorocentrum spp.; Scrippsiella trochoidea

- IF TOXIC, THEY TEND TO BE ICHTHYOTOXIC

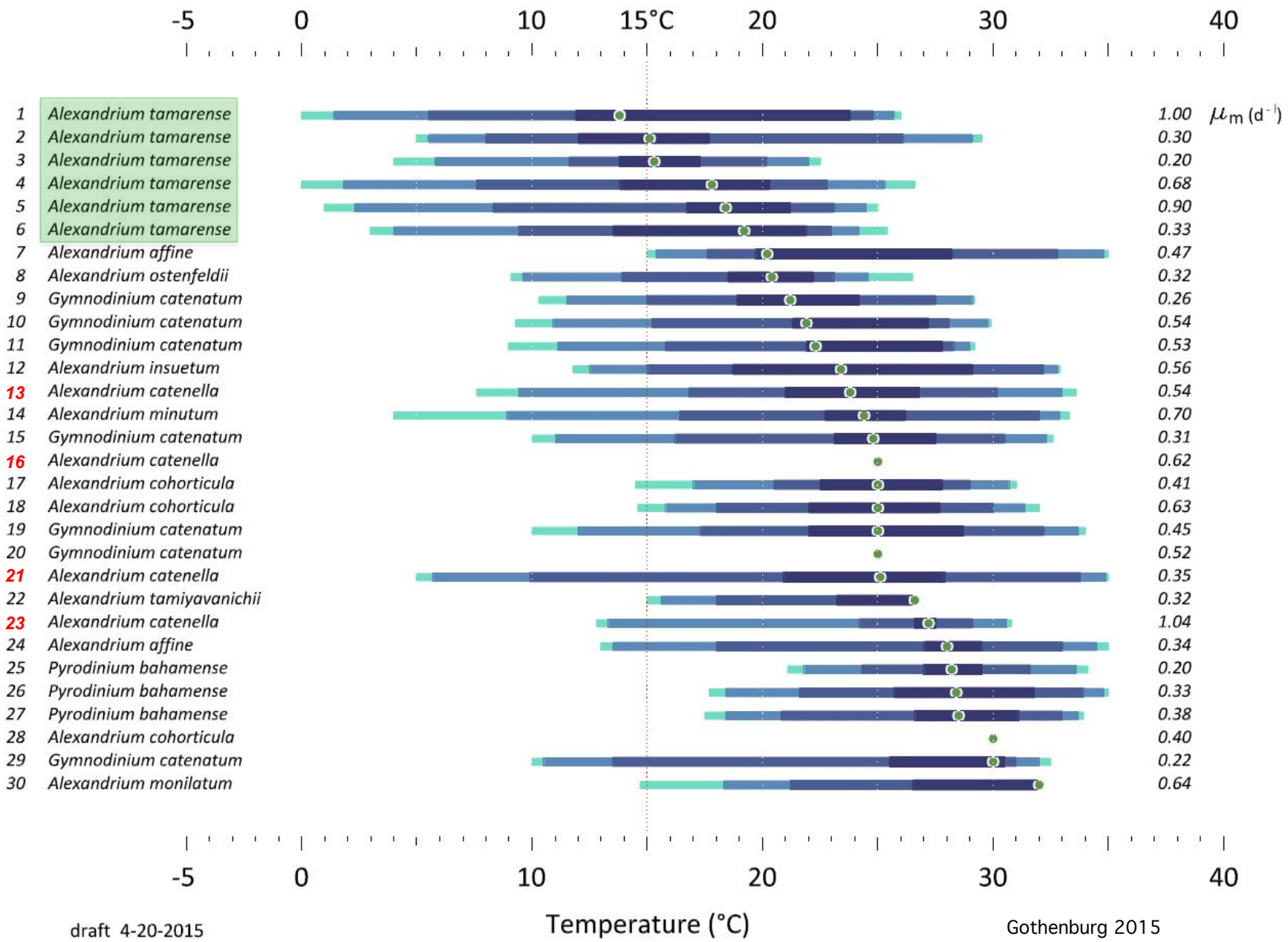
Examples:

Karlodinium veneficum; Prymnesium parvum; Prymnesium polylepis; Chrysochromulina spp.



http://www.whoi.edu/redtide/page.do?pid=14899&tid=542&cid=47594&c=3

Alexandrium, Gymnodinium catenatum & Pyrodinium



draft 4-20-2015

Gothenburg 2015

ALEXANDRIUM SPECIES

- GENERALLY HAVE OPTIMAL GROWTH TEMPERATURES > 15°C,
- GENERALLY GROW POORLY OR ARE INTOLERANT BELOW 15°C.
- EXAMPLES:
  Alexandrium affine; A. minutum;
  A. monilatum; A. ostenfeldii;
  A. tamiyavanichii
- *Alexandrium tamarense – a "cool water species"* - AN EXCEPTION TO *ALEXANDRIUM PATTERN; GROUPS WITH LIFE FORMS I, II, III*
- *Alexandrium catenella – enigma: a "warm water species"?*
- *Alexandrium fundyense complex*

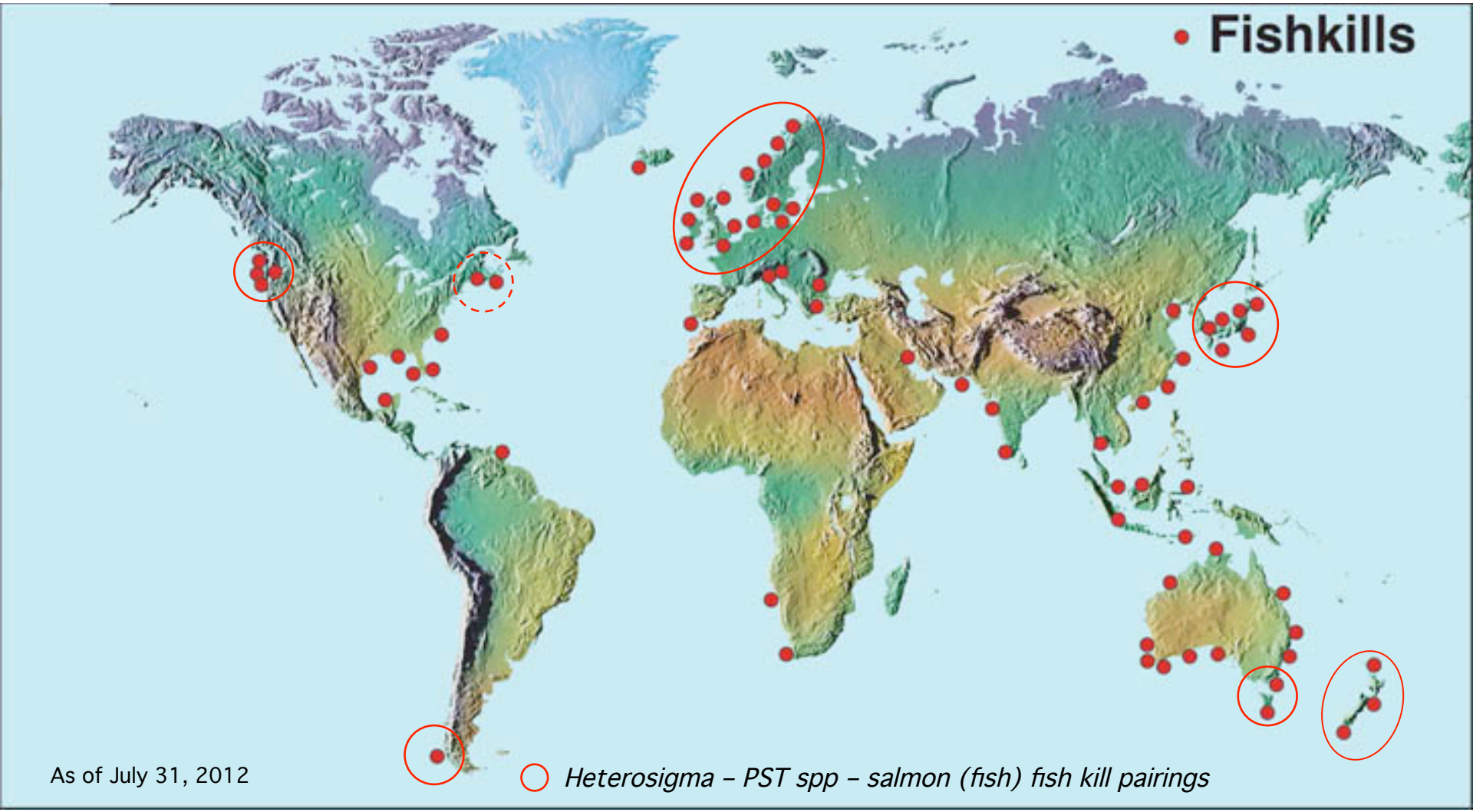
TOXIC PSP SPECIES OTHER THAN *ALEXANDRIUM* AND OTHER TOXICITIES

- MIXING - DRIFT DINOFLAGELLATE SPECIES - LIFE FORMS IV, V, VI - ARE GENERALLY HARMFUL, AND EXHIBIT POOR OR NO GROWTH BELOW 15°C

  Examples:
  Pyrodinium bahamense var. compressum; Gymnodinium catenatum; Lingulodinium polyedrum; Karenia mikimotoi; Karenia brevis

