Factors Affecting Red Tide

Dr. Ronald L. Musselman
Professor Emeritus of Chemistry
Franklin and Marshall College

Outline

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- Brief survey of plankton of importance to the issue of Red Tide

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- History of *Karenia brevis* (Red Tide organism)

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- Anomalous years – 2010, 2013

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- Anomalous years – 2010, 2013
- Temperature effects

Simplified plankton organizational chart

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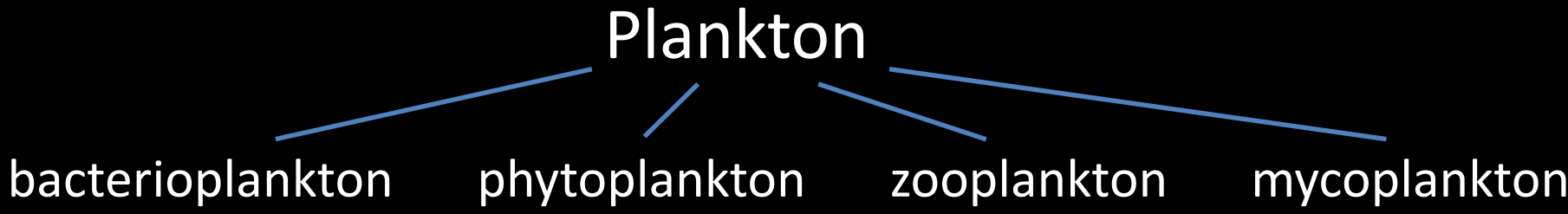

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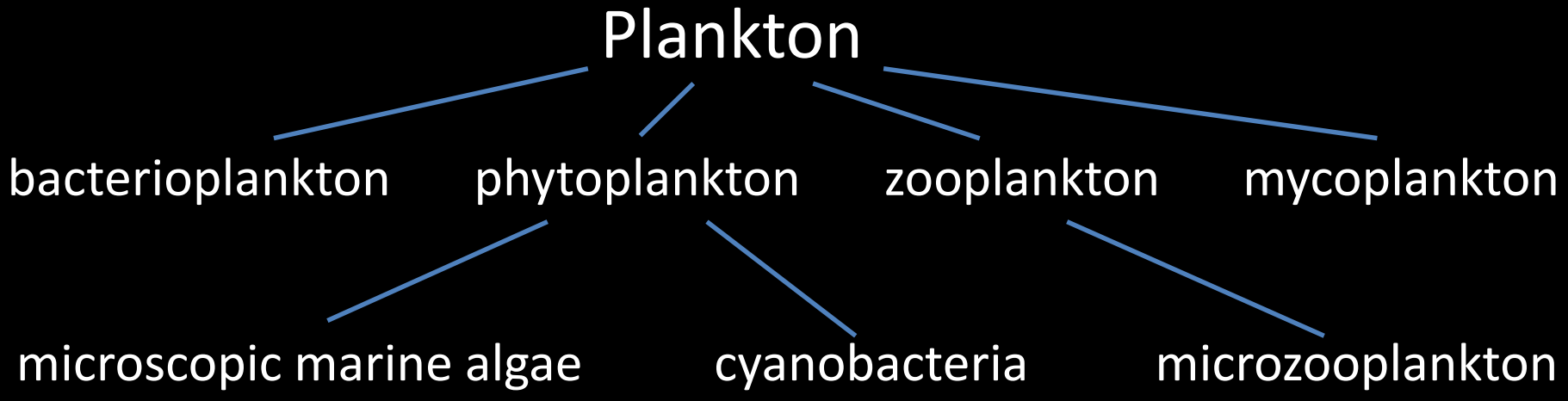

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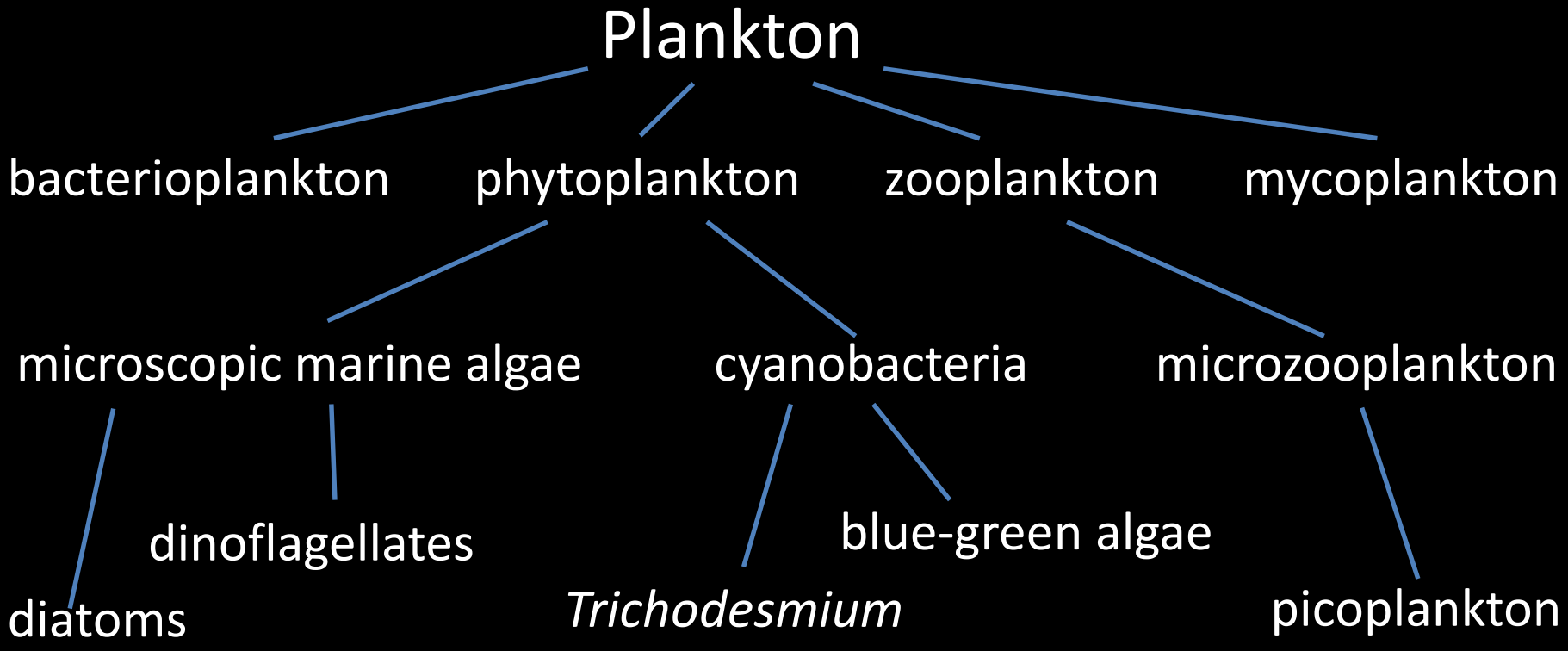

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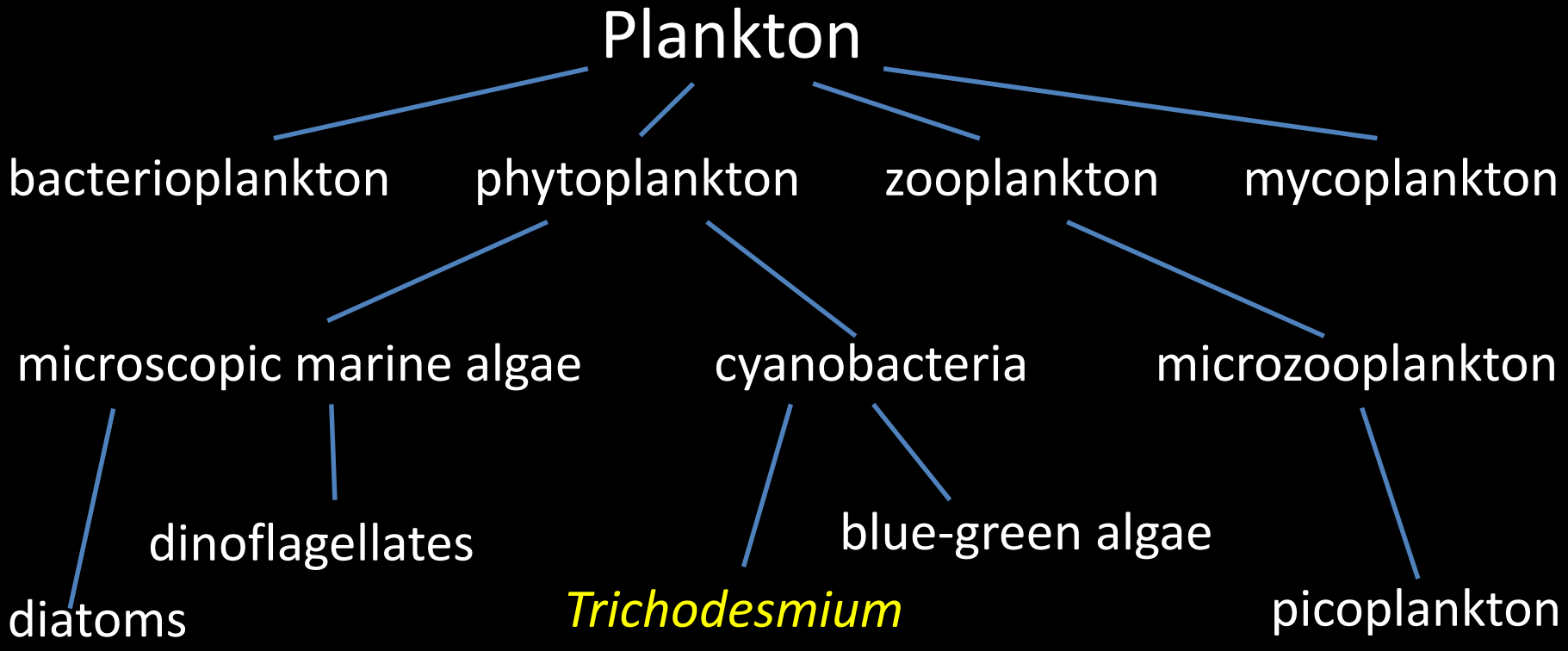

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  - bacterioplankton
  - phytoplankton
    - microscopic marine algae
      - diatoms
      - dinoflagellates
    - cyanobacteria
      - *Trichodesmium*
      - blue-green algae
  - zooplankton
    - microzooplankton
      - picoplankton
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Karenia brevis cell

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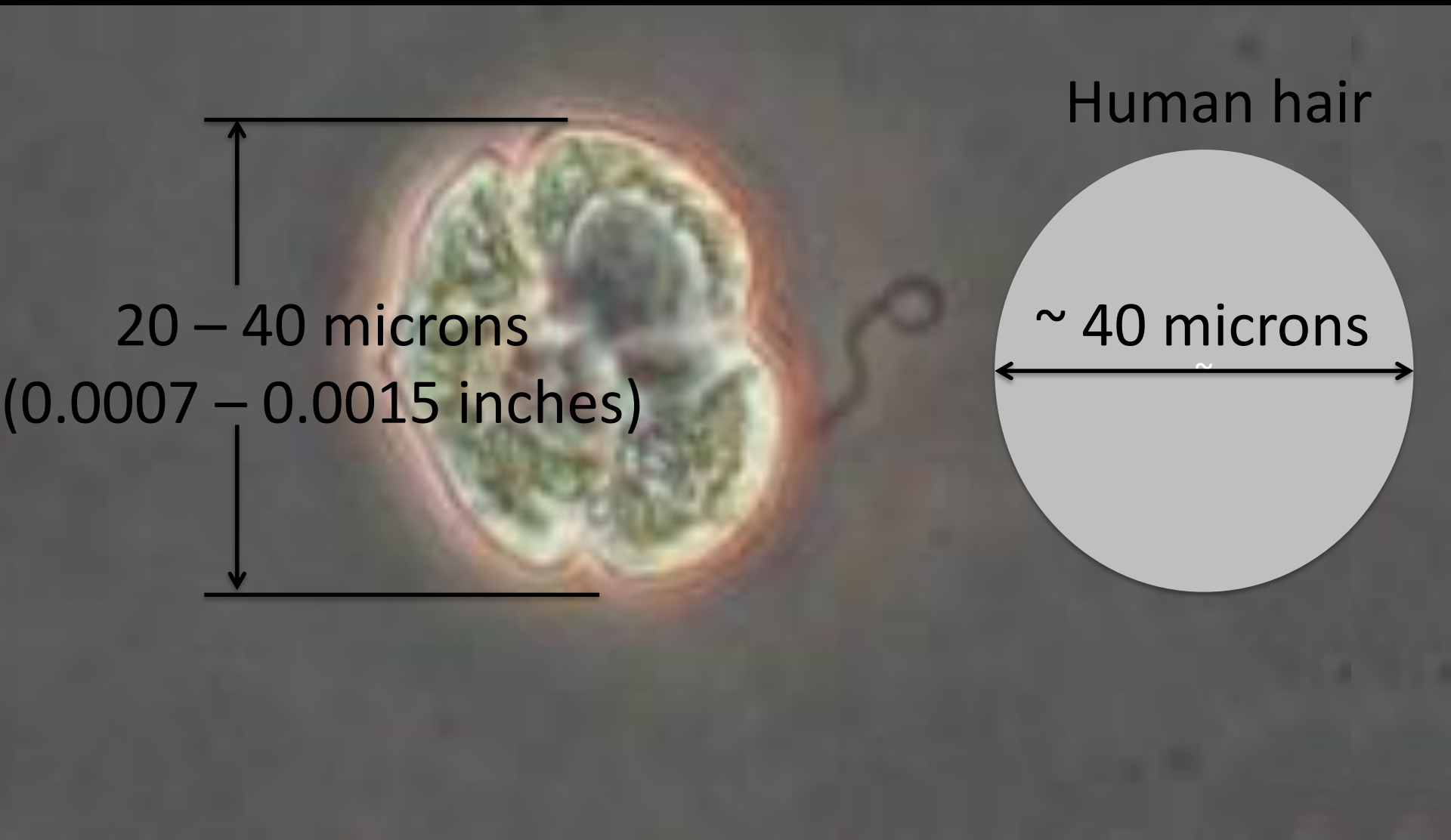
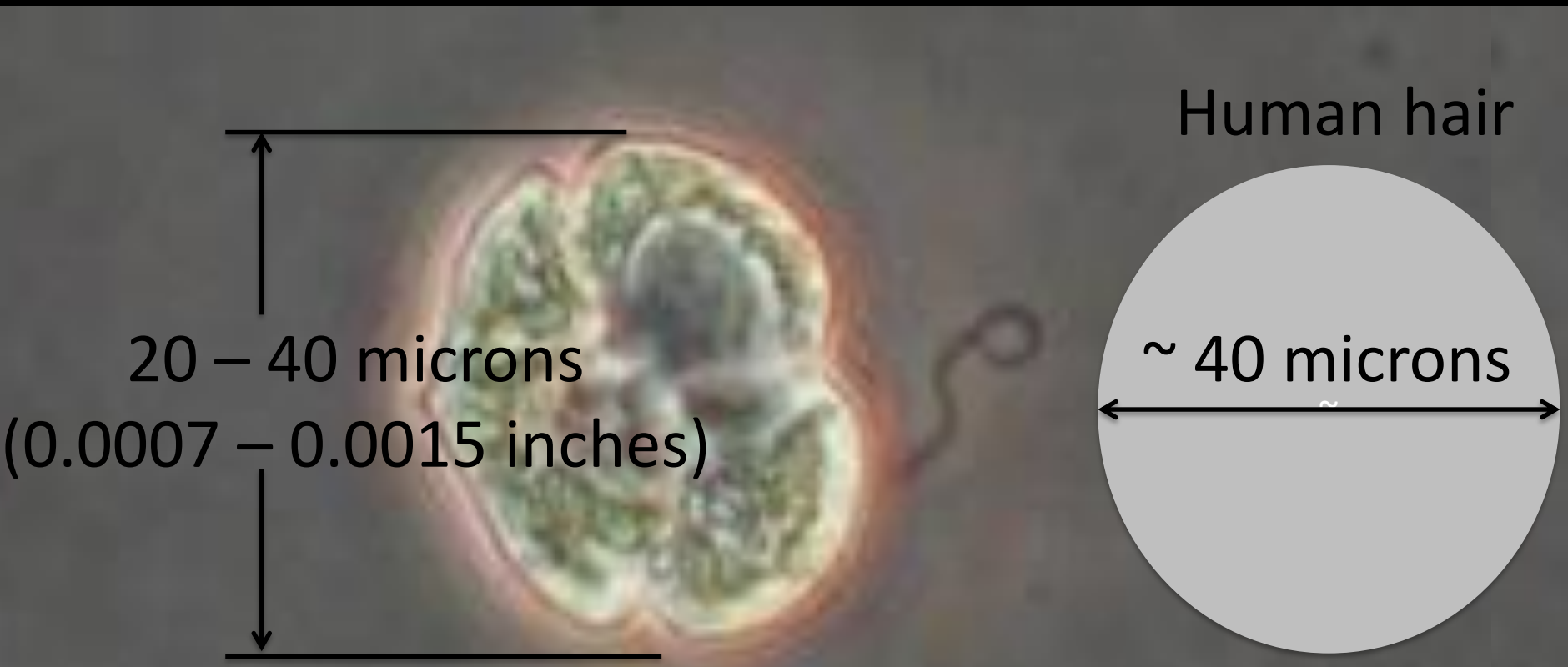


Karenia brevis cell



Produces neurotoxins called, “brevatoxins”

Dr. Karen A. Steidinger

Karenia brevis

Studied red tide for 50 years at the Florida Fish and Wildlife Research Institute.