- PSP SPECIES GENERALLY EXHIBIT A "WARM WATER" PREFERENCE

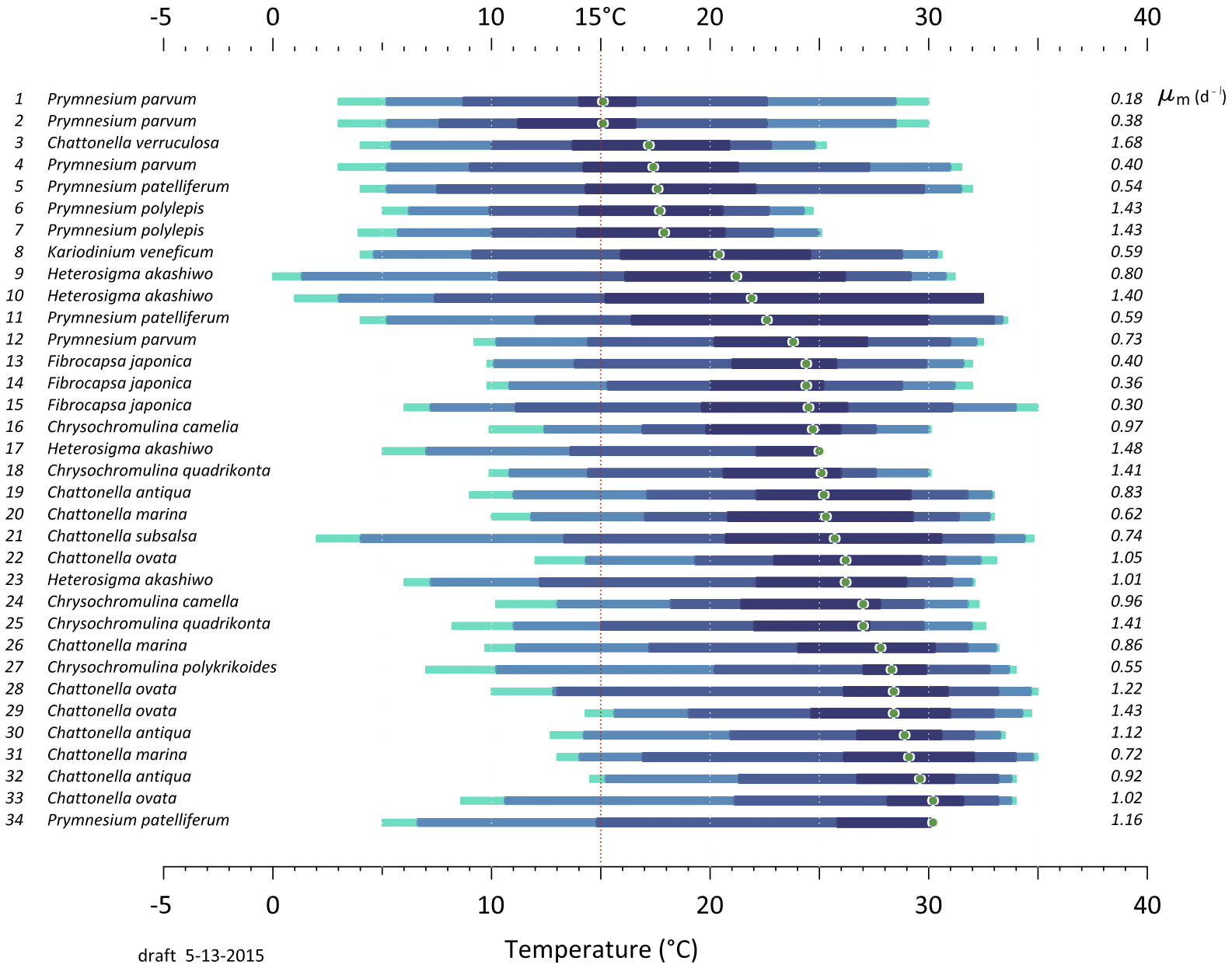
- ICHTHYOTOXIC SPECIES GENERALLY EXHIBIT A "COOL WATER" PREFERENCE



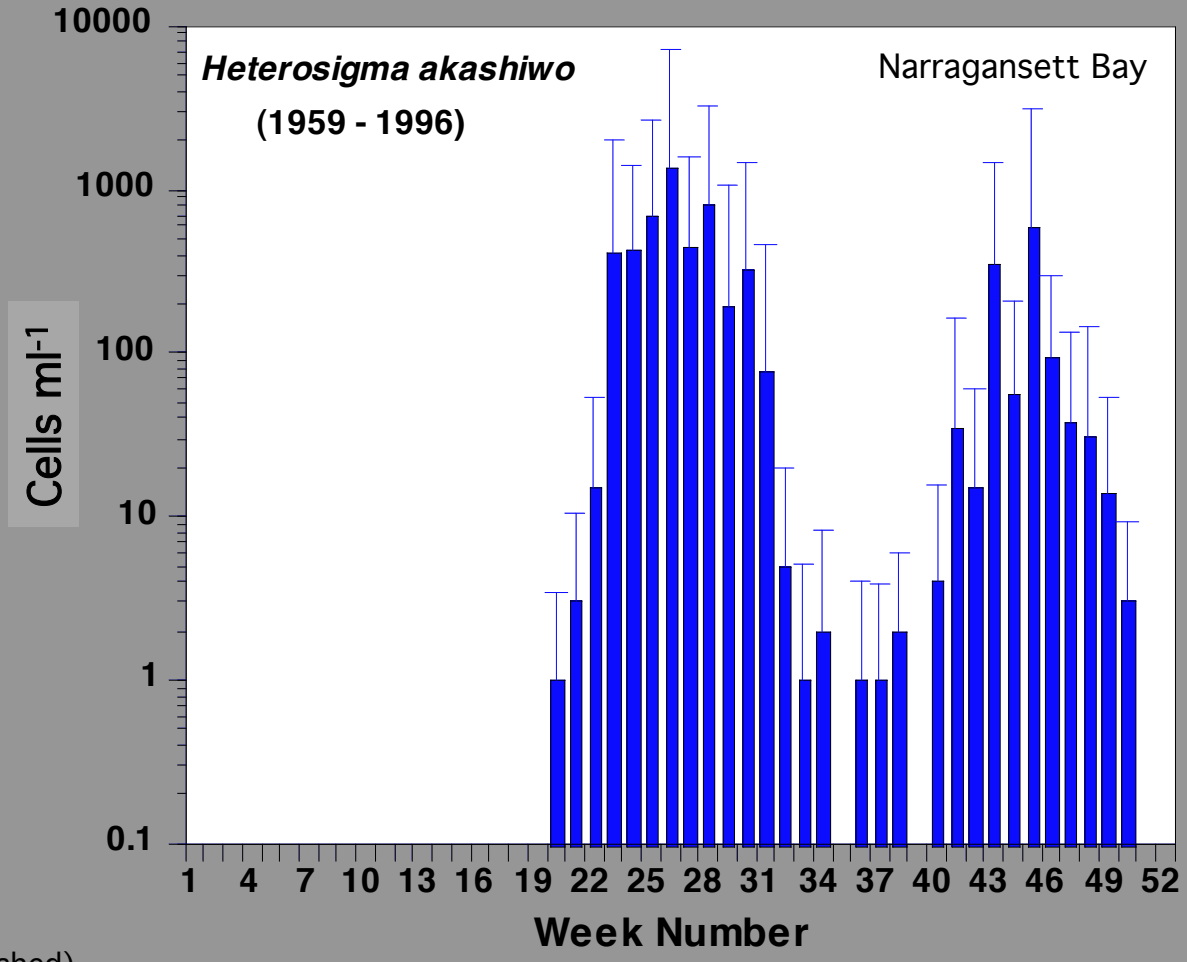
Locations where fish kills have been reported

http://www.whoi.edu/redtide/page.do?pid=18103&tid=542&cid=47596&c=3

Raphidophytes and other ichthyotoxic species

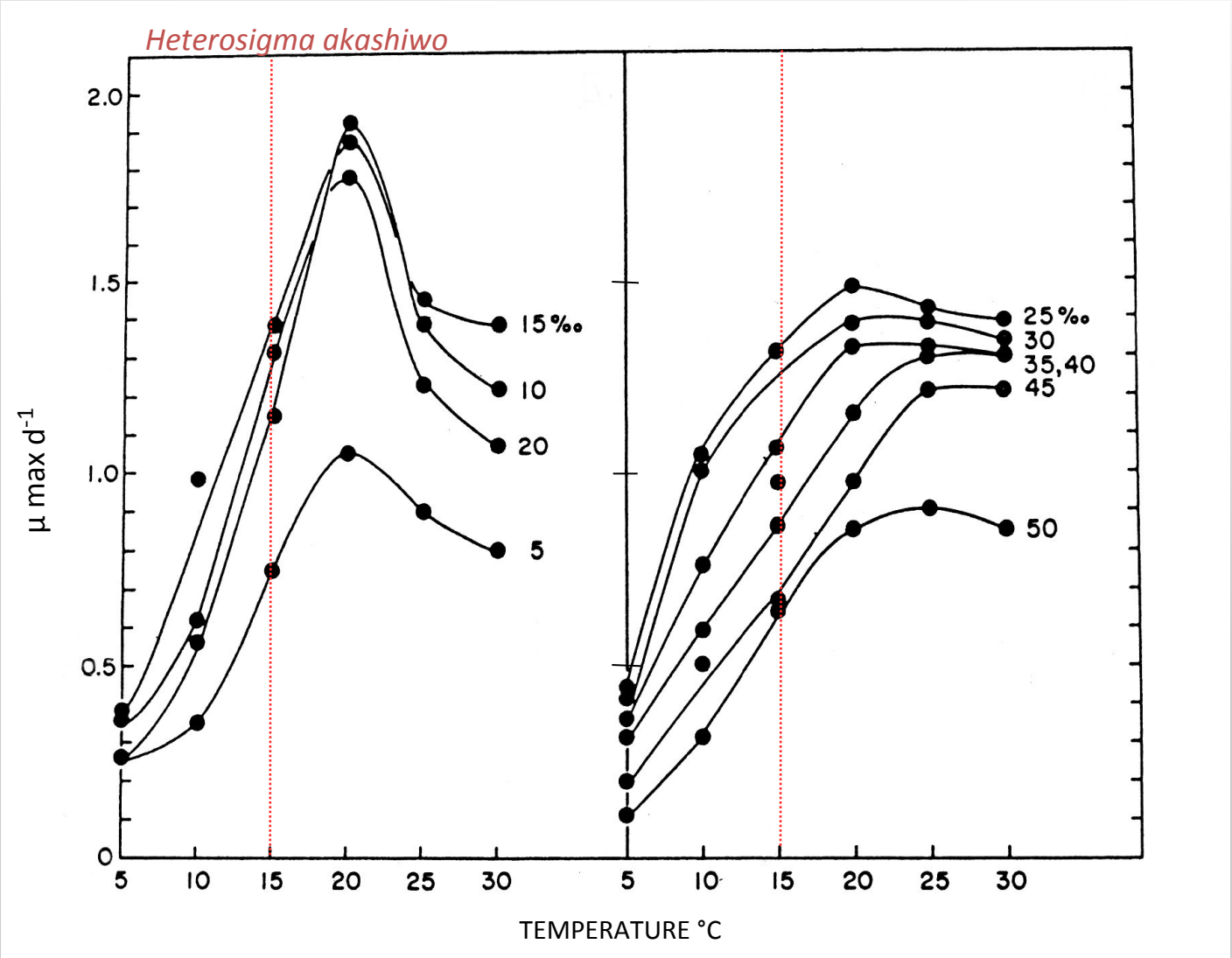


draft 5-13-2015



Smayda (unpublished)

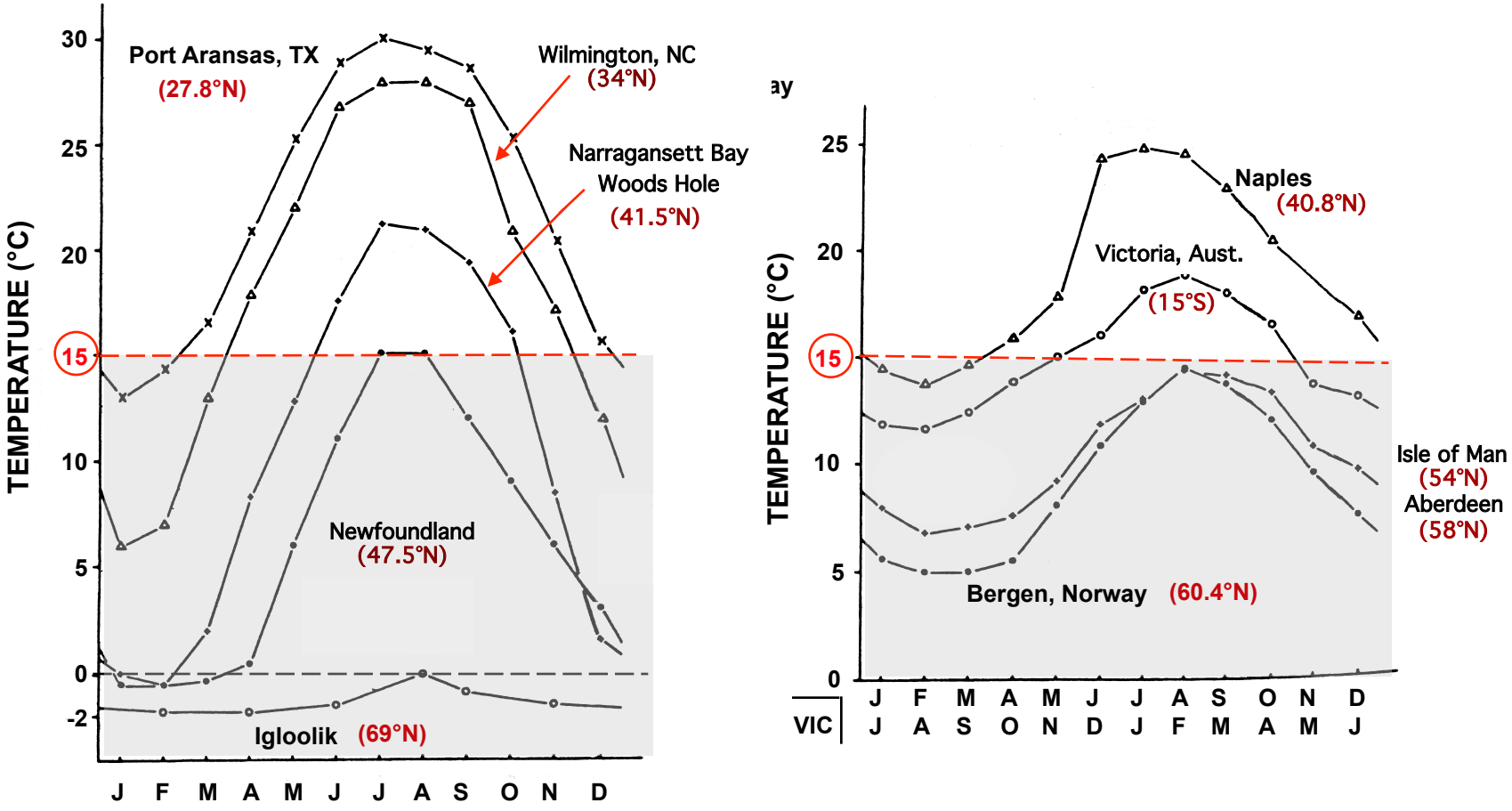
Gothenburg 2015



Tomas (1978)

Seoul (2012)

Mean Annual Temperature Cycles



Modified from Bolton (1983)

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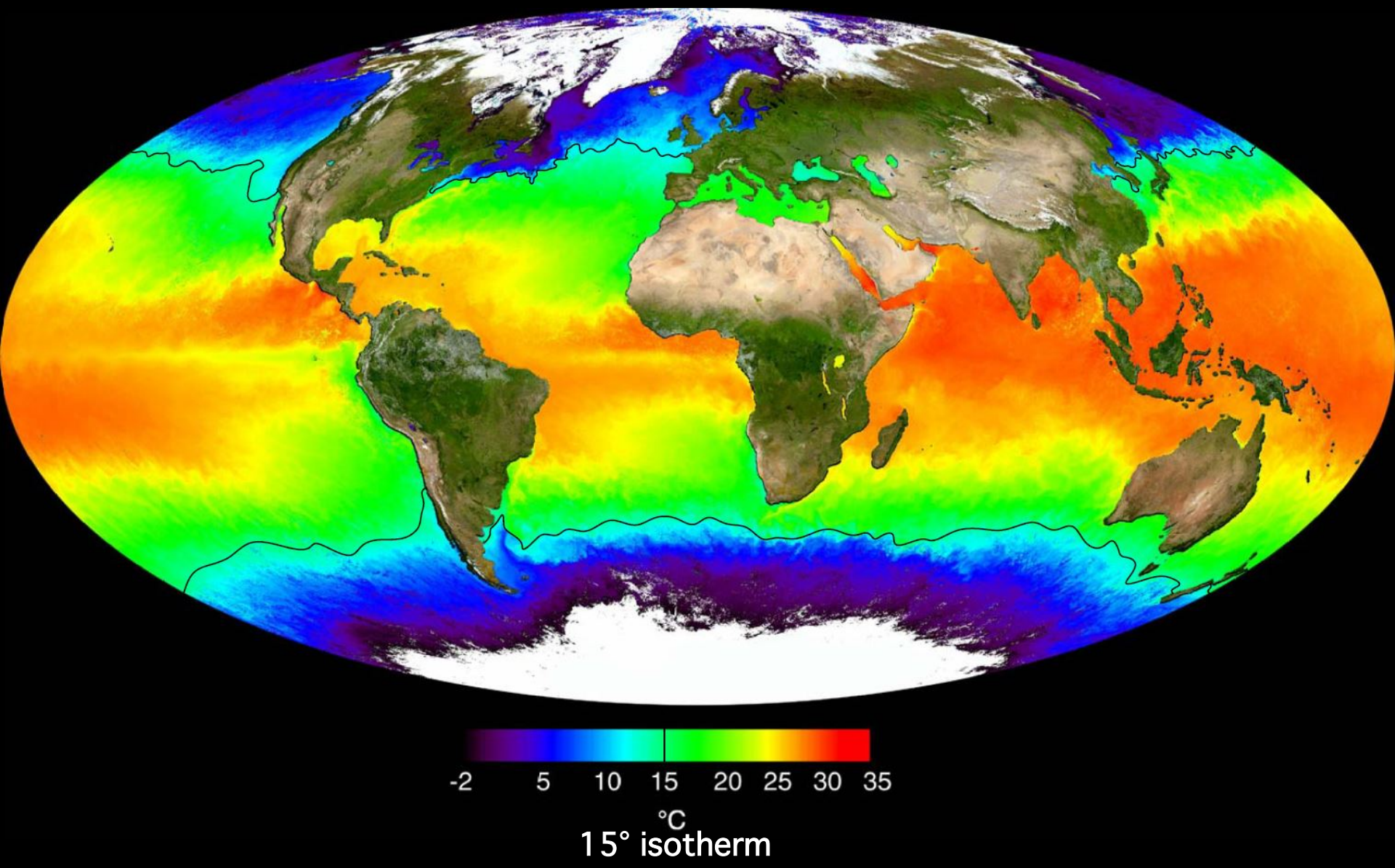
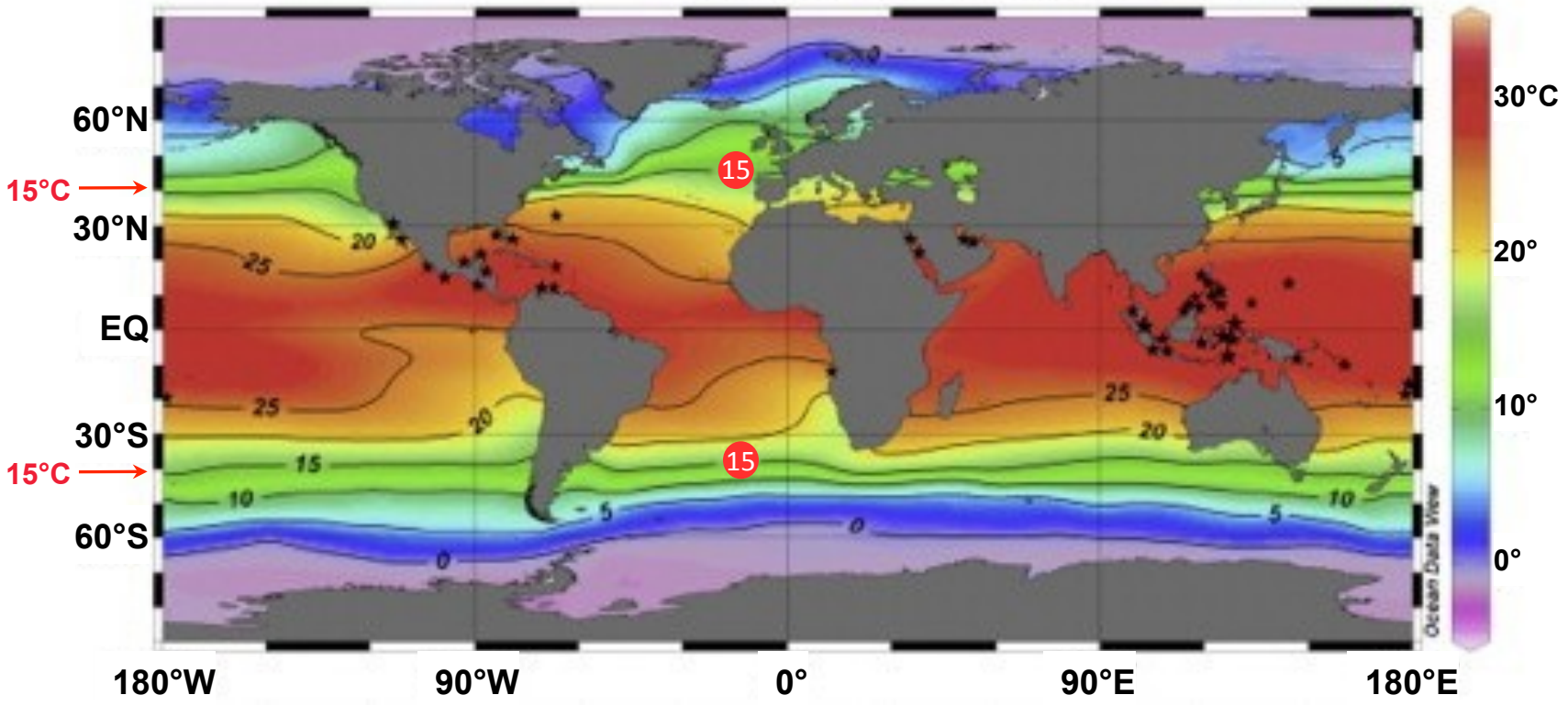
ECOTONES