Photo: FWRI-FWC

History of *Karenia brevis*

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- Spanish explorers noticed fish kills in the 1500's

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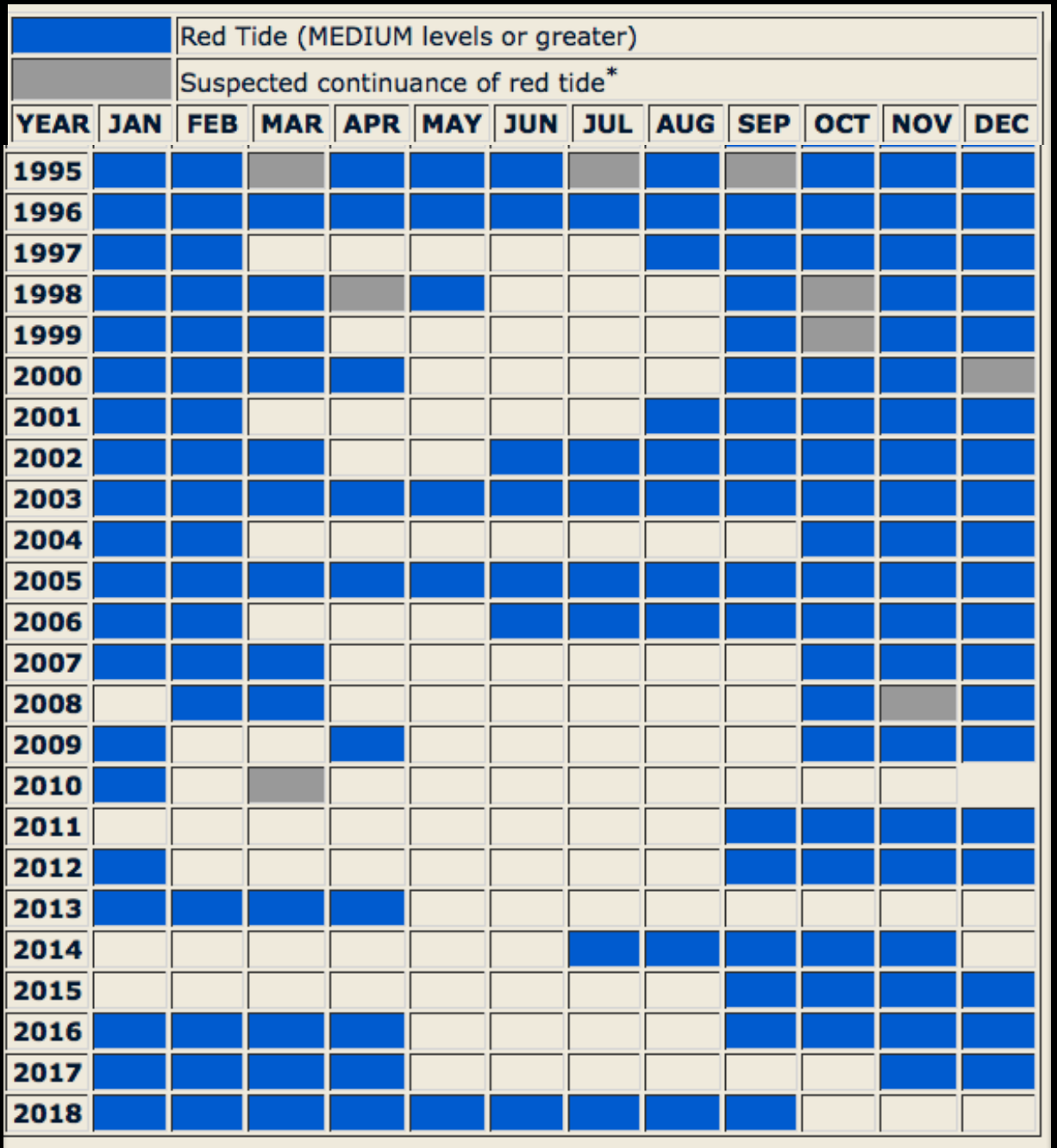
- Blooms have reached West Florida shores nearly every year of the studies.

History of *Karenia brevis*

- Spanish explorers noticed fish kills in the 1500's
- *K. brevis* begins 20 – 40 miles offshore before moving toward the shore
- Numerous major studies in the past 60 years
- Blooms have reached West Florida shores nearly every year of the studies.
- Many factors affect growth of *K. brevis*

K. brevis concentrations 1995 - 2018

Source: Florida Fish and Wildlife Conservation Commission



#/yr	Duration, months
12	
12	
7	26
9	10
7	7
8	8
7	6
10	8
12	
5	21
12	
9	17
6	10
5	2
5	4,1
2	4
4	
5	5
4	8
5	5
4	8
8	
6	8
9	11

Growth rate of *K. brevis* cells

Rate = 0.33 div/day

One division every three days

Growth rate of *K. brevis* cells

One division every three days

	Total number
1 x	1

Growth rate of *K. brevis* cells

One division every three days

	Total number
1 x	1
4 x x	2

Growth rate of *K. brevis* cells

One division every three days

	Total number
1 x	1
4 x x	2
7 x x x x	4

Growth rate of *K. brevis* cells

One division every three days

		Total number
1	x	1
4	x x	2
7	x x x x	4
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One division every three days

		Total number
1	x	1
4	x x	2
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13	x x x x x x x x x x x x x x x x	16

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1	x	1
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Growth rate of *K. brevis* cells

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1	x	1
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Sources of nutrients for *K. brevis*

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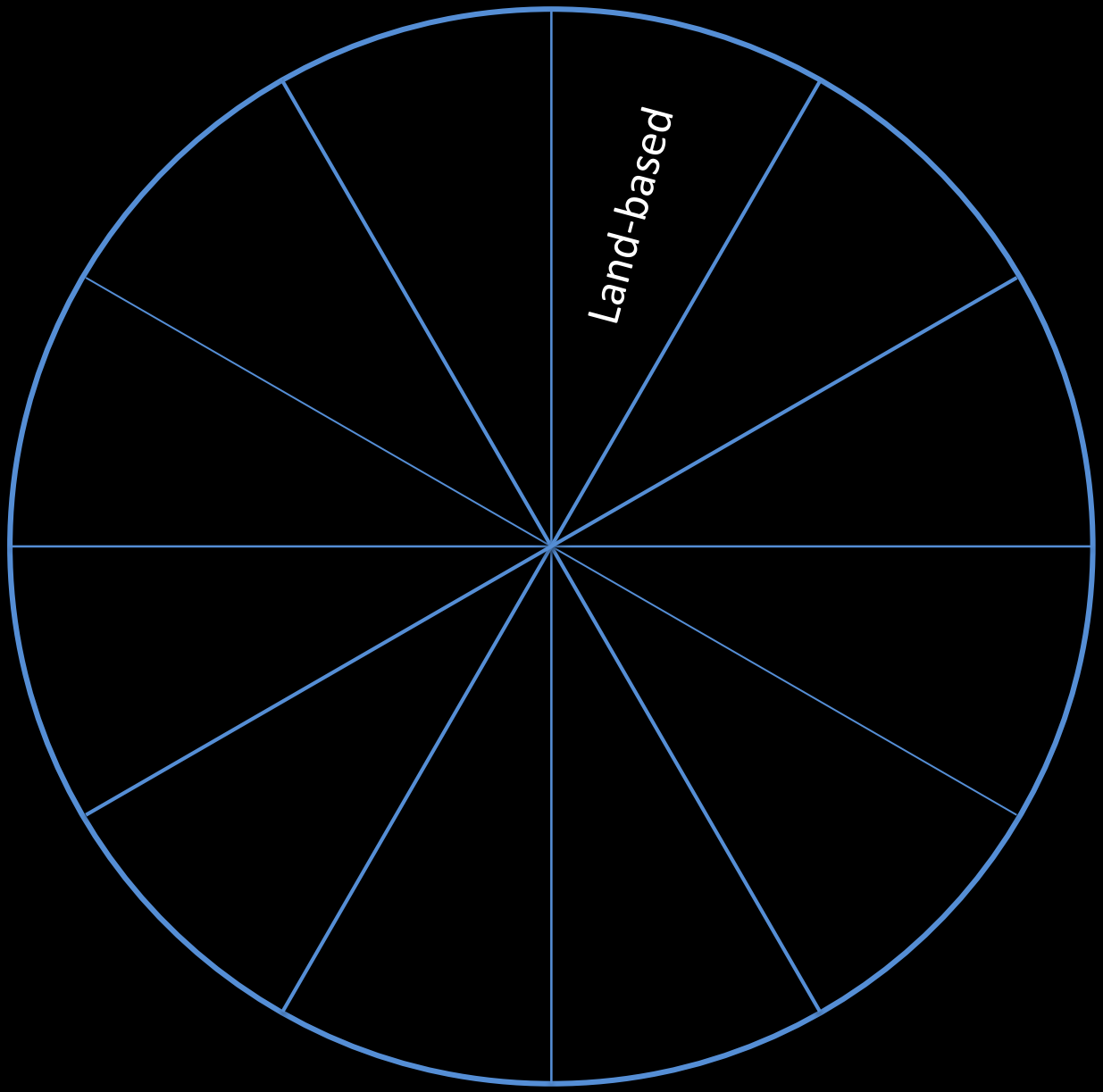
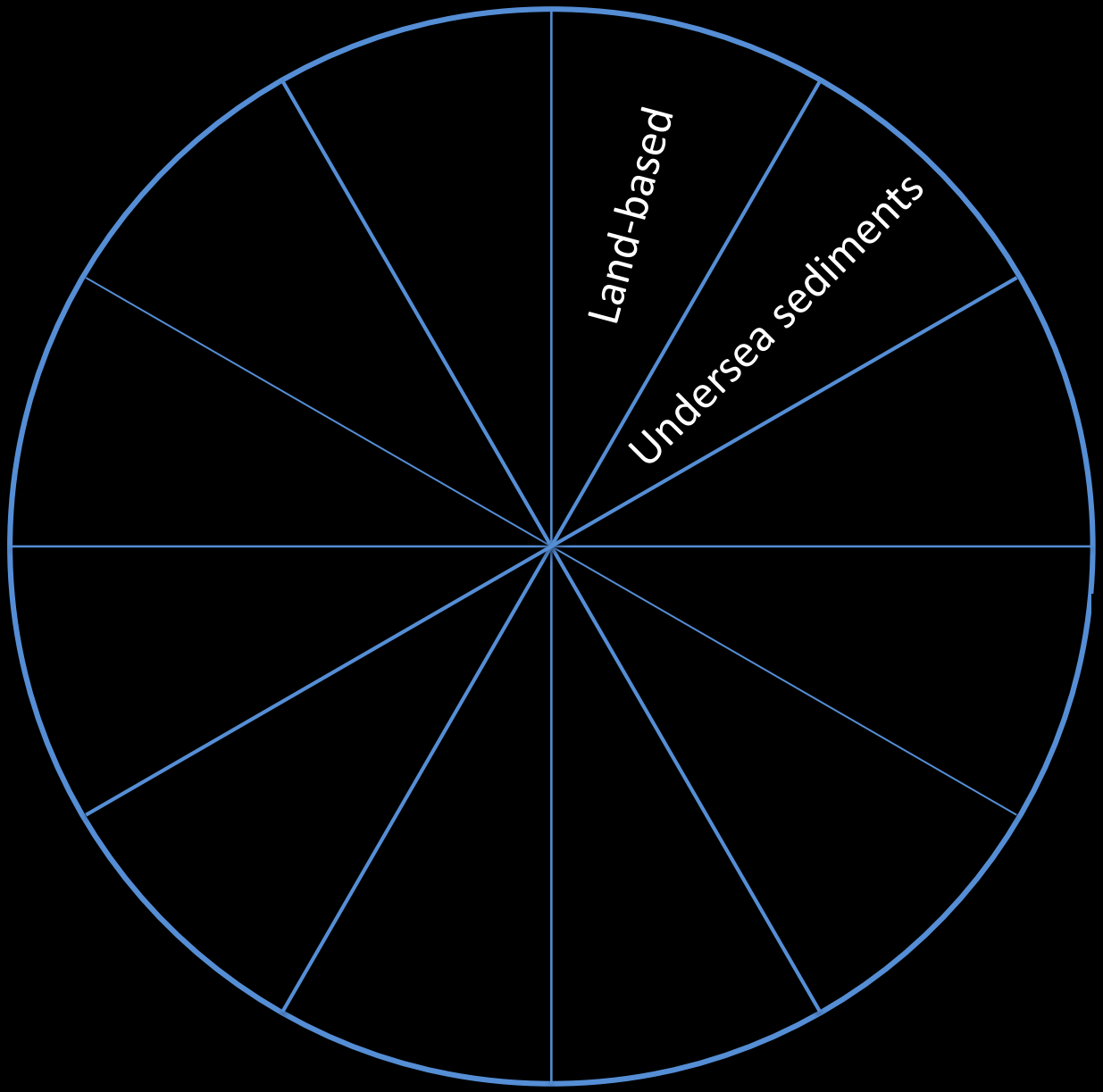


Land-based

- Estuary flow
- Fertilizer
- Animal waste
- Septic tanks
- Vegetation

Sources of nutrients for *K. brevis*



Undersea sediments

- Minerals incl. Fe from Sahara
- Plankton exoskeletons
- N, P compounds

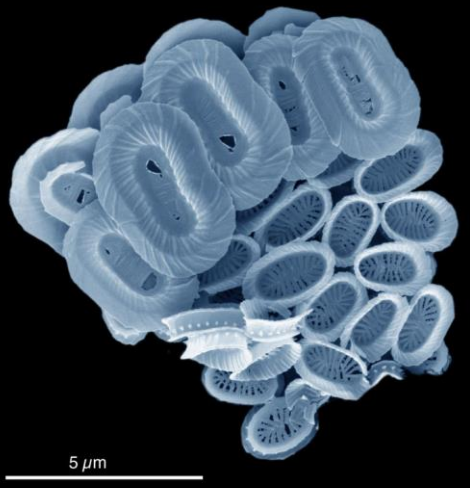


Photo: ucl.ac.uk

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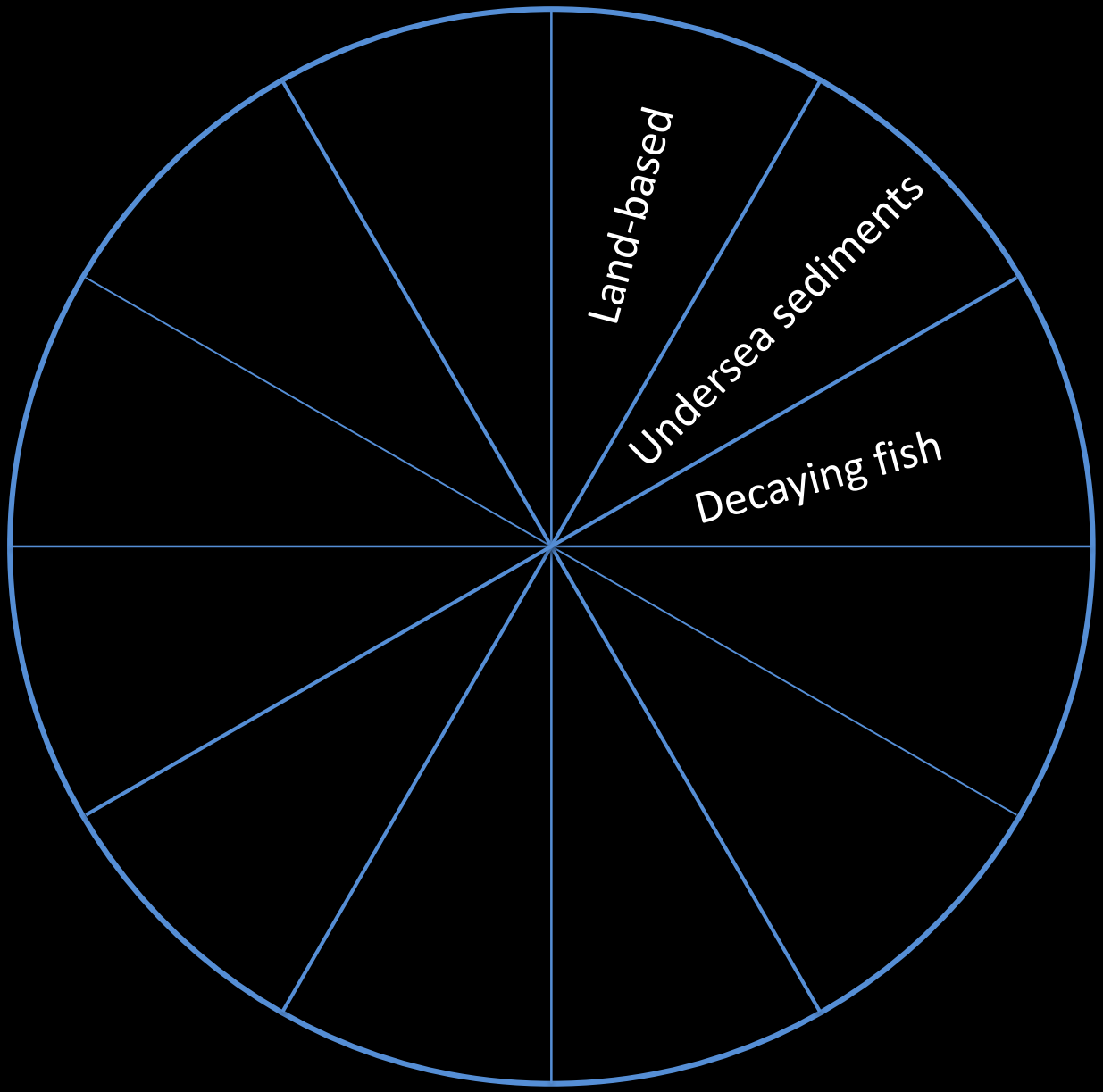