REDISTRIBUTION

REFUGIA

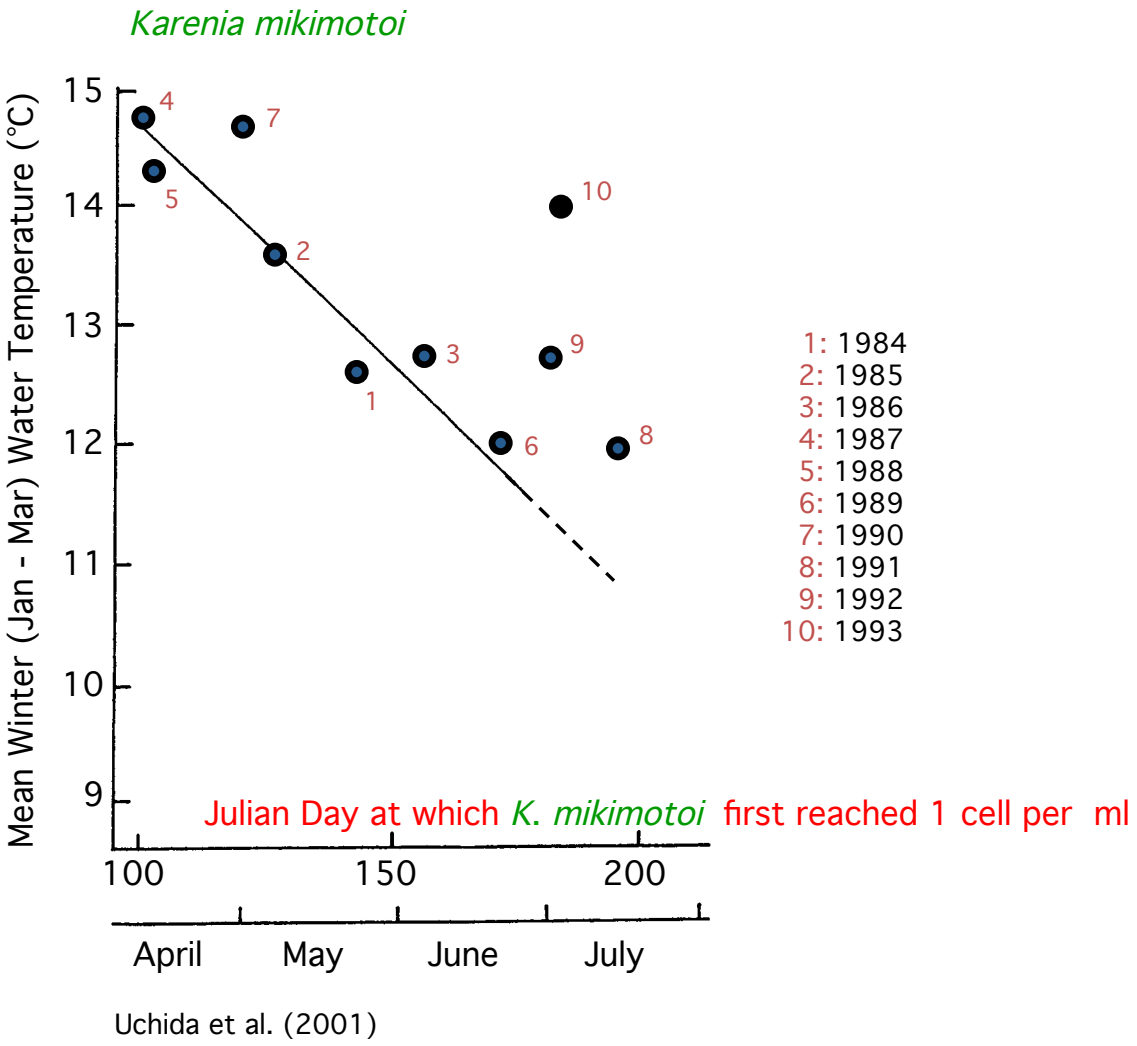
COLONIZATION


-2
5
10
15
20
25
30
35
°C
15° isotherm

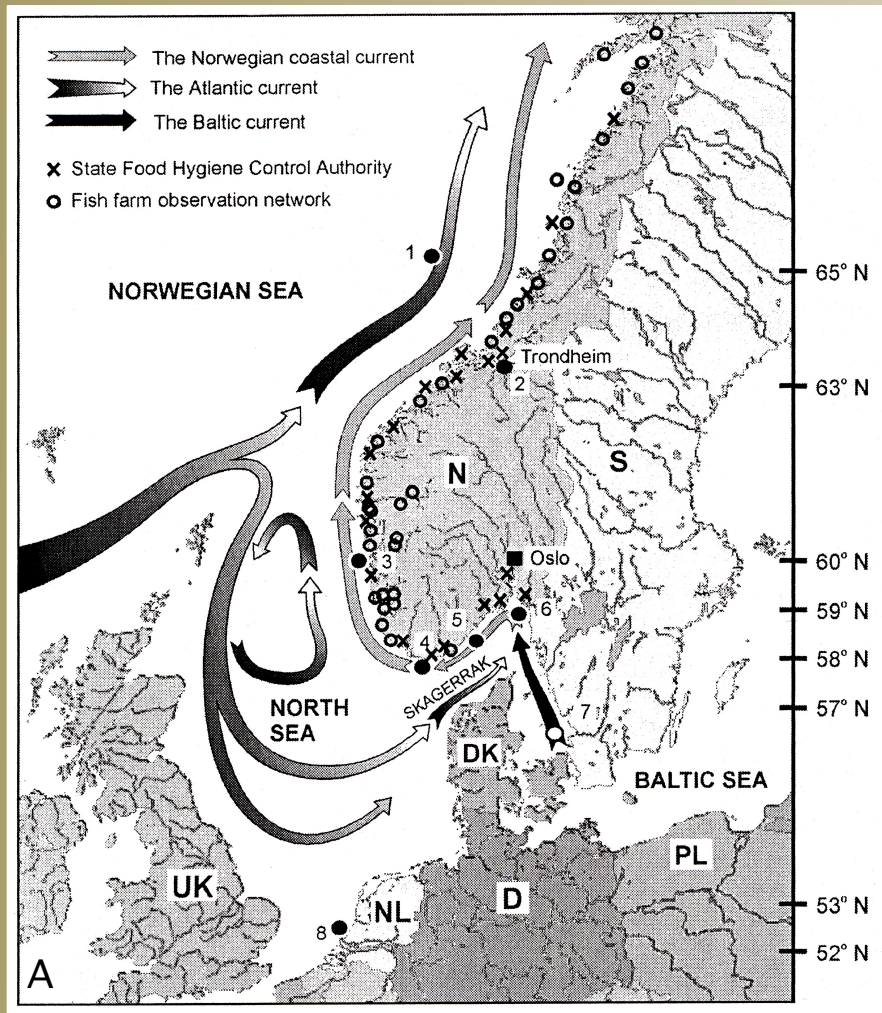


Geographical distributions of Pyrodinium bahamense in relation to surface water temperature in summer. Temperature gridded using the 1-degree World Ocean Atlas 2005 (Locarnini et al., 2006) and the Ocean Data View software (Schlitzer, 2010).

Modified from Usup et al. (2012)



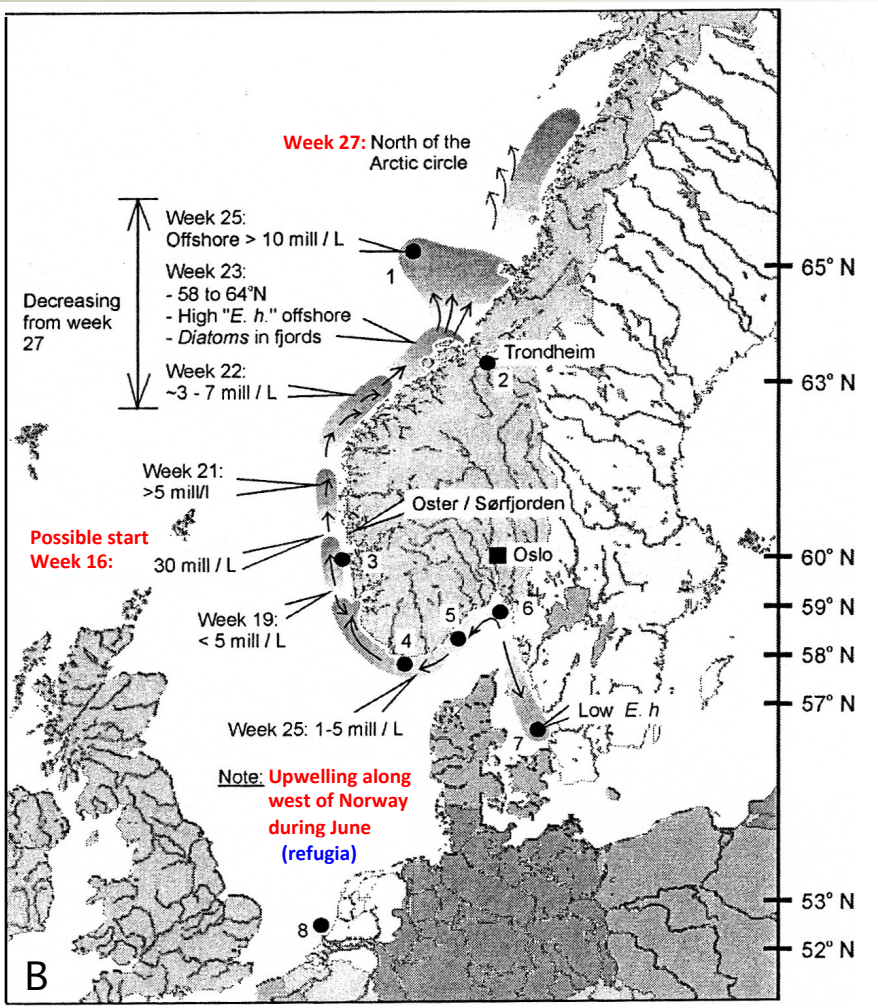
Uchida et al. (2001)



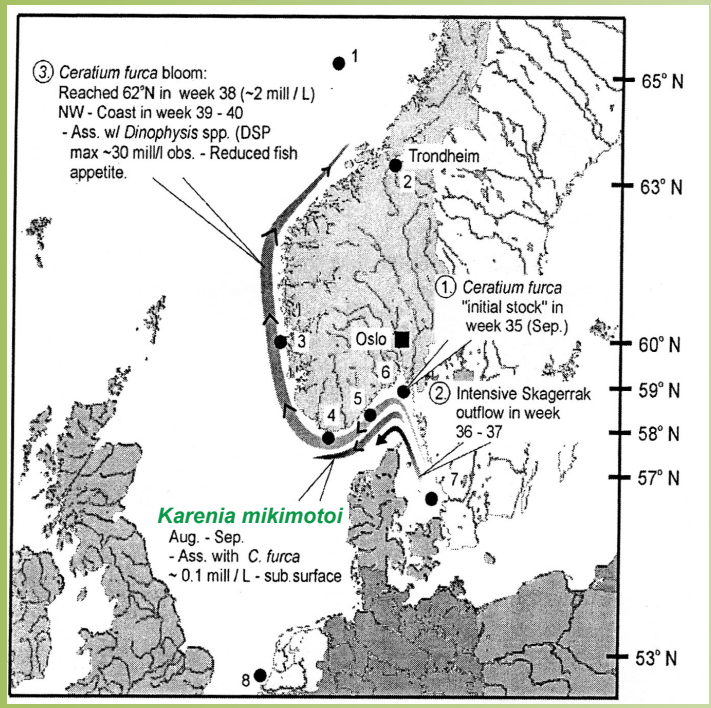
Seawatch buoy stations, observation network sites, and schematic surface circulation in northwest Europe.

Modified from Johnsen et al. (1997)

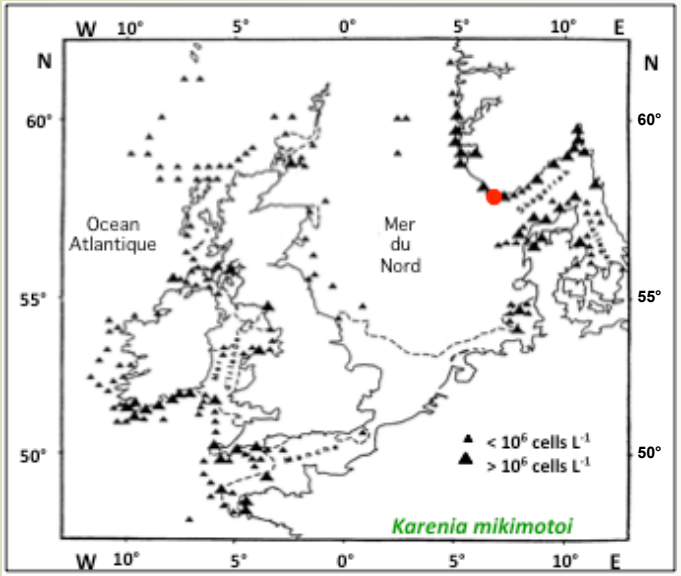
Gothenburg 2015



Emiliania huxleyi bloom in 1993 along the Norwegian west Coast. Bloom began in April and passed the Arctic Circle in July.



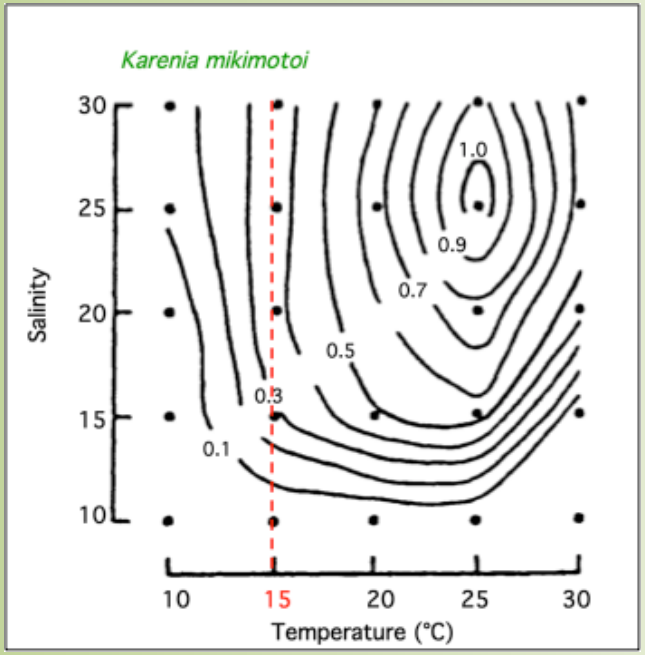
Modified from Johnsen et all. 1997



Tireté : Position moyenne des fronts de marée selon

Pingree & Griffiths (1978)

Partensky & Sournia (1986)



Yamaguchi & Honjo (1989)

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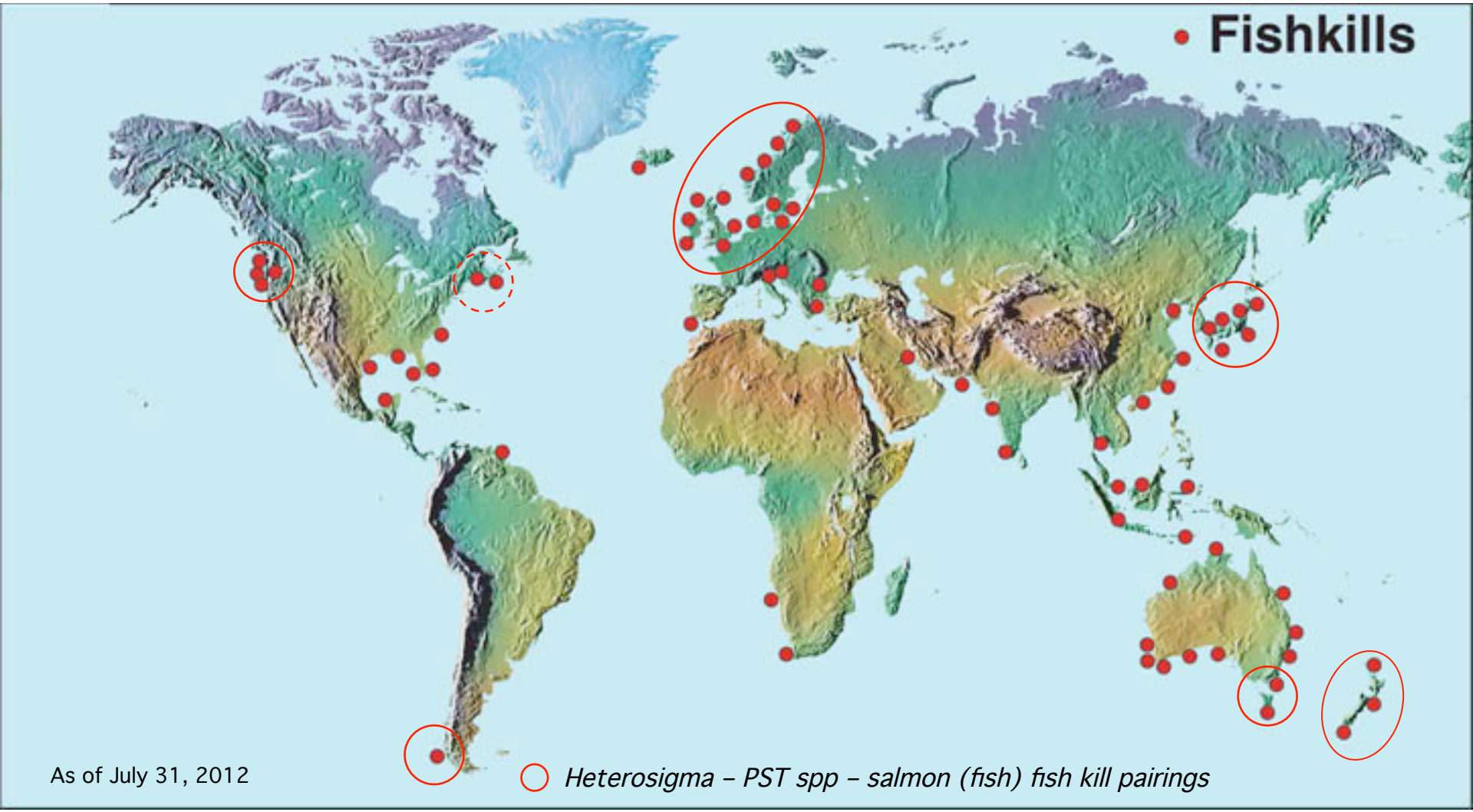
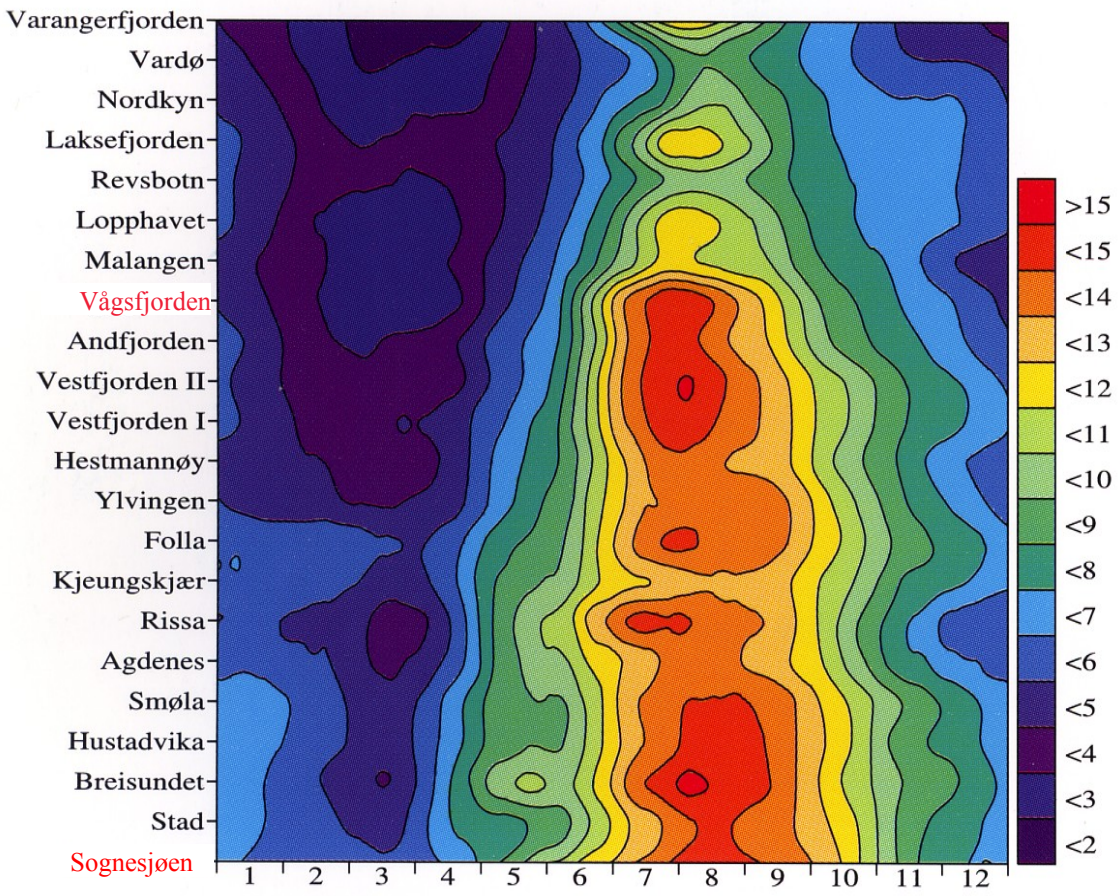
SOME PROJECTIONS



Locations where fish kills have been reported

http://www.whoi.edu/redtide/page.do?pid=18103&tid=542&cid=47596&c=3


Greenland
Iceland
Norwegian Sea
Sápmi
FAROE ISLANDS
Finland
Norway
Åland Islands
Shetland Islands
North Atlantic Ocean
Sweden
Orkney Is.
Western Isles (Hebrides)
Est.
Latvia
Scotland
North Sea
Baltic Sea
Denmark
Lith.
N. Ireland
Russia
Man
Ireland
Poland
Wales
England
Netherlands
Germany
Belgium
France
Lux.
Czech Rep.