Decaying fish

- Often a result of the brevatoxin from *K. brevis* itself

Photo: dailymail.co.uk

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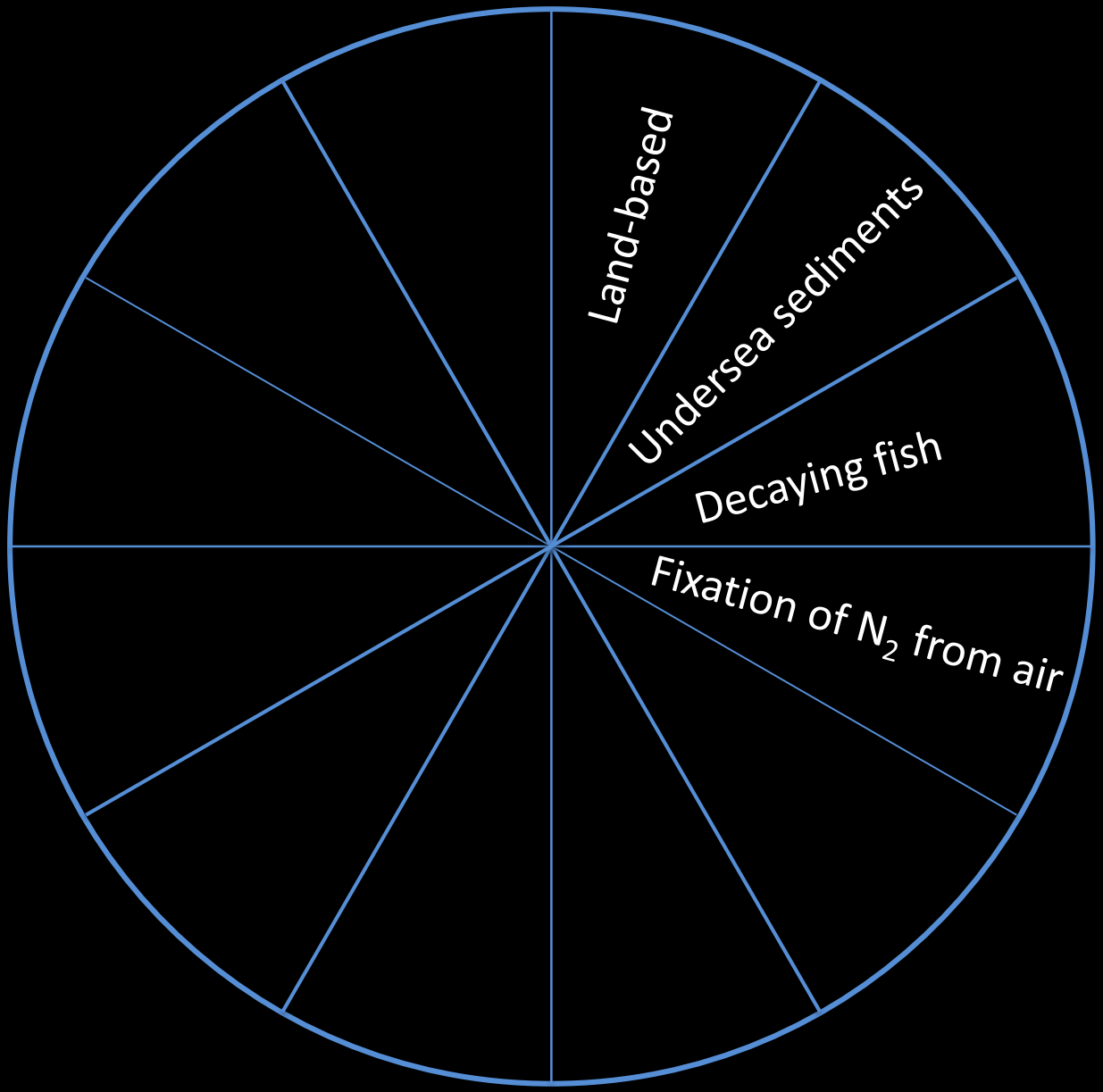
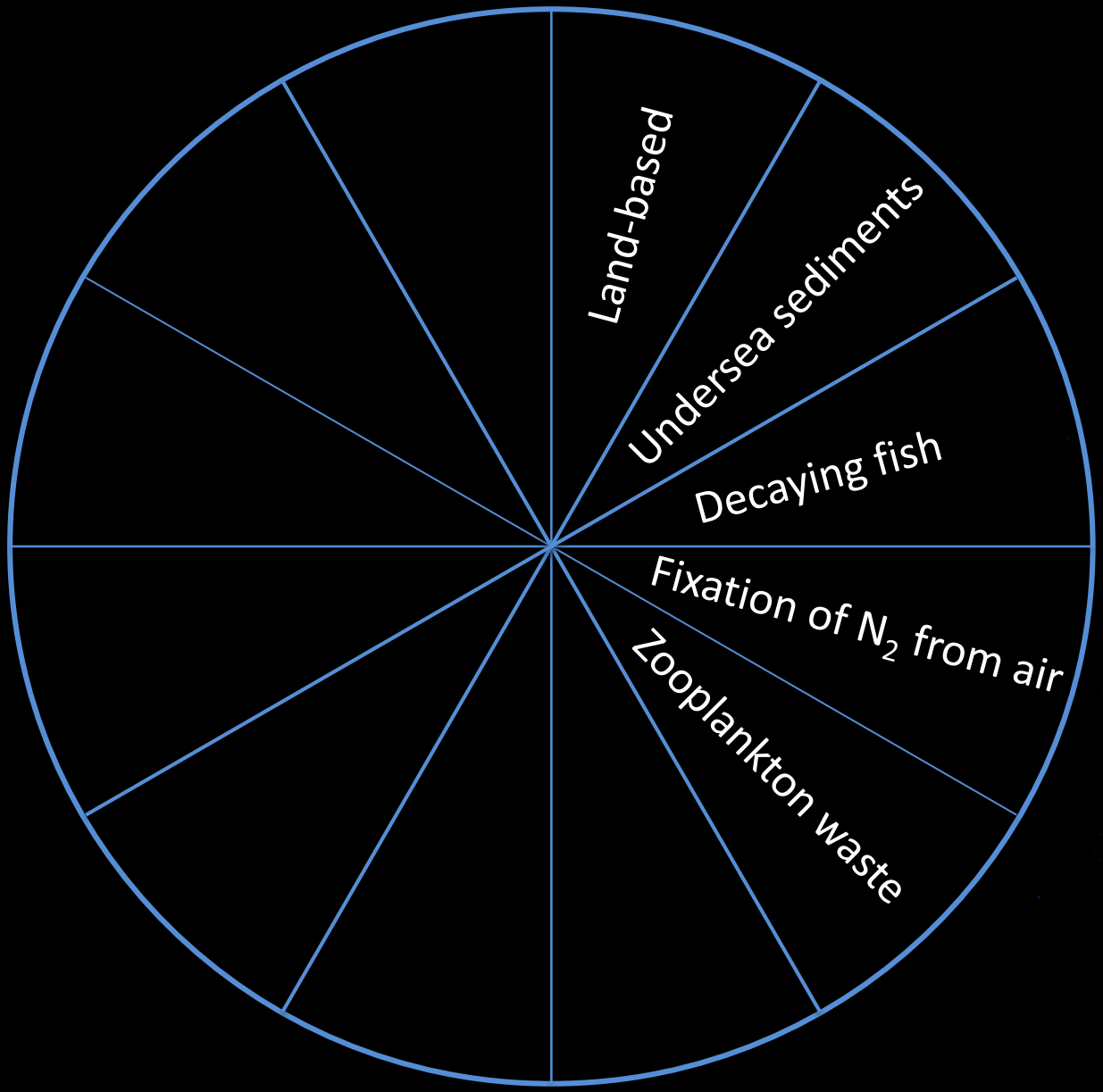


Fixation of nitrogen (N_2) from air

- N_2 to ammonia (NH_3)
- Largely by *Trichodesmium*
- Reside above *K. brevis*; use sunlight

Photo: Phys.org

Sources of nutrients for *K. brevis*



Waste from zooplankton

- Small aquatic animals invisible to the eye

Photo:ecoscope.com/hyperia

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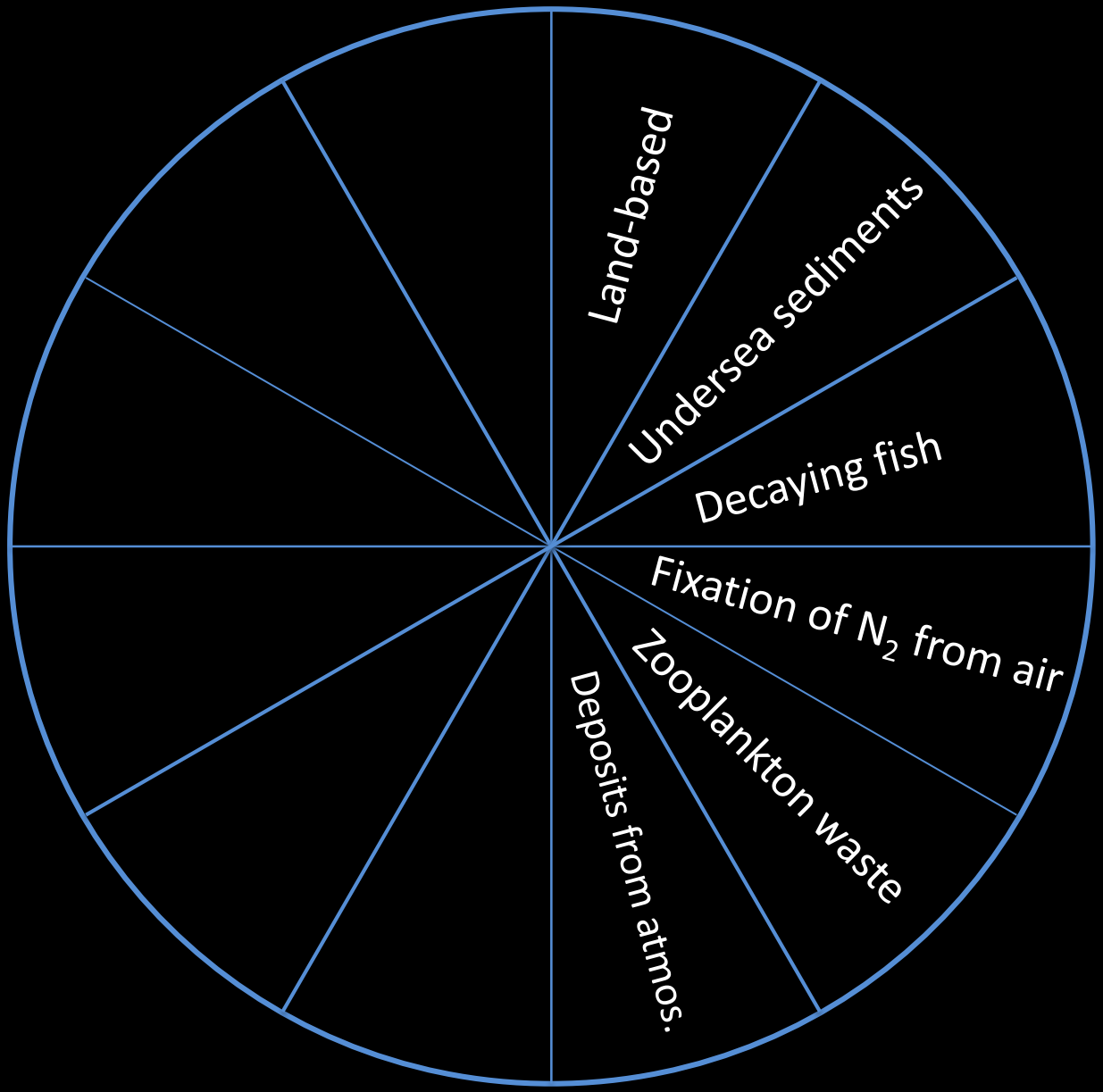
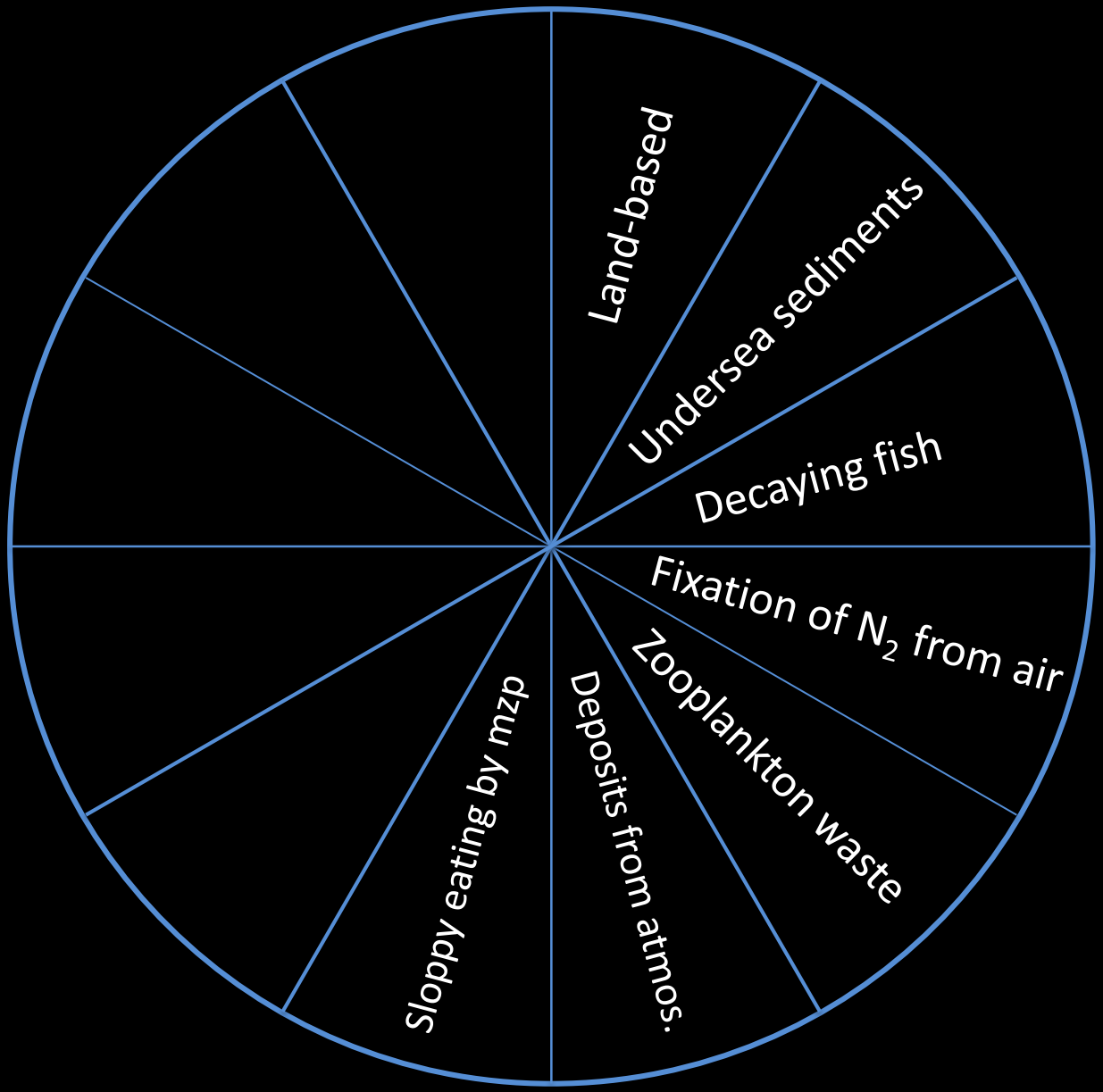


Deposits from the atmosphere

- Sahara dust
- Nitrates from lightning
- SO_4^{-2} from burning coal

Photo: bbc.com

Sources of nutrients for *K. brevis*

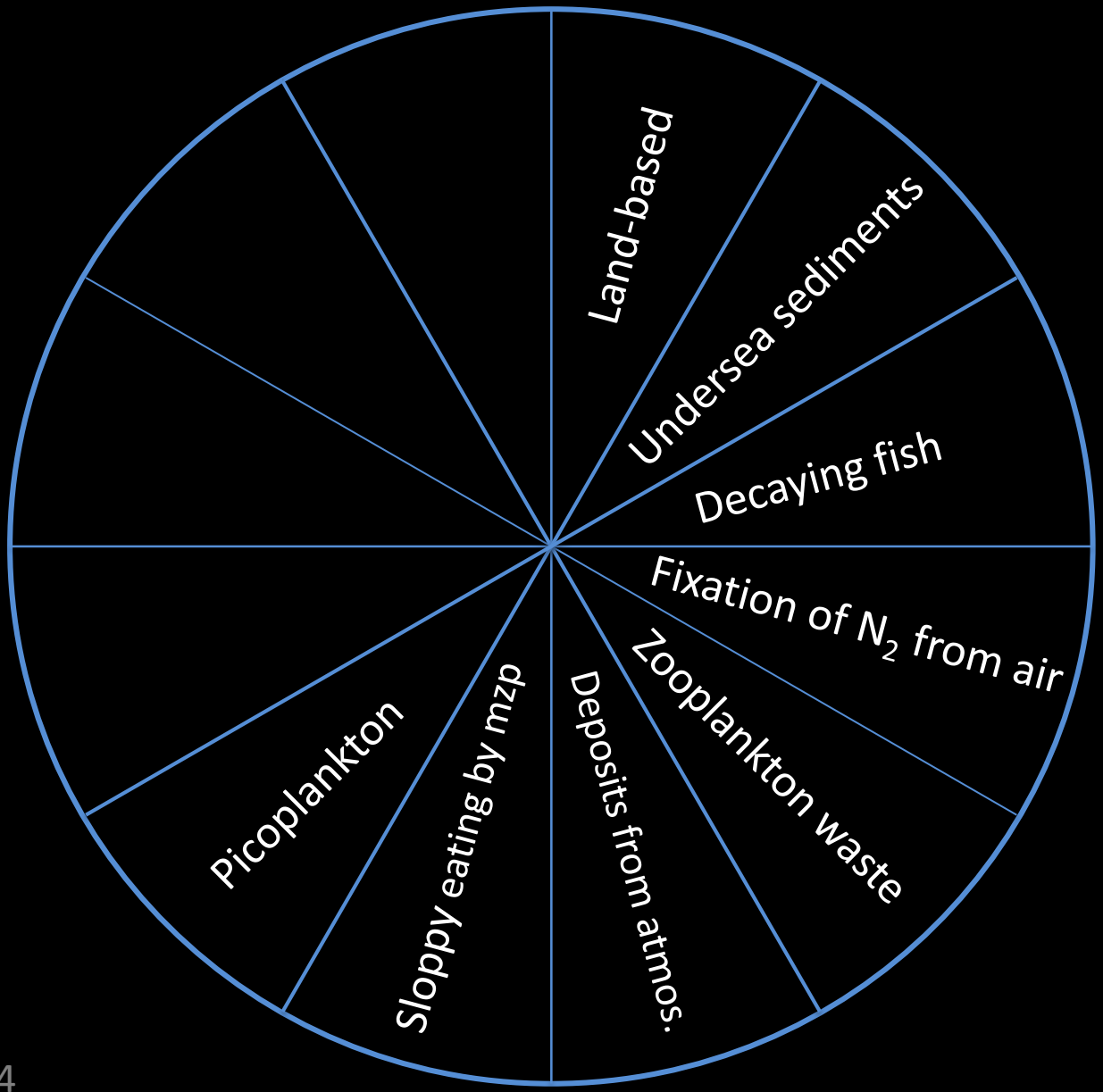


Sloppy eating by microzooplankton (mzp)

- Small morsels left behind
- Waste from mzp's

Photo: Woods Hole Oceanographic Institution

Sources of nutrients for *K. brevis*



Picoplankton

- Small enough to be eaten by *K. brevis*
- ~1/20 the size of *K. brevis*

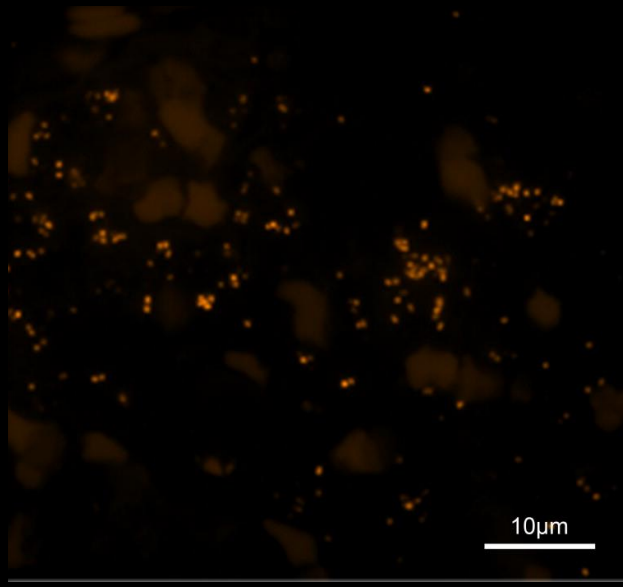
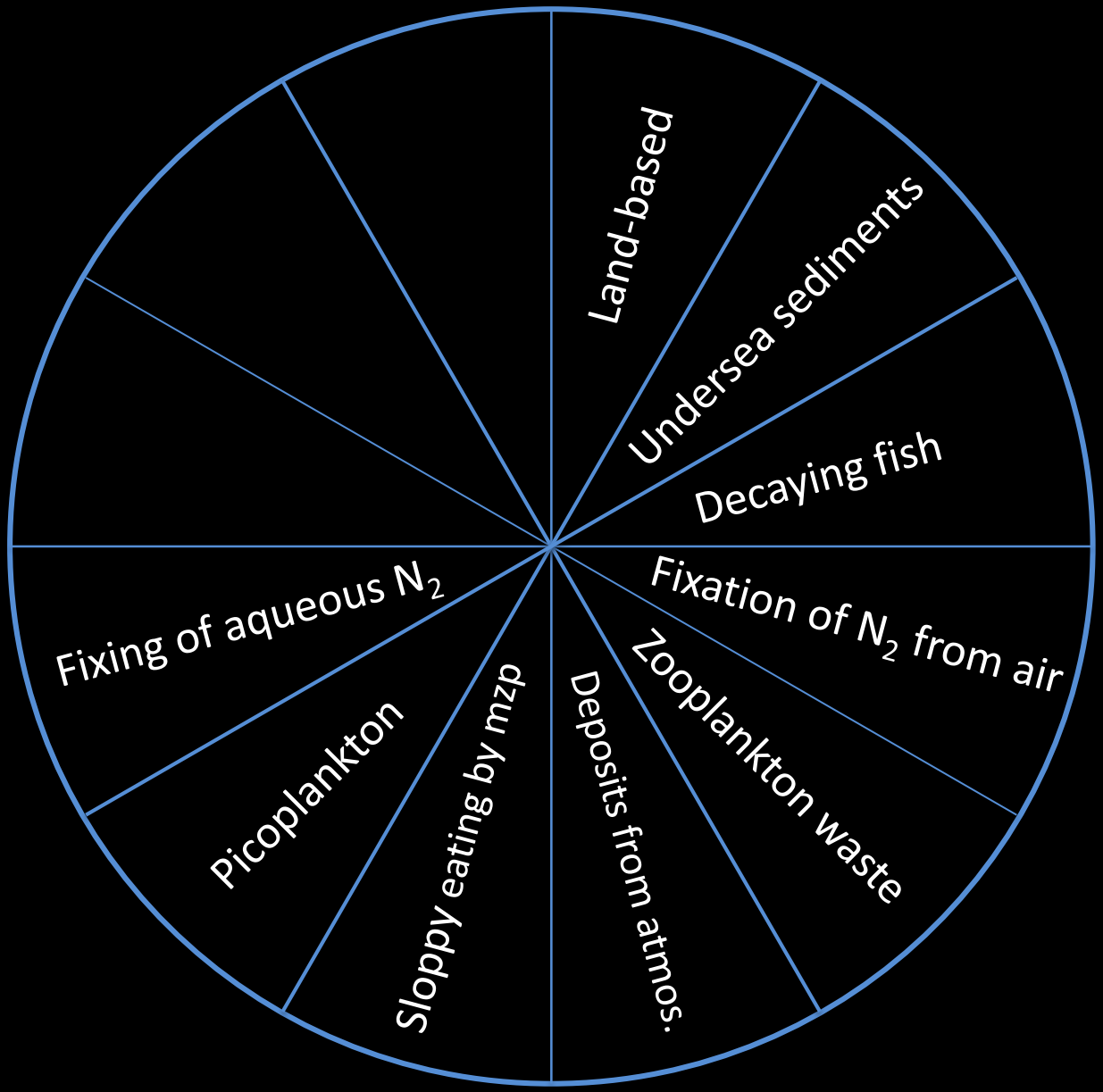


Photo: D. Schmeidel *et al,* Clinical Microbiol..V20

Sources of nutrients for *K. brevis*



Fixing of aqueous N_2

- By bacteria, including *Anabaena azollae*

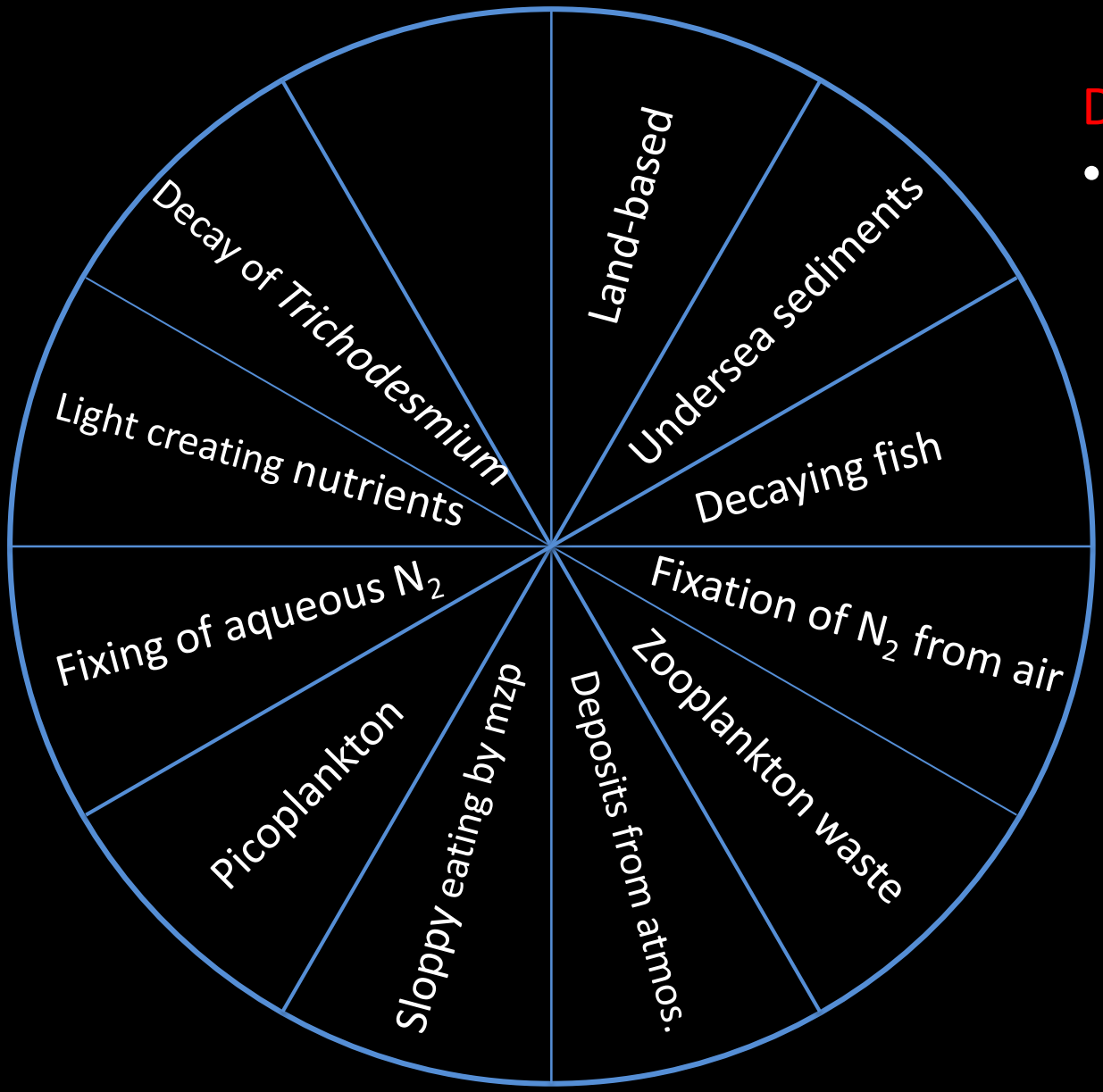
Photo: scivit

Sources of nutrients for *K. brevis*

Light creating nutrients

- From natural dissolved compds.
- Tannins
- DOC contain as much C as the atmosphere (as CO_2)

Sources of nutrients for *K. brevis*

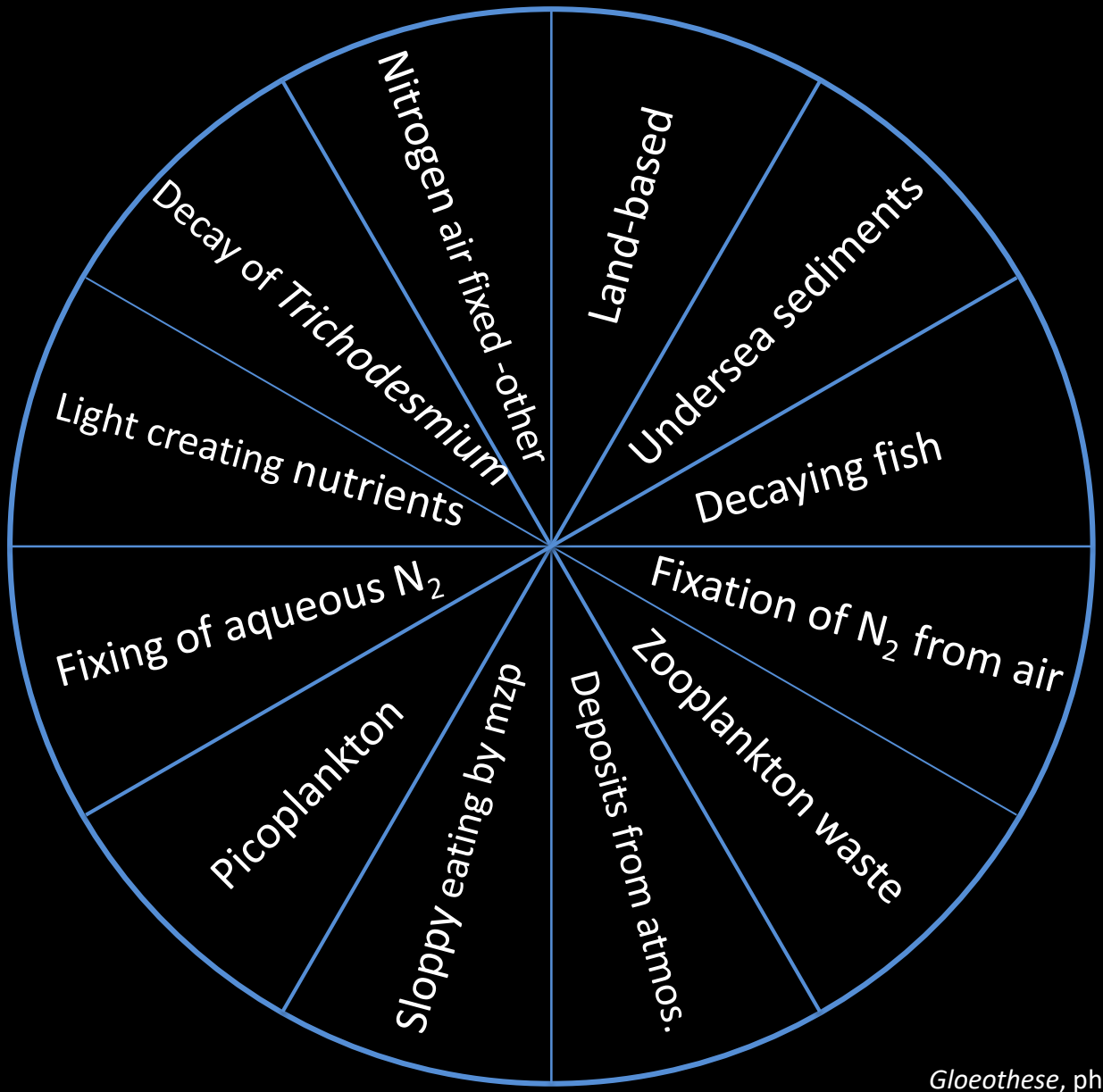


Decay of *Trichodesmium*

- Newly documented as a long-term nutrient source

Photo: Phys.org

Sources of nutrients for *K. brevis*

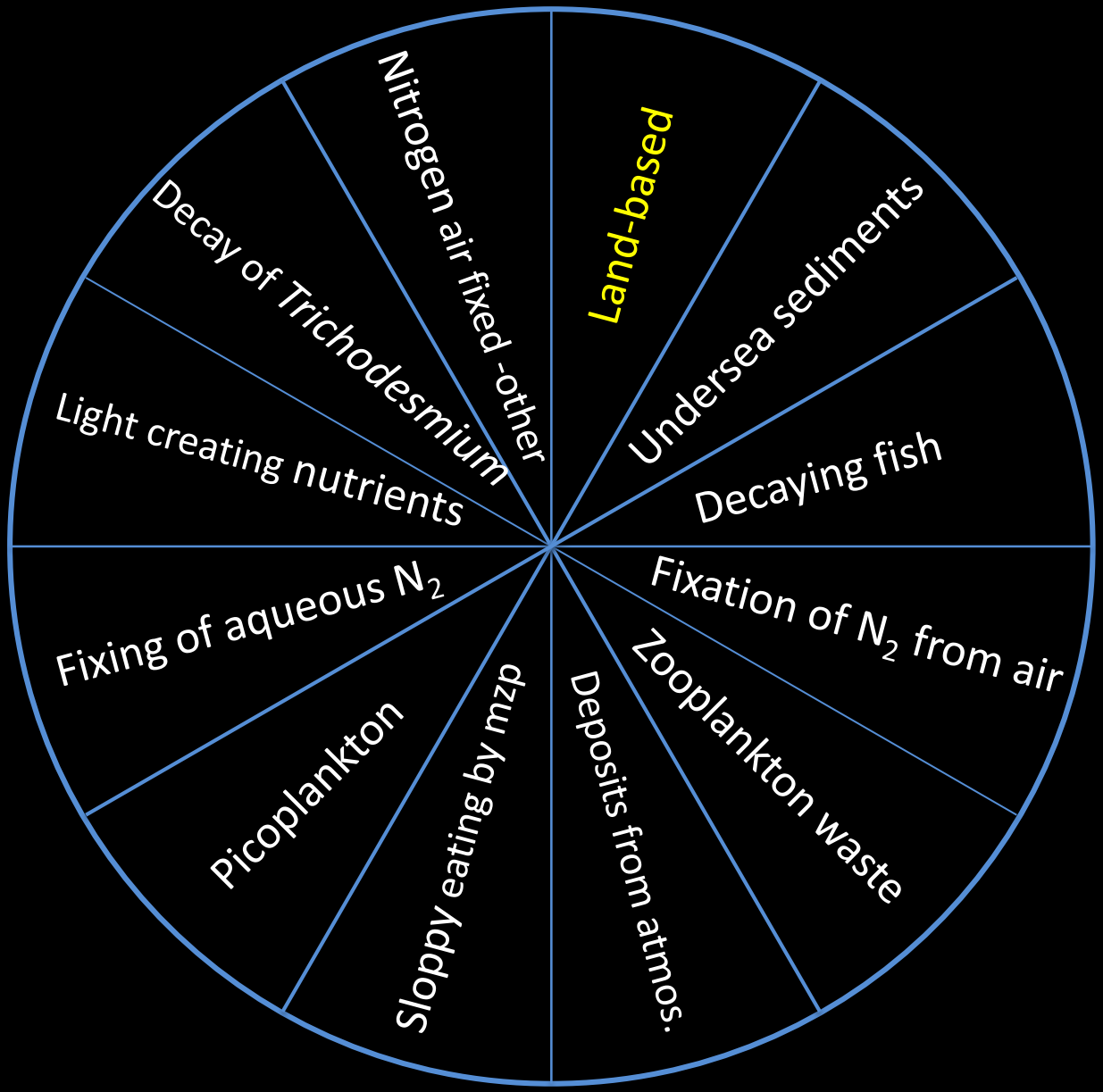


Nitrogen in air fixed by other cyanobacteria

- Distinguished from aqueous N_2
- Not by *Trichodesmium*

Gloeothese, photo: B. Bergman, FEMS Microbiology Review, V19

Sources of nutrients for *K. brevis*



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- Septic tanks
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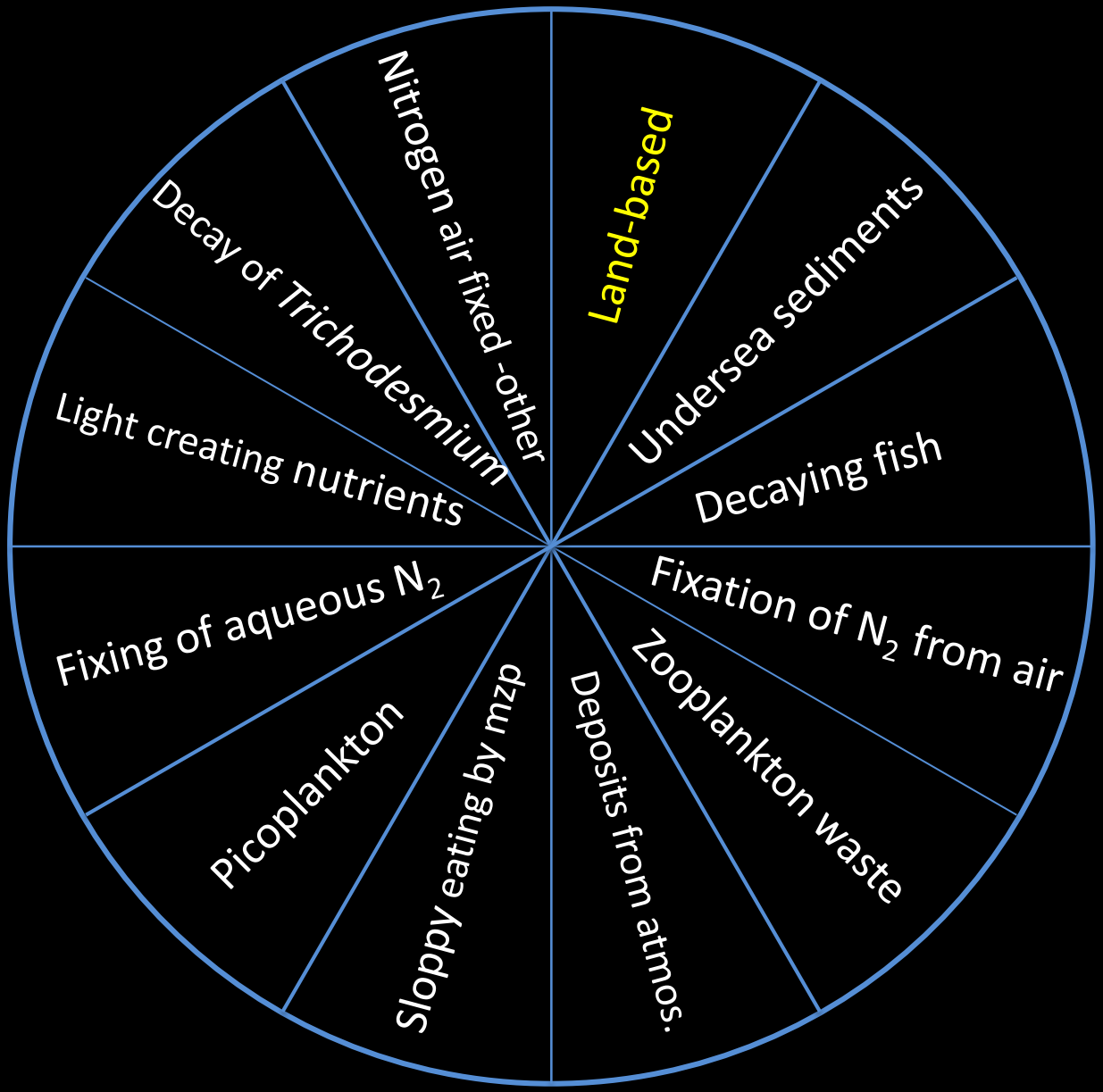

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Fertilizer regulations

Fertilizer regulations

- Apply at IFAS* recommended rates

* Institute of Food and Agricultural Sciences

Fertilizer retention

Ammonium ions (NH_4^+) are held in the soil but excess nitrate ions can be leached out. That's been accounted for in the fertilizer regulations.