Surface temperature along the Norwegian coast in 1998

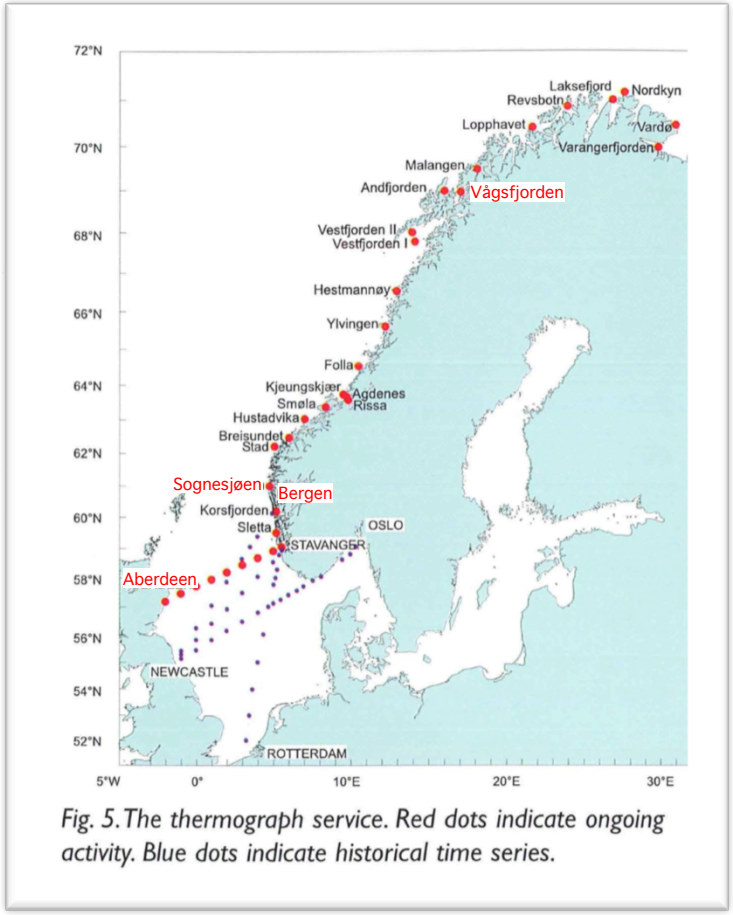
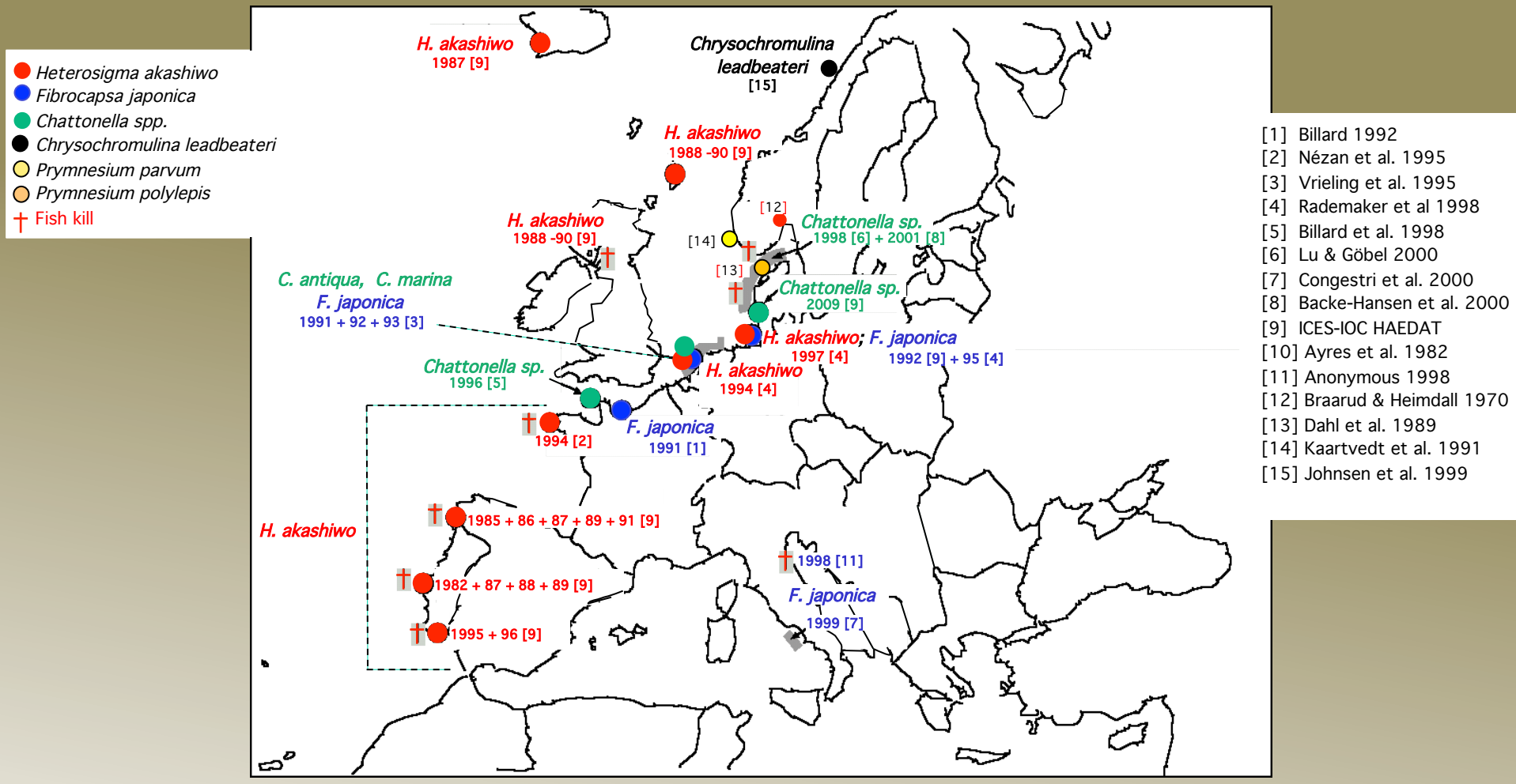


Fig. 5. The thermograph service. Red dots indicate ongoing activity. Blue dots indicate historical time series.

Institute of Marine Research (IMR) Norway

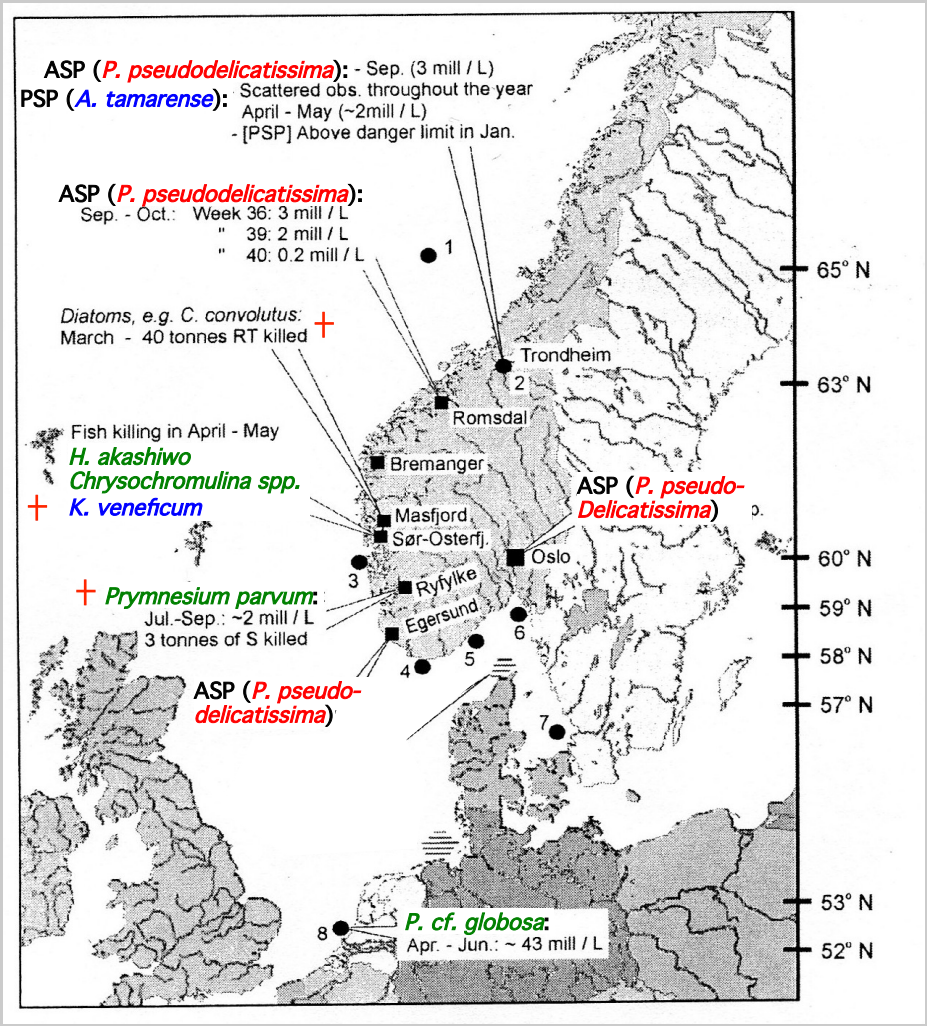
Gothenburg 2015



Potentially harmful raphidophytes and ichthyotoxic events in Europe [references 1-8] augmented with data from the ICES-IOC HAEDAT (Harmful Event Database, [9]). Flagellate 'X' [10] is *H. akashiwo* according to Li & Smayda (2000).