D.P. Rainey, UF/FAS Extension

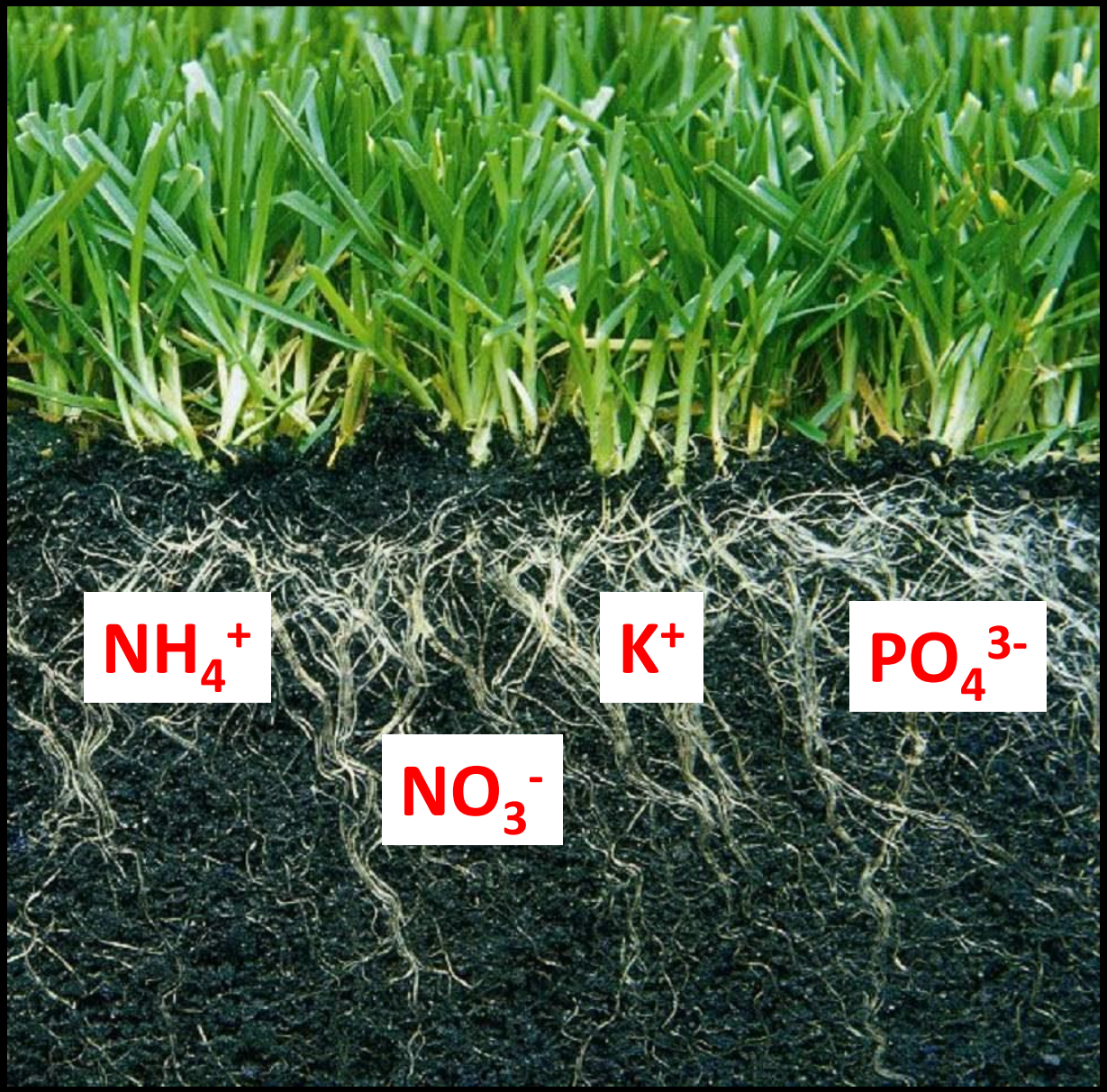


Photo: Lawnscience

Fertilizer retention

Phosphates are immobilized in the soil. Consequently, P does not pose a threat to groundwater reserves from leaching.

ncrs.usda.gov

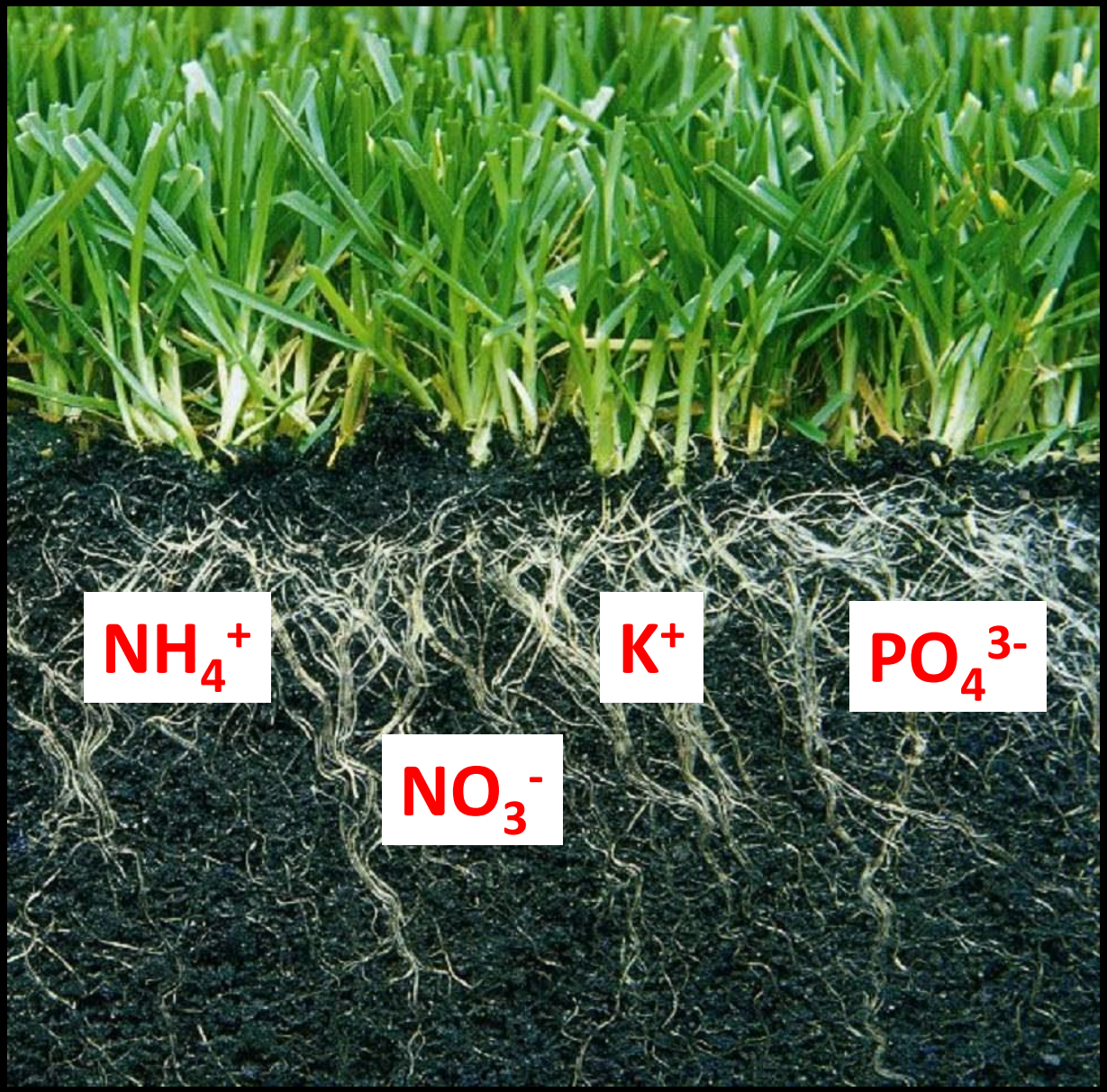
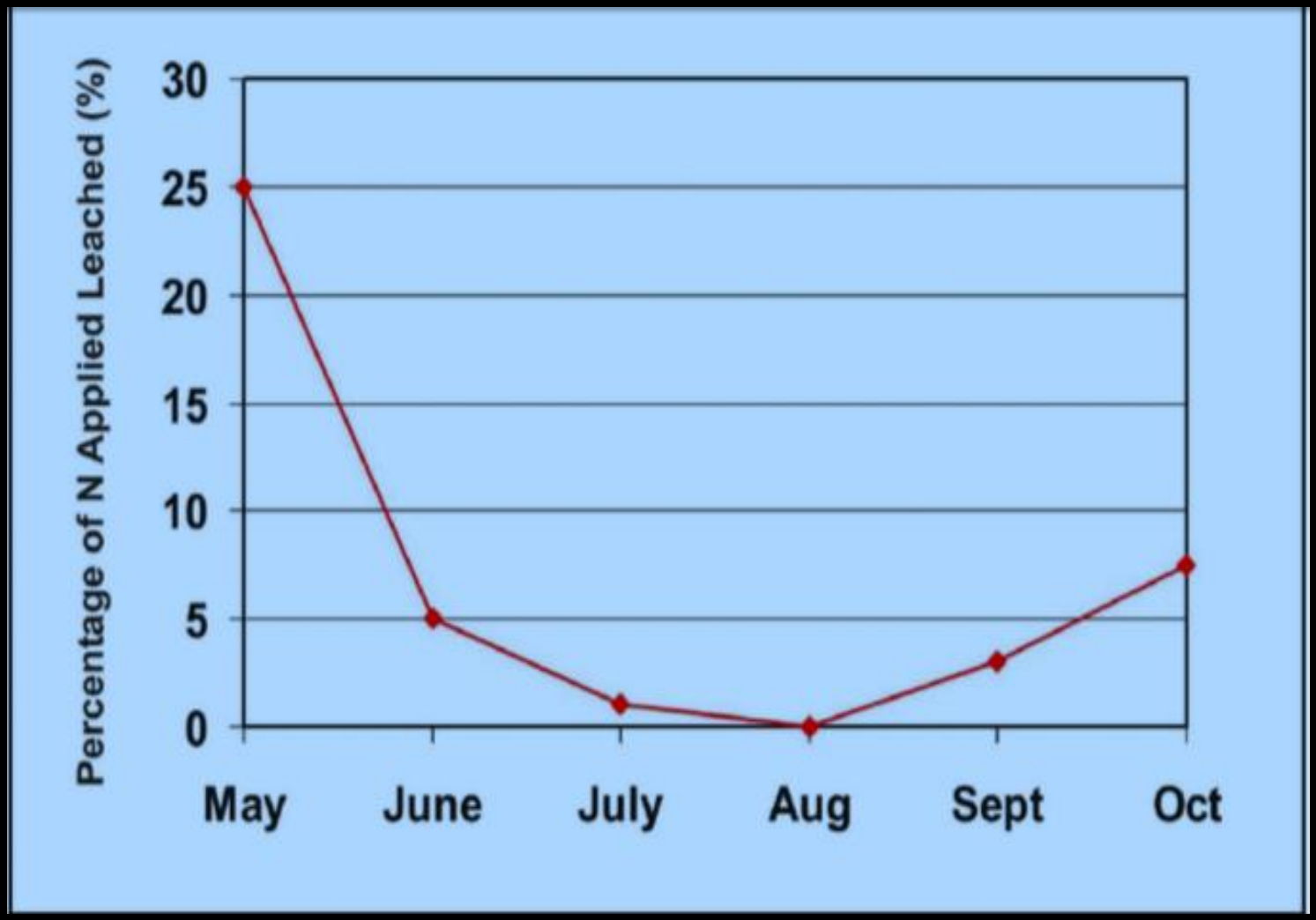


Photo: Lawnscience

Percent NO_3^- leaching by month



G. Hochmuth *et al*, IFAS Extension SL283

Fertilizer regulations

- Apply at IFAS* recommended rates
- Apply during active growth – summer months, not during winter dormancy

* Institute of Food and Agricultural Sciences

Fertilizer regulations

- Apply at IFAS* recommended rates
- Apply during active growth – summer months, not during winter dormancy
- IFAS does not recommend a fertilizer ban.
- (If one is implemented, it should be a winter ban, not a summer ban.)

* Institute of Food and Agricultural Sciences

Summary re land-based nutrients

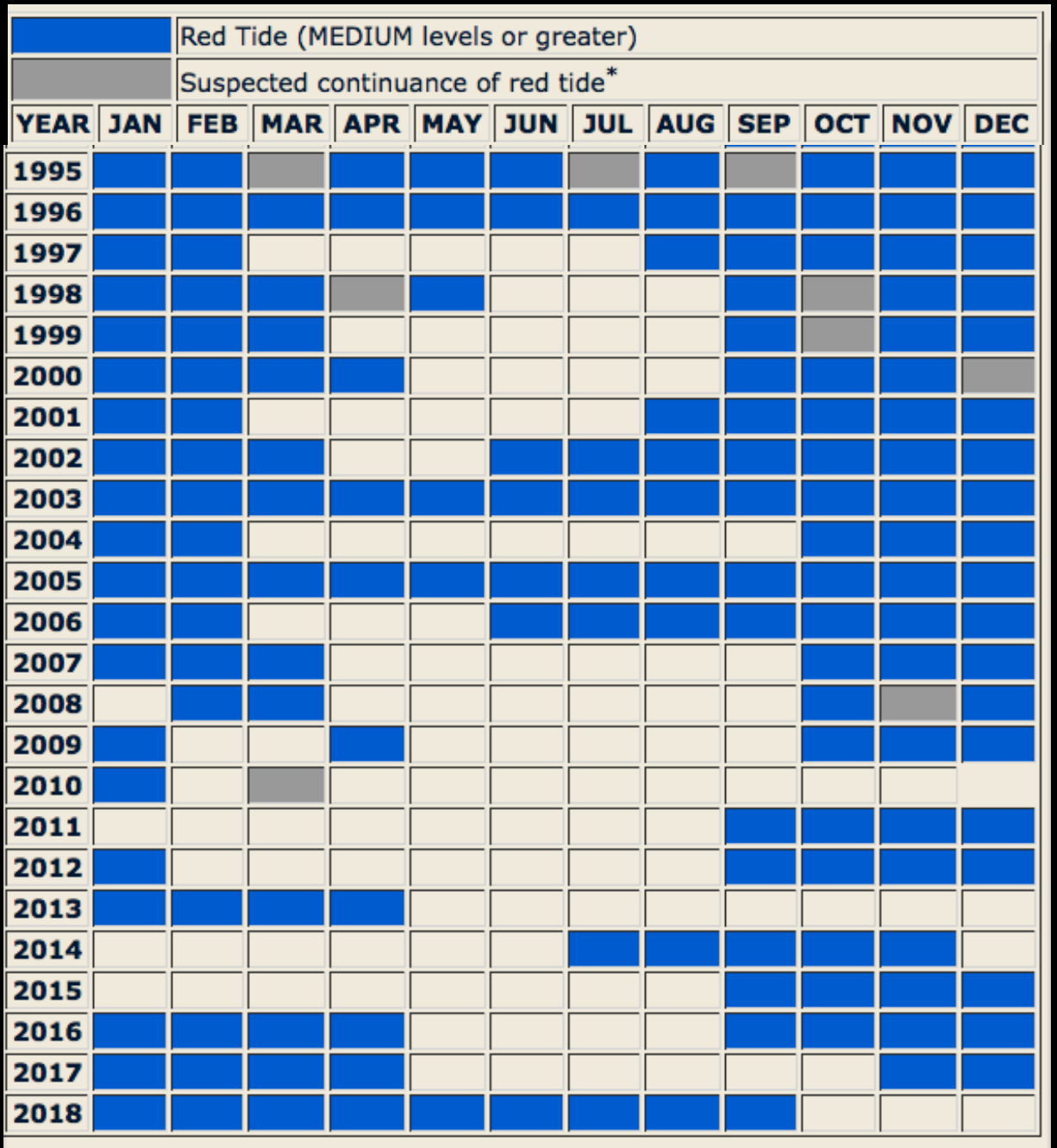
"I can say categorically that land-based nutrients are NOT the cause of *K. brevis* blooms. They may exacerbate them a bit but we have no clear evidence of their even being a cause; they are definitely not the main factor. A fact often missed is that there have been these blooms long before agriculture in Florida."

Dr. Robert Weisberg
Distinguished University Professor
Physical Oceanography
University of South Florida

Anomalous years – 2010, 2013

K. brevis concentrations 1995 - 2018

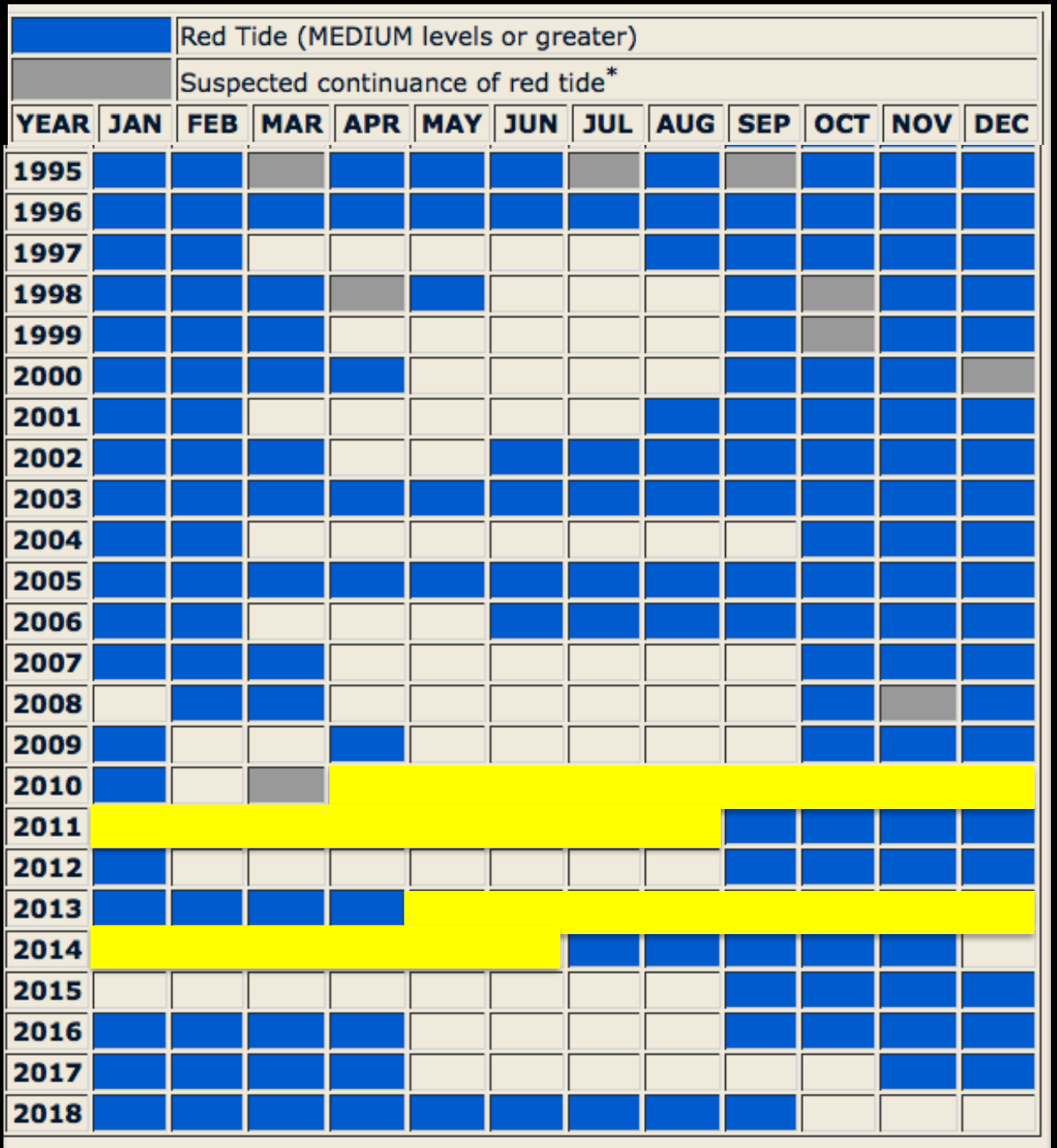
Source: Florida Fish and Wildlife Conservation Commission



#/yr	Duration, months
12	
12	
7	26
9	10
7	7
8	8
7	6
10	8
12	
5	21
12	
9	17
6	10
5	2
5	4,1
2	4
4	
5	5
4	8
5	5
4	8
8	
6	8
9	11

K. brevis concentrations 1995 - 2018

Source: Florida Fish and Wildlife Conservation Commission



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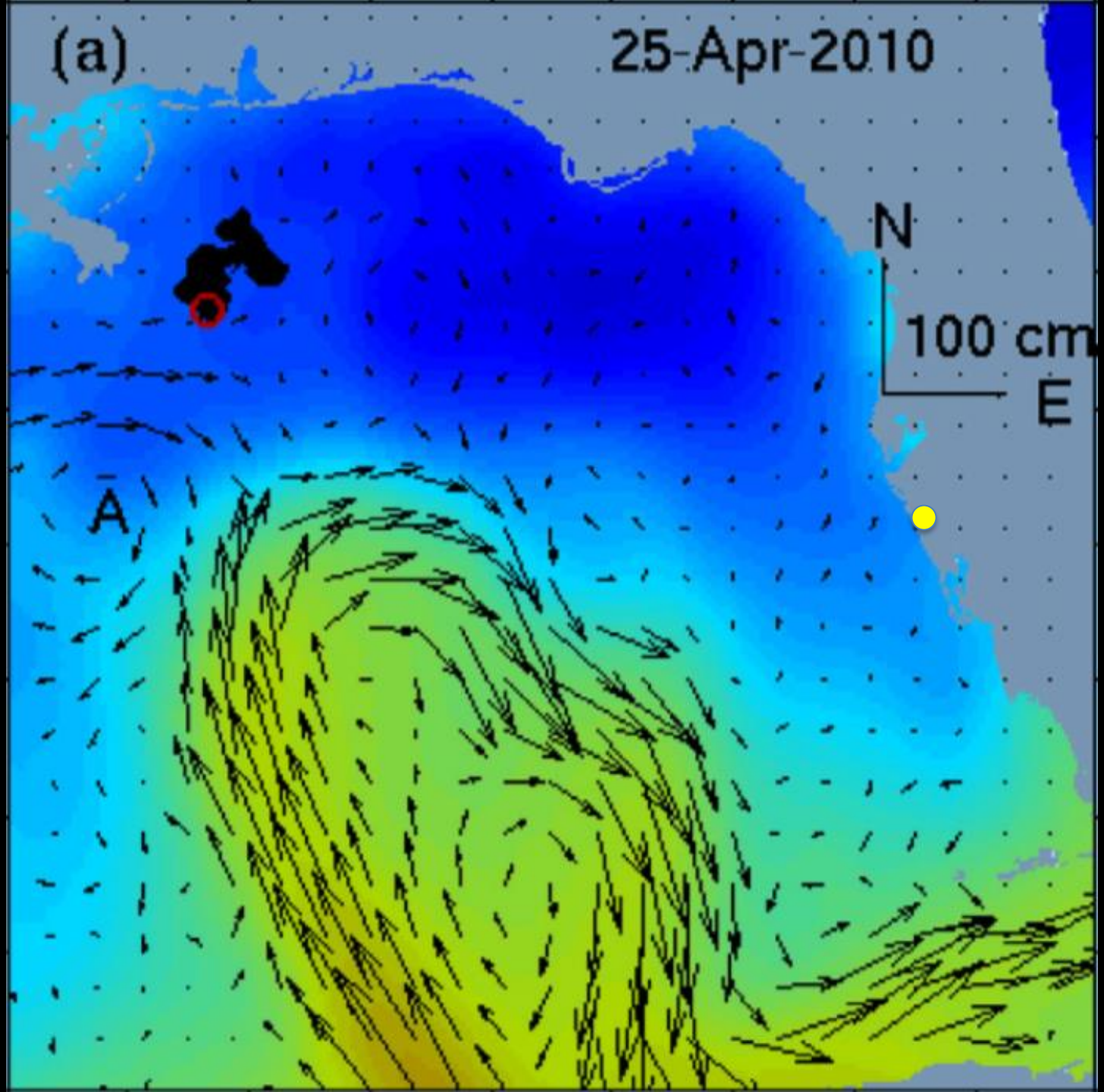
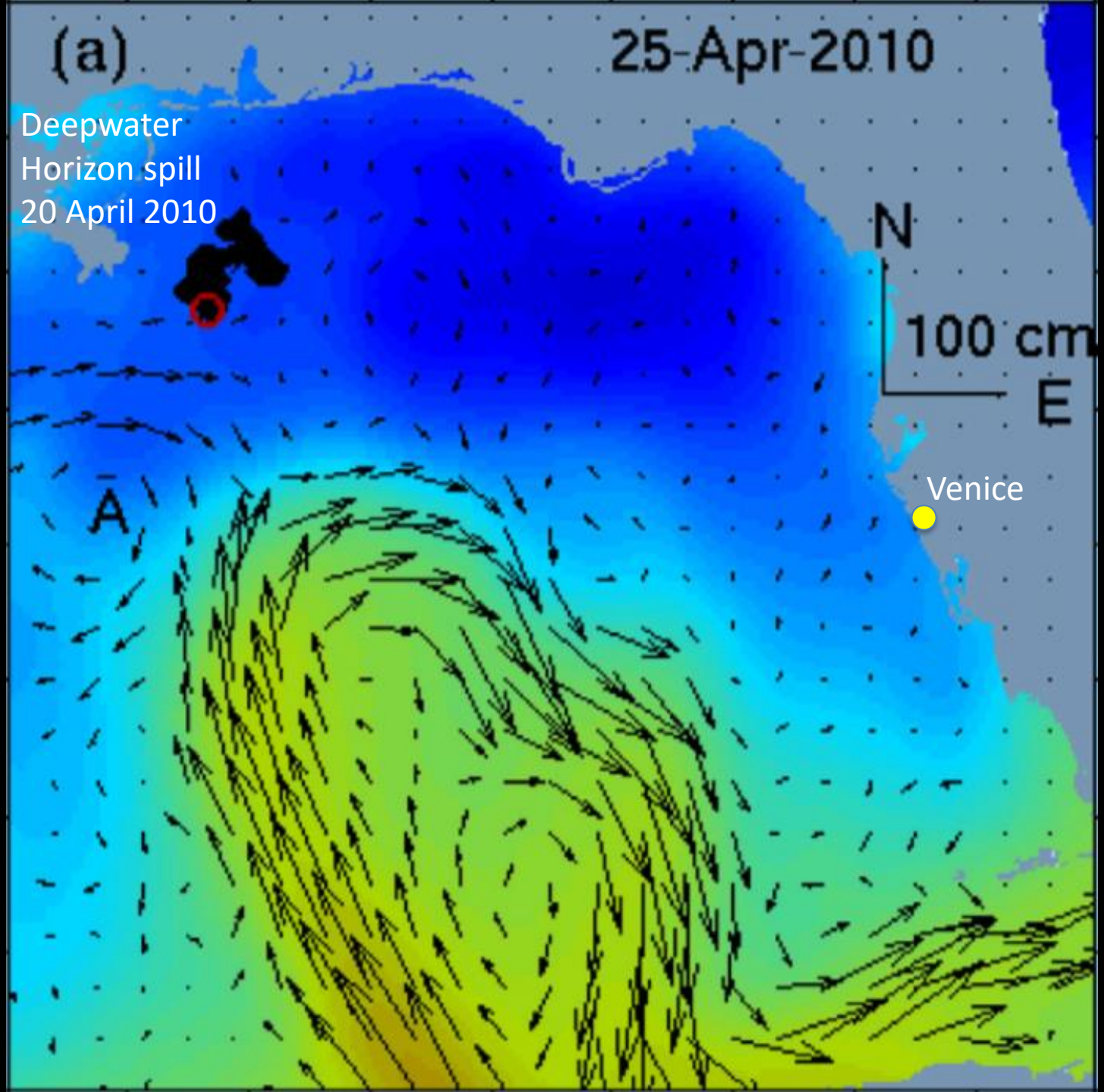
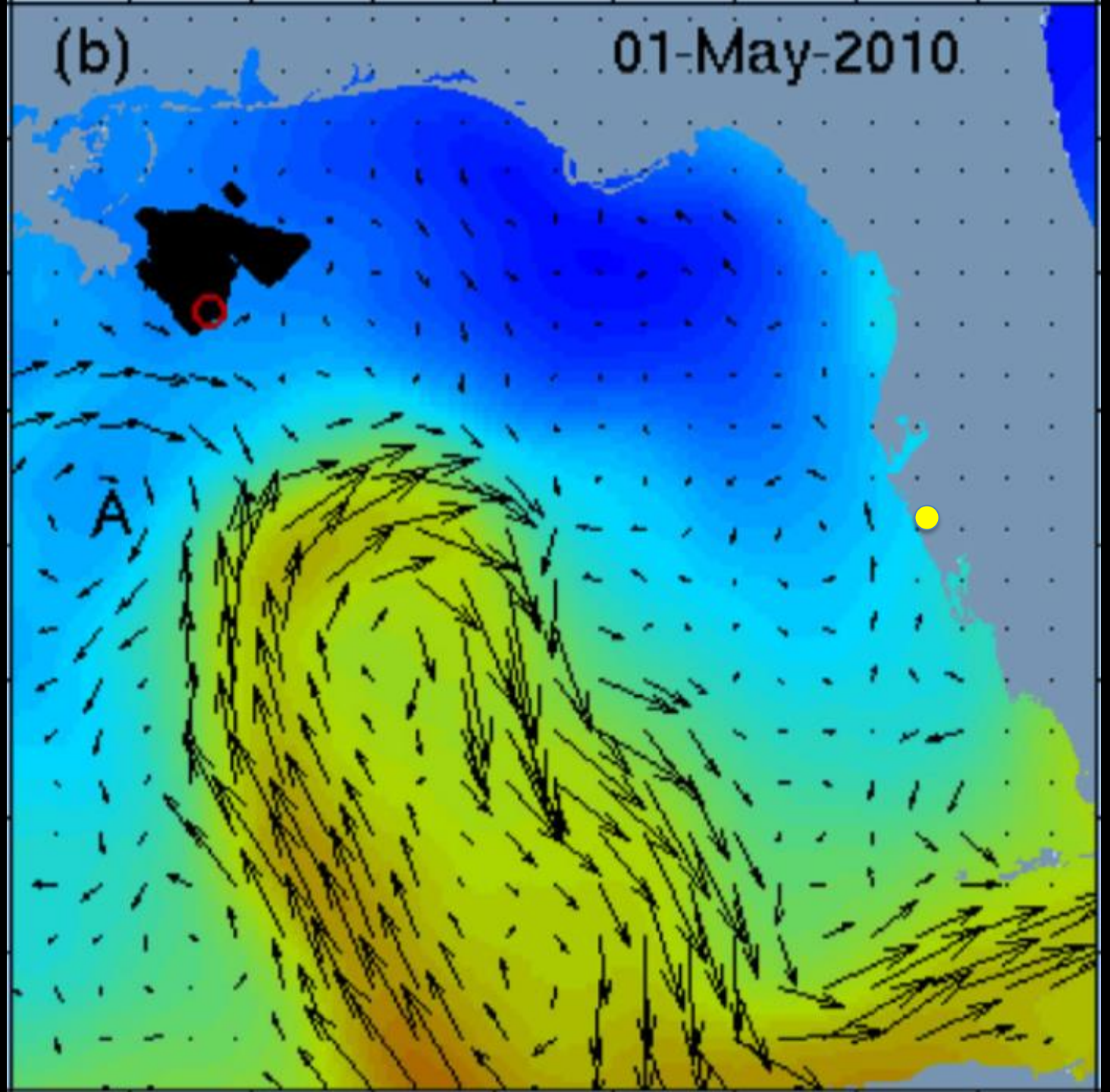


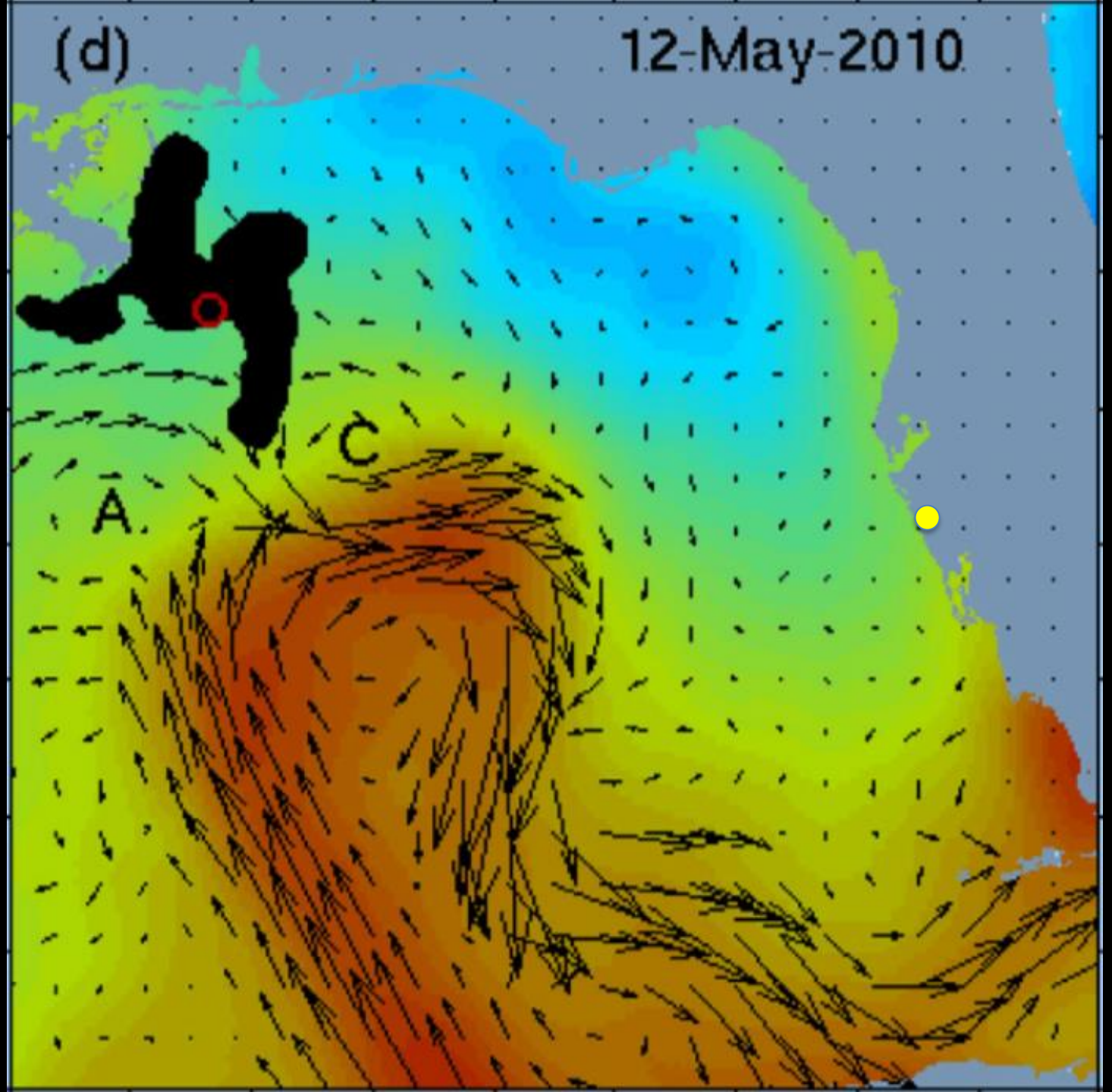
Weisberg *et al*, Harrnful Algae 38, (2014) 119-126



Weisberg *et al*, Harrnful Algae 38, (2014) 119-126



Weisberg *et al*, Harrnful Algae 38, (2014) 119-126



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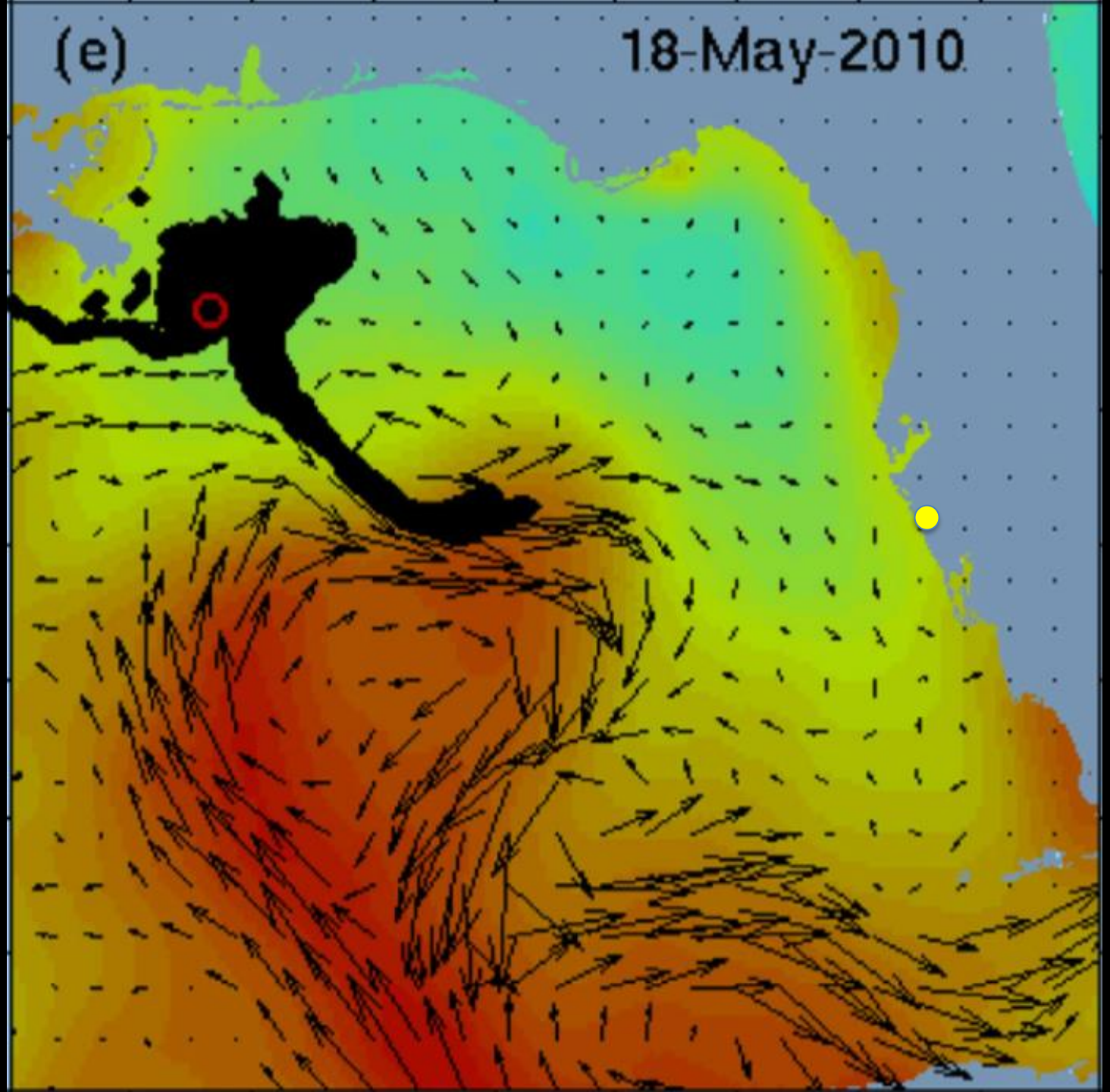