Modified from Peperzak, 2002

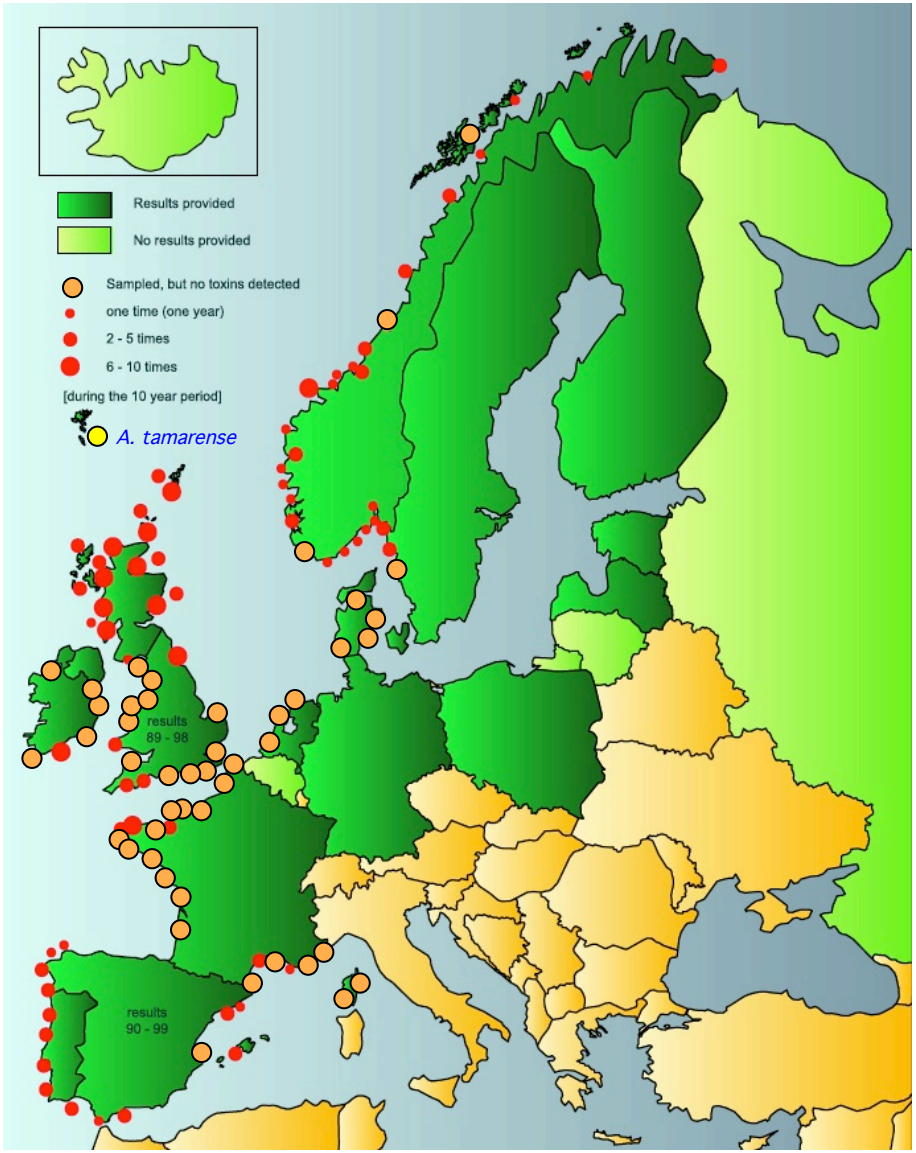
Gothenburg 2015



Local blooms of harmful phytoplankton in 1993. RT = Rainbow Trout, S = Atlantic Salmon fish kills

Modified from Johnsen et al. (1997)

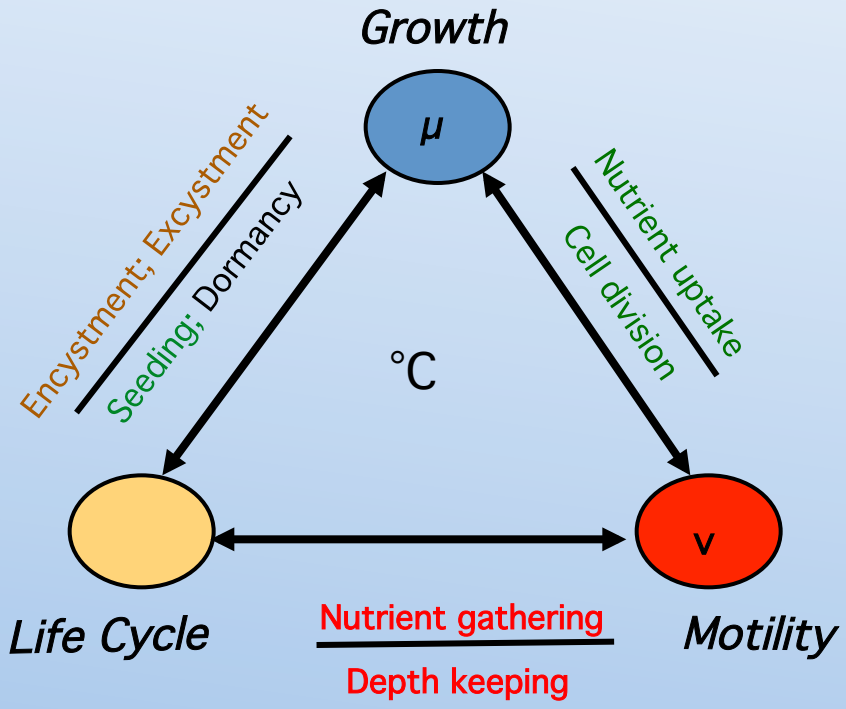
Gothenburg 2015



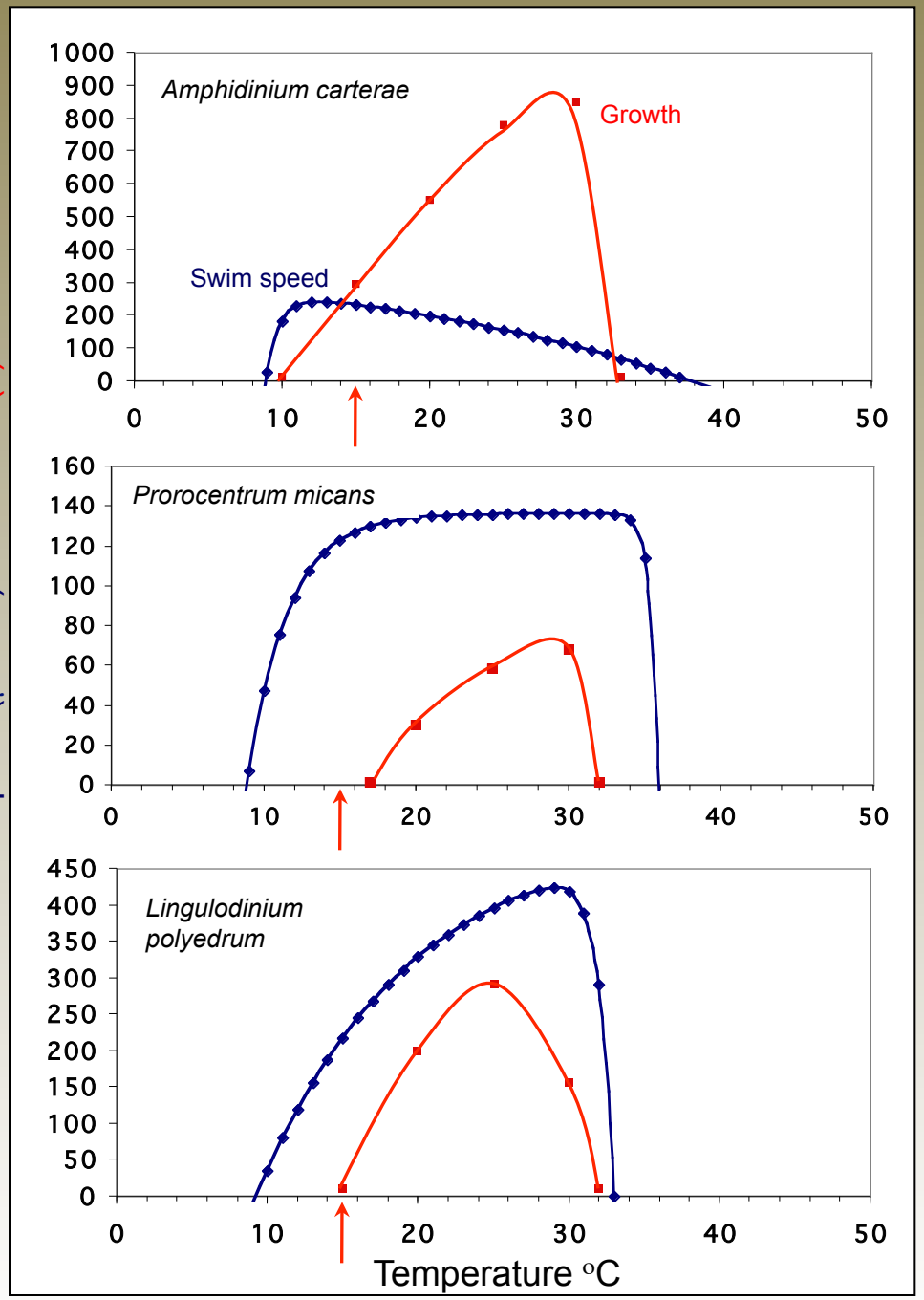
Location where Paralytic Shellfish Poisoning toxins were found in Europe 1993-2002.

Modified from: http://oceanworld.tamu.edu/resources/oceanography-book/harmfulagalblooms.htm

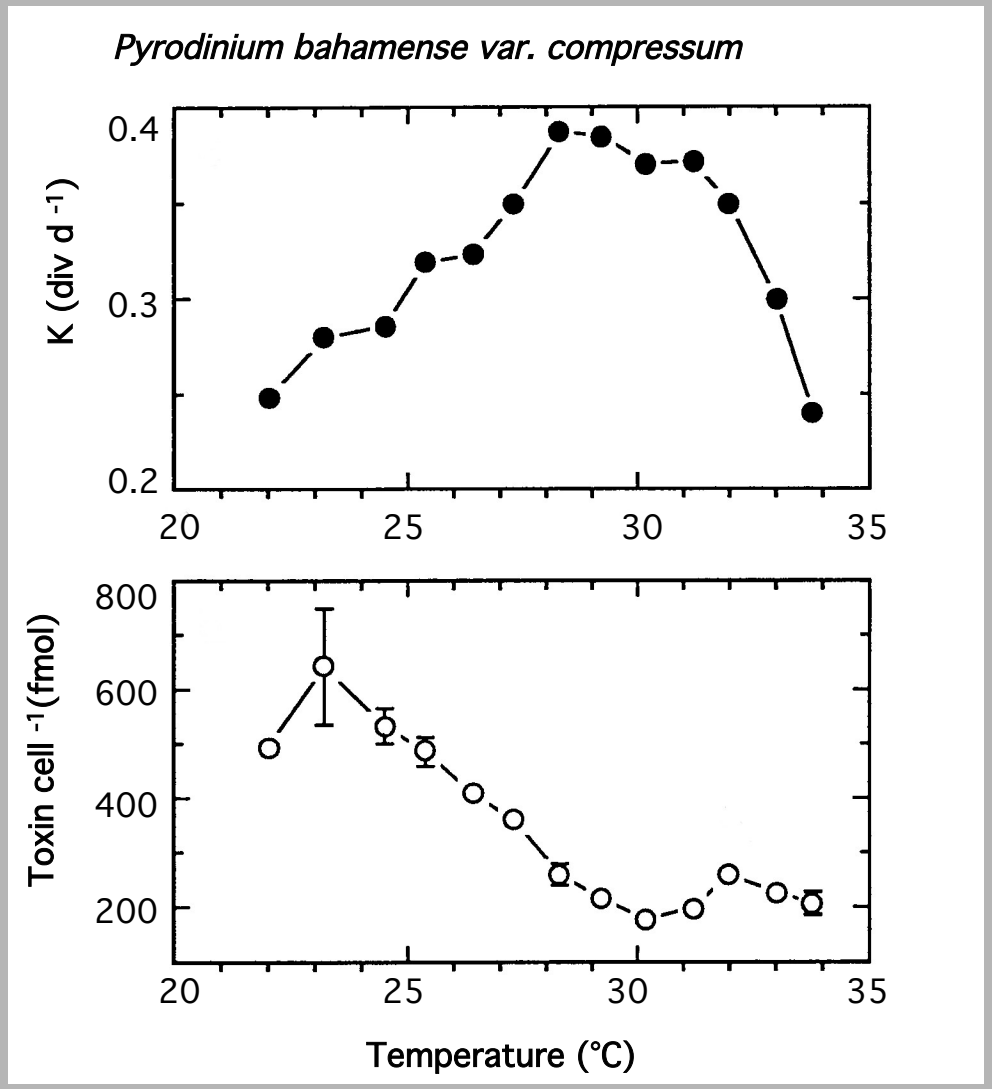
TEMPERATURE
and
CELLULAR; POPULATION PROCESSES