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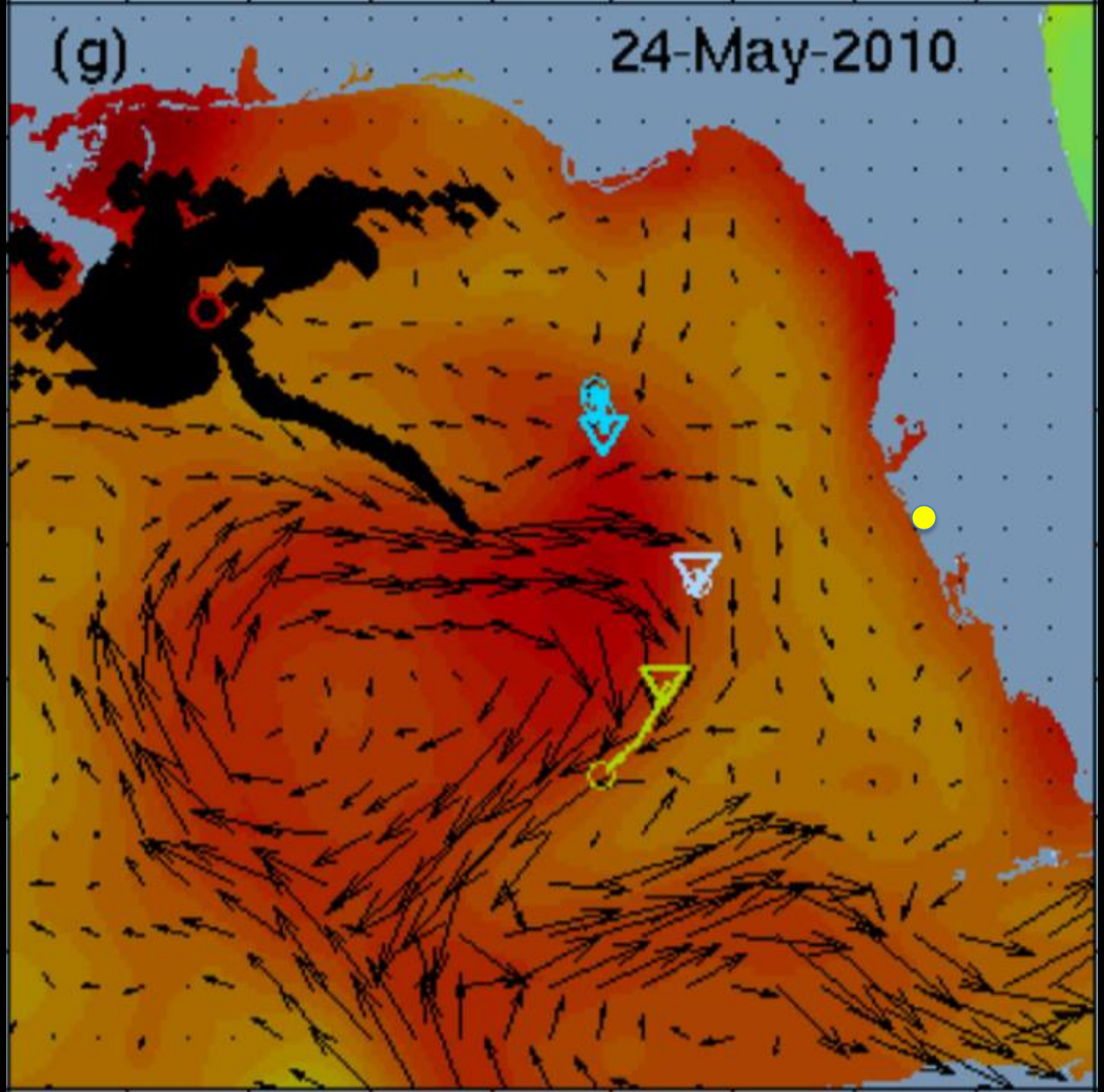

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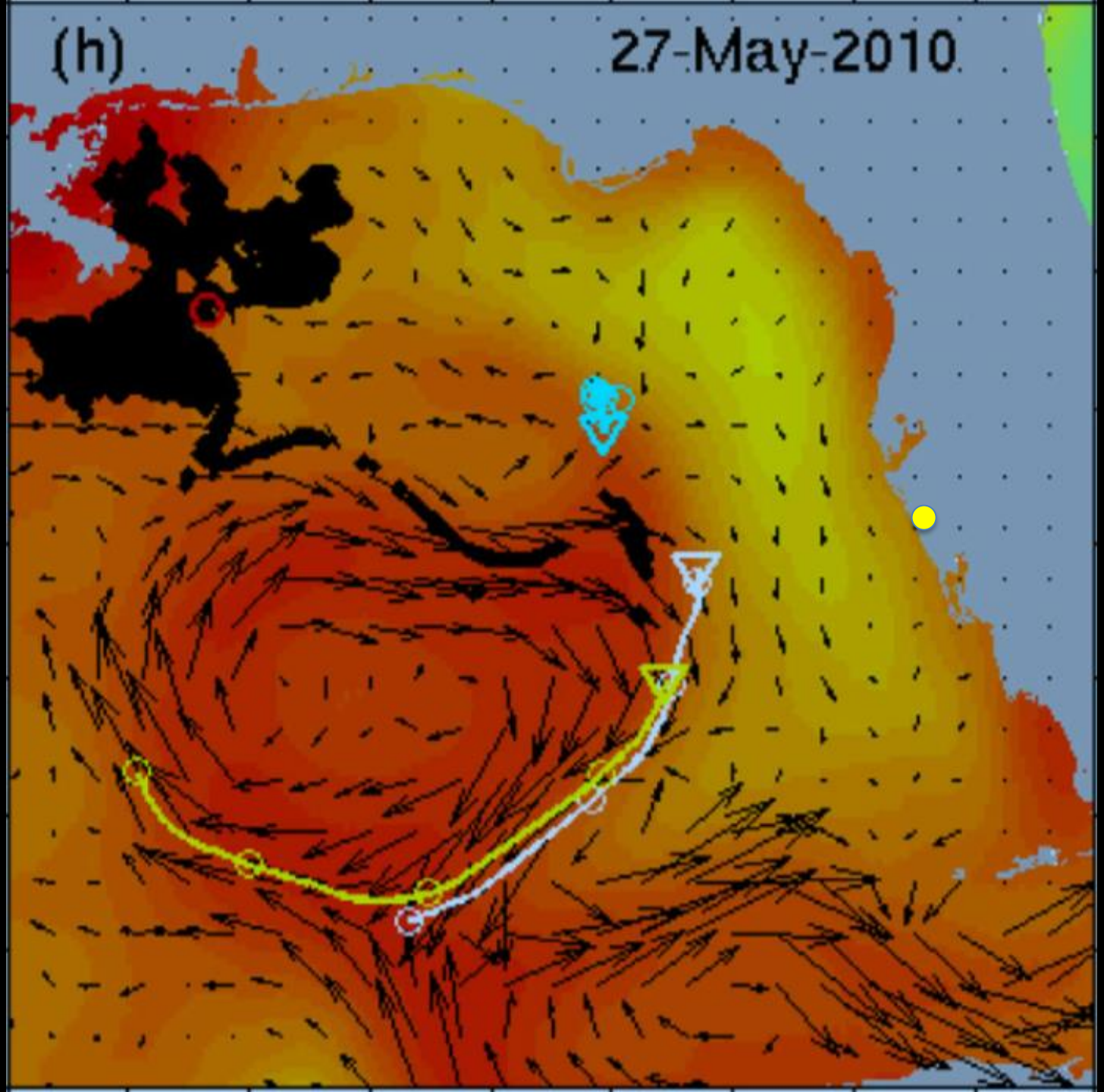

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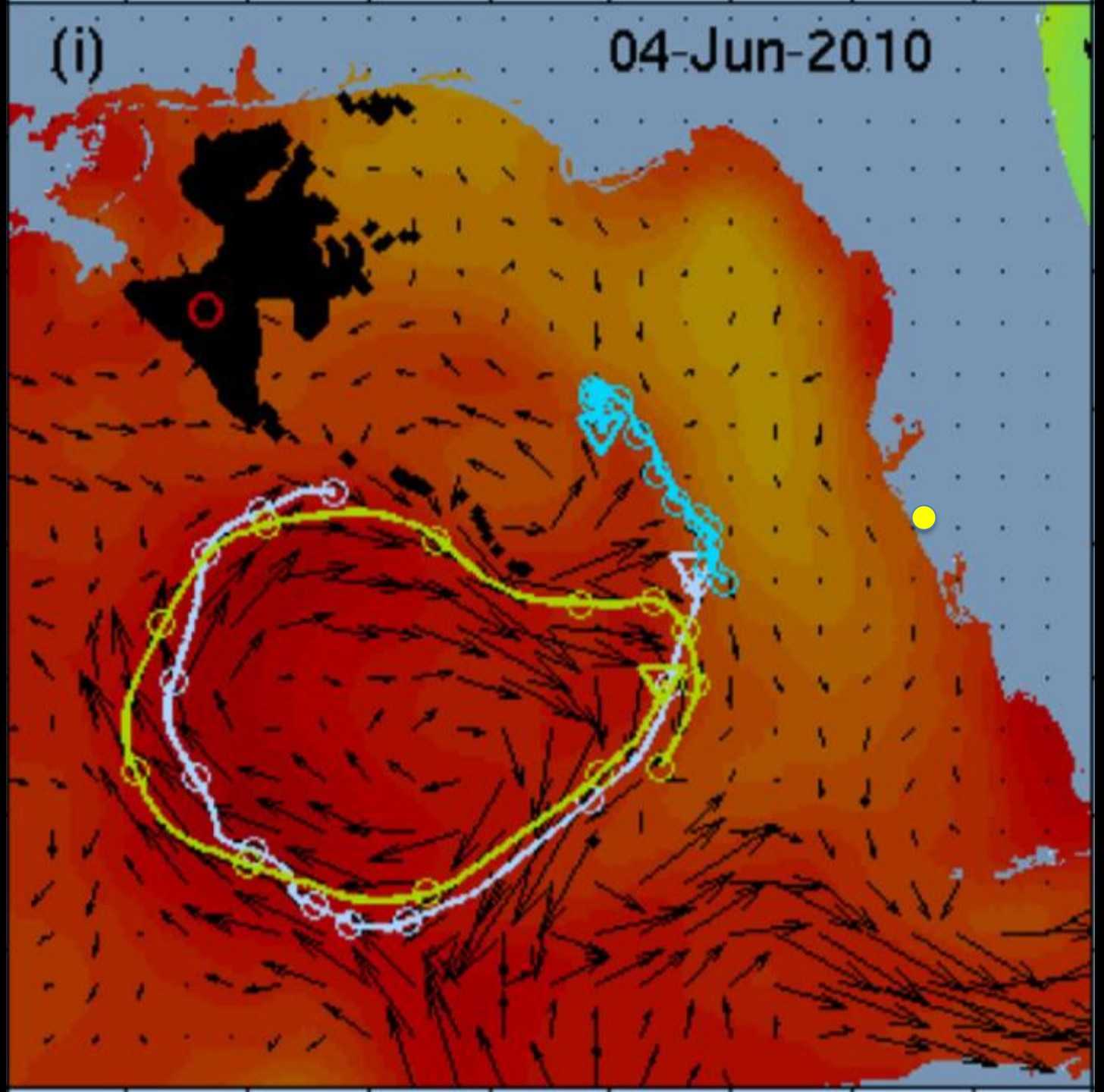
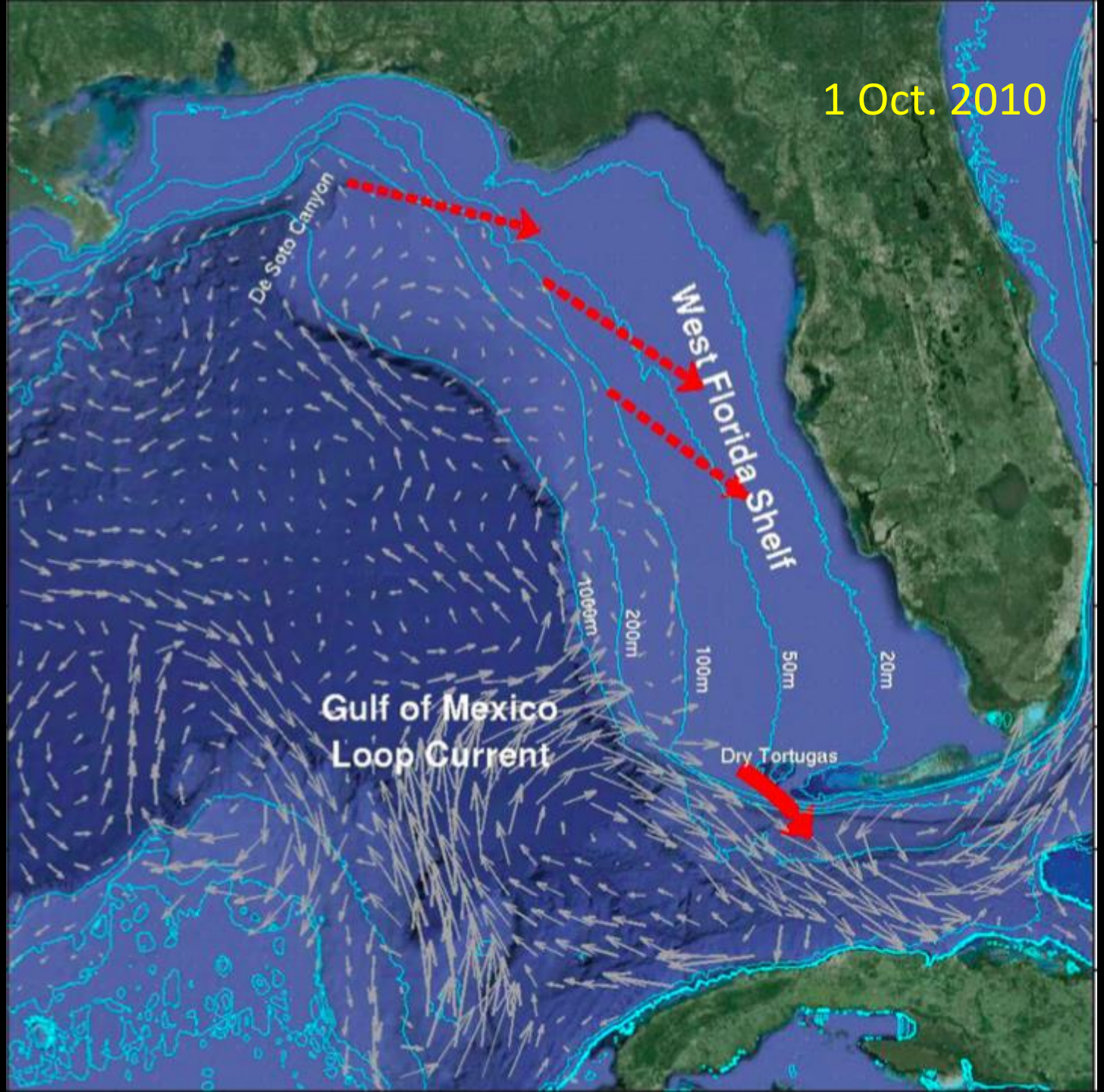


Weisberg *et al*, Harrnful Algae 38, (2014) 119-126



Liu *et al*, J. Geophys. Res.: Oceans *121*, 5501 – 5515 (2016)

Relative growth rates after N, P spike

diatoms dinoflagellates (*i.e.*, *K. brevis*)

0.72 div/day 0.34 div/day (25 - 30^{o}C)

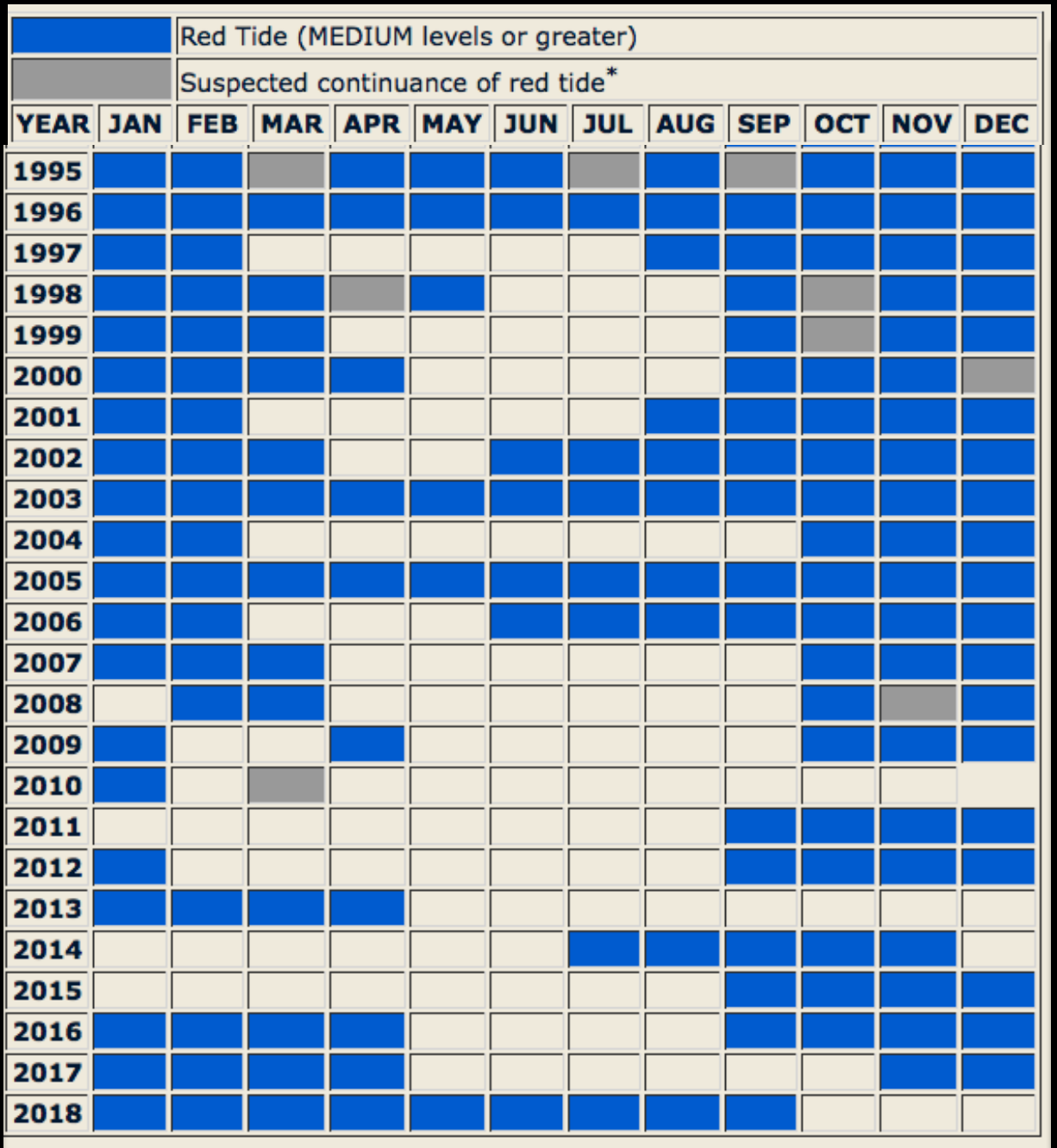
Y. Zhao, A. Quigg, PLoS ONE (9): e88732

"…it should not be surprising that abundant new inorganic nutrients under anomalous upwelling conditions might suppress *K. brevis* bloom development by favoring more rapidly growing phytoplankton species (diatoms)."