Gothenburg (2015)



Kamykowski and McCollum, 1985


Pyrodinium bahamense var. compressum
K (div d -1)
0.4
0.3
0.2
20
25
30
35
Toxin cell -1(fmol)
800
600
400
200
20
25
30
35
Temperature (°C)

Usup (1995)

TEMPERATURE – HABs (I)

- Along 15°C Isotherm
  1. "red tide" species = irruptive blooms of pulsating introductions of seed populations more likely than blooms of successful colonization (i.e. redistribution events)
  2. Icthyotoxic raphidophyte blooms may increase at fish-farm sites because of elevated temperature (i.e., temperature stimulation)
- Between latitudes 30°N – 30°S – increase in temperature will have modest effect on HABs
- Nutrient availability will determine temperature impact; otherwise, phenology may change, but not local HAB intensity, frequency, etc.
- An increase in stratification may not promote HAB behavior because nutrient flux &/or nutrient gathering diminished (i.e. physical & biological interference)
- The indirect effects of temperature on HAB cellular behavior will mask its direct effects

TEMPERATURE – HABs (II)

- Available experimental and field data inadequate to model effect of elevated temperature in modifying HAB dynamics
- Unlikely specific effects of temperature in altering HAB dynamics can be modeled

Four axioms of harmful blooms

STOCHASTICITY

OPPORTUNISM

CONTINGENCY

VULNERABILITY

1. *"being in the right place at the right time"* - stochasticity

2. *"a species will bloom whenever/wherever nutrients increase"* - opportunism

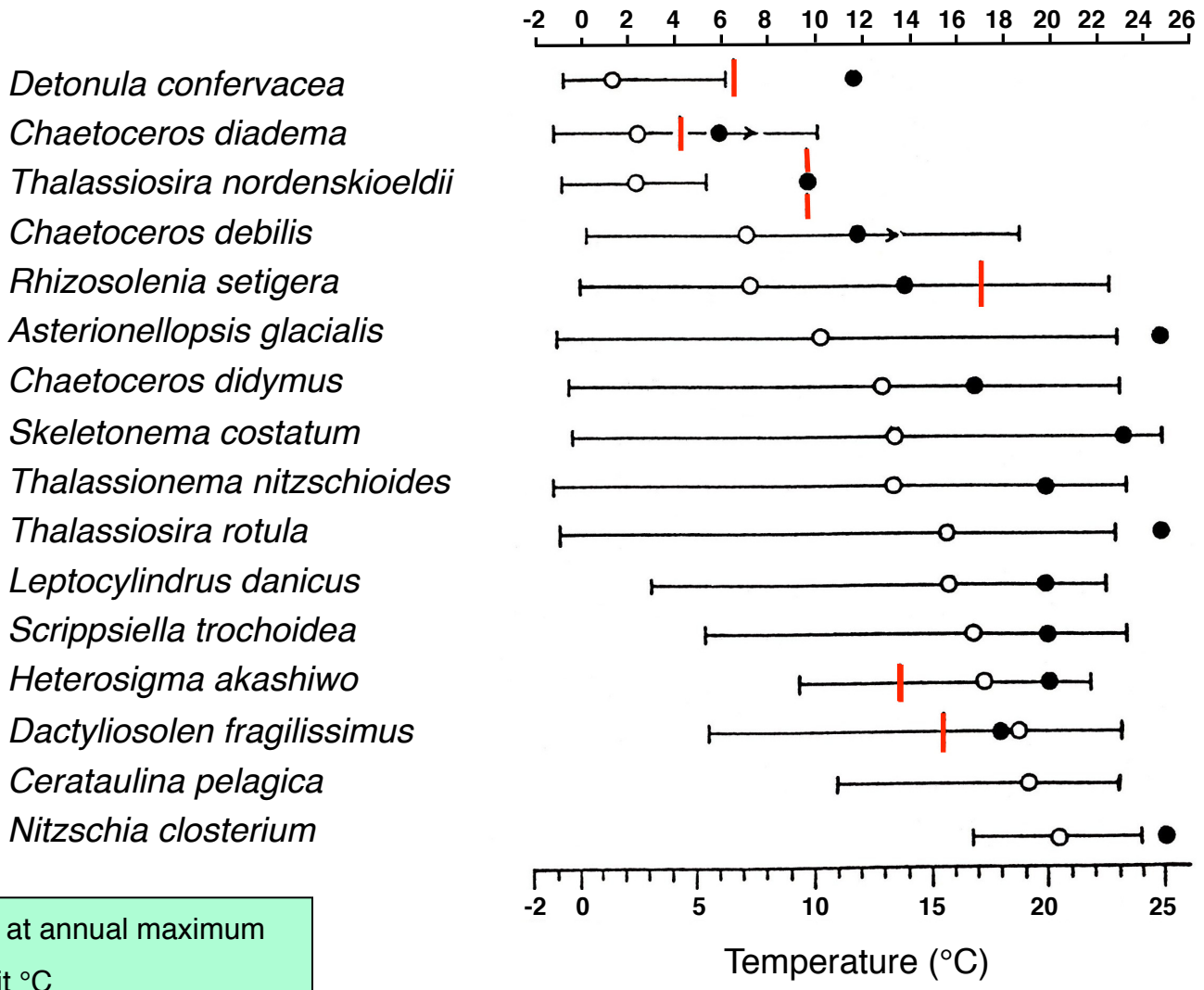
3. *"there is no plan to blooms; they do not occur by their own nature"* - contingency

4. *"temperature only growth factor not auto-regulated"* - *vulnerability*

"behavior is essential to fitness"

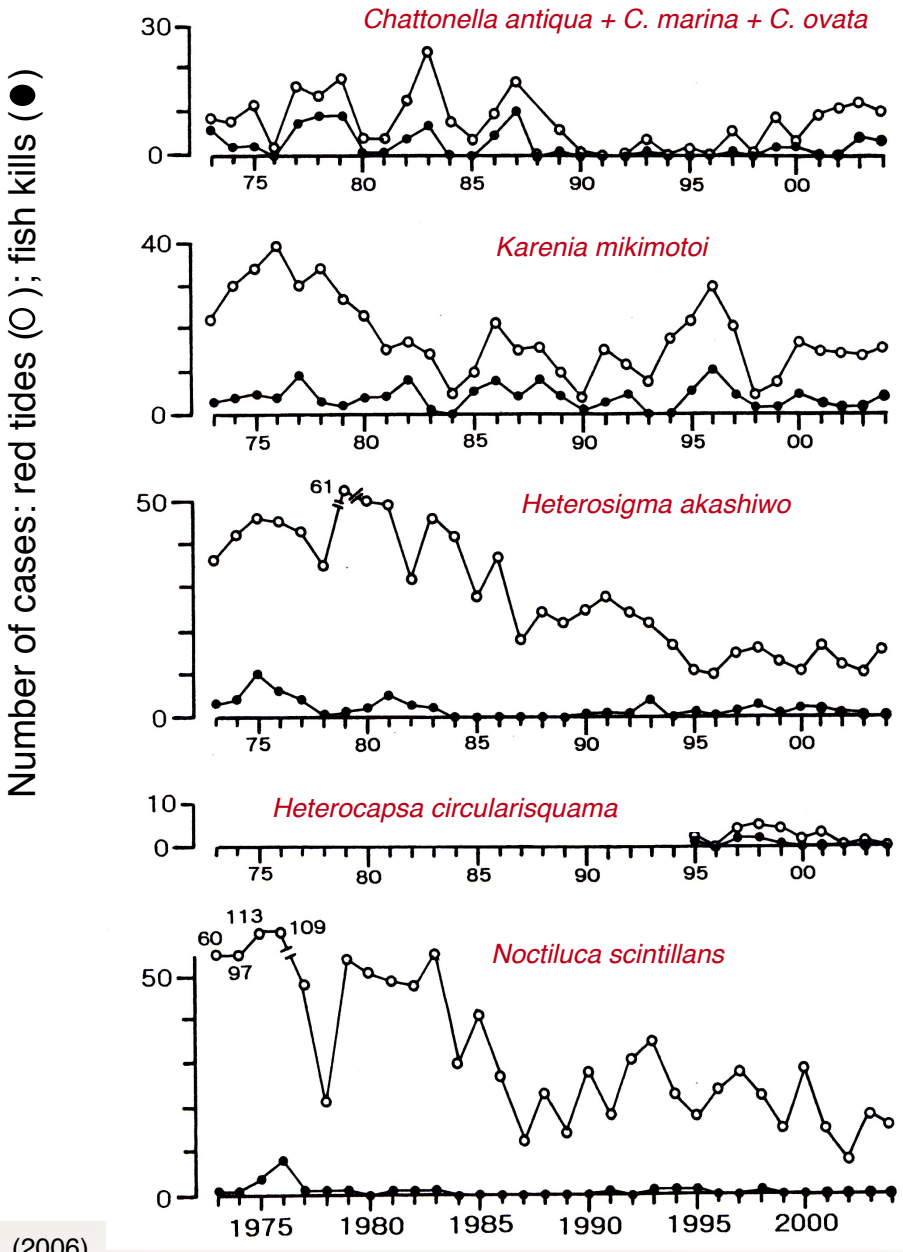
Gothenburg (2015)

TEMPERATURE AND SEASONAL OCCURRENCE PATTERNS OF SOME DOMINANT SPECIES IN NARRAGANSETT BAY (1959 - 1980)



Karentz & Smayda, (1984)

Seto Inland Sea (1973 - 2004)



Imai et al. (2006)

Gothenburg (2015)

END