Liu *et al.*, J. Geophys. Res.: Oceans *121*, 5501 – 5515 (2016)

K. brevis concentrations 1995 - 2018

Source: Florida Fish and Wildlife Conservation Commission



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Temperature re *K. brevis* blooms

Water temps this week

Above Oct. average, °F

+4.3

+5.0

+9.6

+5.1

+6.6

+4.9

+5.2

+6.9

+5.1

Water Temperature Table of the Eastern Gulf of Mexico (Google Maps-based Web page)

Last Updated: Sun Oct 21, 02:32:03 UTC 2018

Location	Recent Temperatures	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY
Blackwater Sound, FL		82	76	73	65	72	71	78	83
Little Blackwater, FL	85.3 (10/21/2018 00:00 UTC)	81	75	71	62	70	70	76	82
Long Sound, FL	86.0 (10/21/2018 01:00 UTC)	81	76	73	64	72	71	78	83
Highway Creek, FL	89.6 (10/21/2018 00:00 UTC)	80	78	71	63	71	71	77	84
Duck Key, FL	85.1 (10/21/2018 00:00 UTC)	80	75	71	62	70	69	76	82
Trout Cove, FL	87.6 (10/21/2018 00:00 UTC)	81	76	71	63	71	70	77	83
Butternut Key, FL	84.9 (10/21/2018 01:00 UTC)	80	75	71	63	69	69	76	82
Little Madeira, FL	86.2 (10/21/2018 01:00 UTC)	81	76	72	63	71	71	77	83
Taylor River, FL	86.9 (10/21/2018 01:00 UTC)	80	74	70	63	71	72	78	84
Bob Allen, FL	85.1 (10/21/2018 01:00 UTC)	80	76	72	62	71	70	78	84

nodc.noaa.gov/dsdt/cwtg/egof.html

Temperature re *K. brevis* blooms

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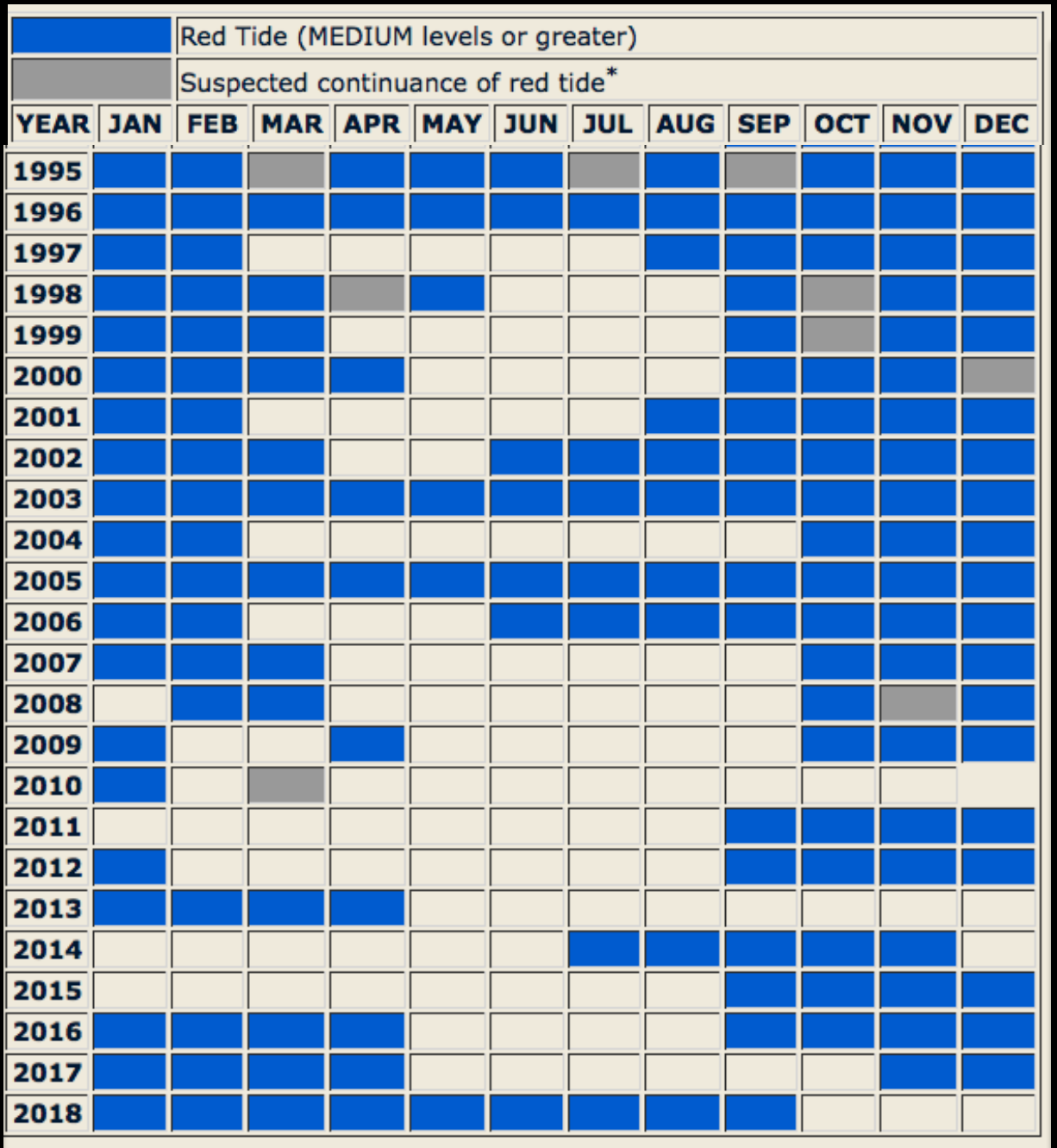
- *K. brevis* gets its start on the shelf in cold, deeper water so it doesn't need warm temperatures to grow,

Temperature re *K. brevis* blooms

- *K. brevis* gets its start on the shelf in cold, deeper water so it doesn't need warm temperatures to grow,
- Also, *K. brevis* blooms come to shore usually in the fall when temperatures have lowered.

K. brevis concentrations 1995 - 2018

Source: Florida Fish and Wildlife Conservation Commission



#/yr	Duration
12	
12	26
7	10
9	7
7	8
8	6
7	8
10	21
12	17
5	10
12	3
9	2
6	4
5	1
5	4
2	
4	5
5	8
4	
5	5
4	8
8	8
6	11
9	

Growth rate of *K. brevis* cells

Temp, °C	Temp, °F	Growth rate, div/day
15	59	0.12
20	68	0.32
25	77	0.36
30	86	0.33

Salinity = 35 ppt; H. Magana, T. Villareal, Harmful Algae 5 (2006) 192 - 198

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Temperature re *K. brevis* blooms

- *K. brevis* gets its start on the shelf in cold, deeper water so it doesn't need warm temperatures to grow,
- Also, *K. brevis* blooms come to shore usually in the fall when temperatures have lowered.
- Thus, extra warm temperatures are not the cause of *K. brevis* blooms.

R.H. Weisberg, Univ of Florida

Conclusions

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Conclusions

- Red Tide is primarily an ocean physics problem
- The nutrient ecosystem is complex and land-based nutrients play a very minor role, if any
- A large increase in inorganic nutrients tends to supress *Karenia brevis* growth
- Higher than normal temperatures are not a cause of *K. brevis* blooms

Resources

Robert H. Weisberg, Univ. of South Florida, St. Petersburg

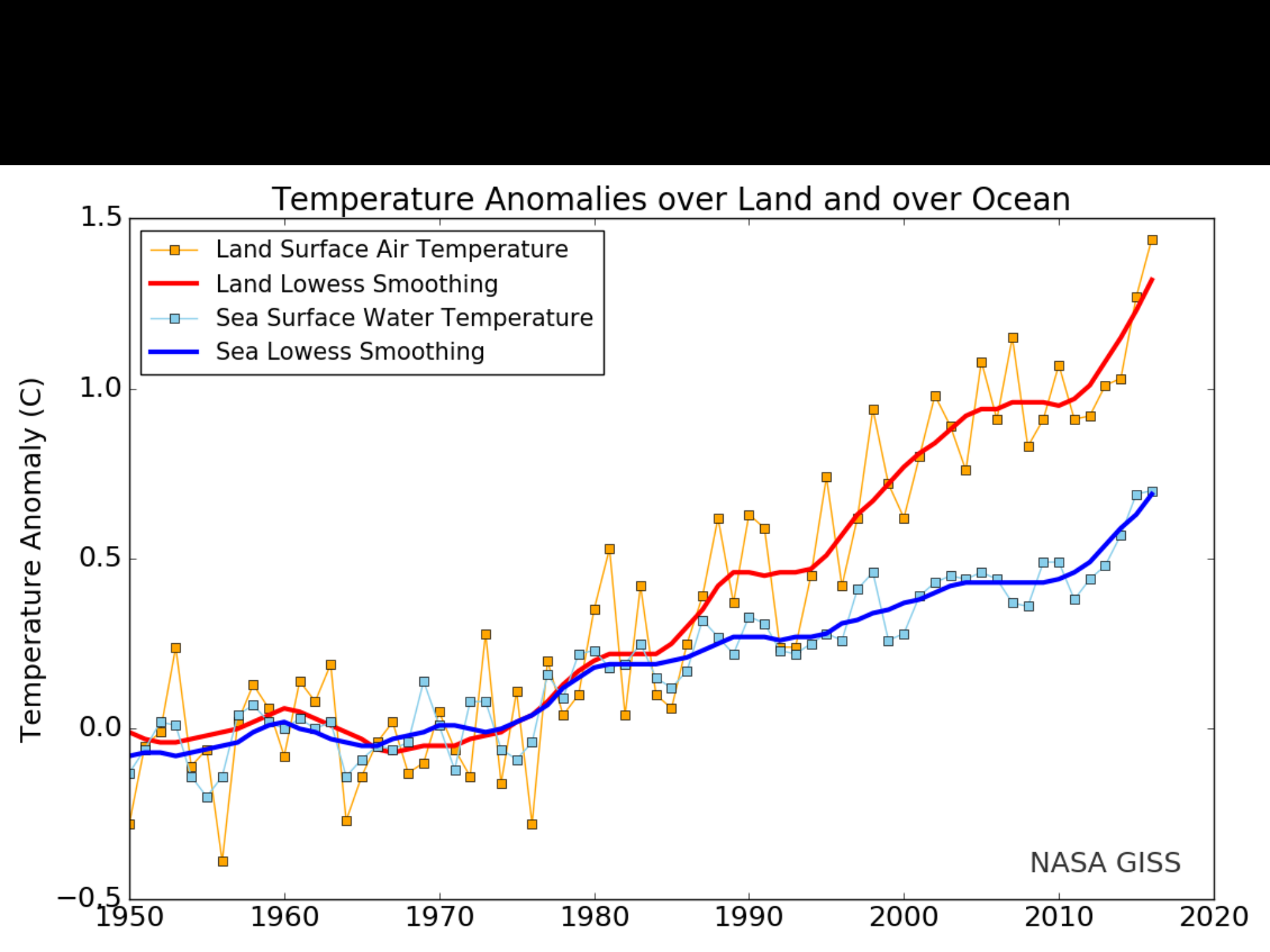
Donald Rainey, Univ. of Florida Extension

Florida Fish and Wildlife Conservation Commission

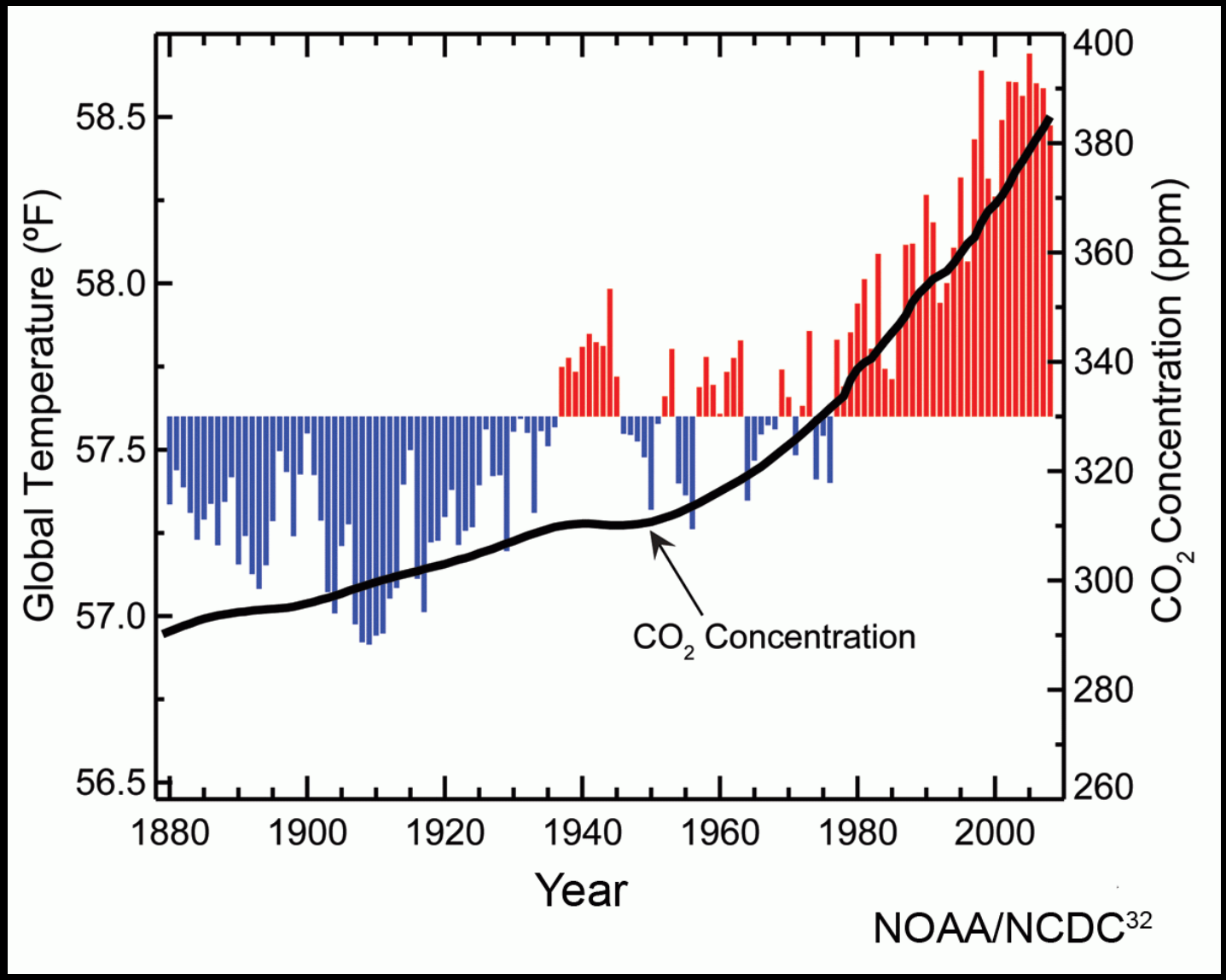
Mote Marine Laboratory

Harmful Algae Vol. 38

Red tide late July 2018


Temperature Anomalies over Land and over Ocean
Land Surface Air Temperature
Land Lowess Smoothing
Sea Surface Water Temperature
Sea Lowess Smoothing
Temperature Anomaly (C)
1.5
1.0
0.5
0.0
−0.5
1950
1960
1970
1980
1990
2000
2010
2020
NASA GISS

Temp. increases, CO_2 concentrations



Result of higher CO_2 concentrations

CO_2 pressure, ppm	growth rate of *K. brevis,* div/day	
	T=25°C	T=30°C
350 (current)	0.29	0.21
1000 (est 2100)	0.43	0.30

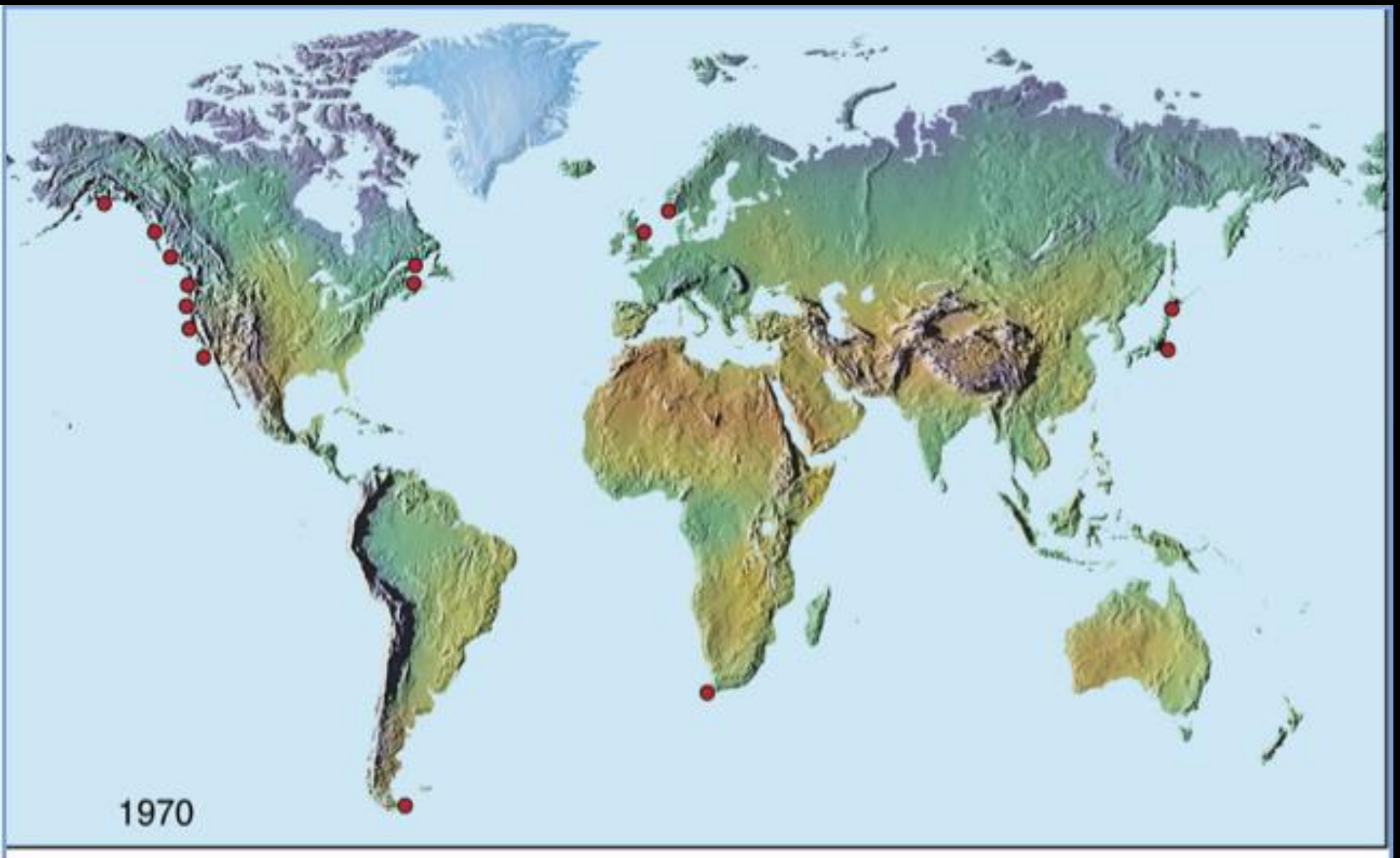
R.M. Errera et al, Harmful Algae 38 (2014) 110 - 116

Sources of nutrients for *K. brevis*

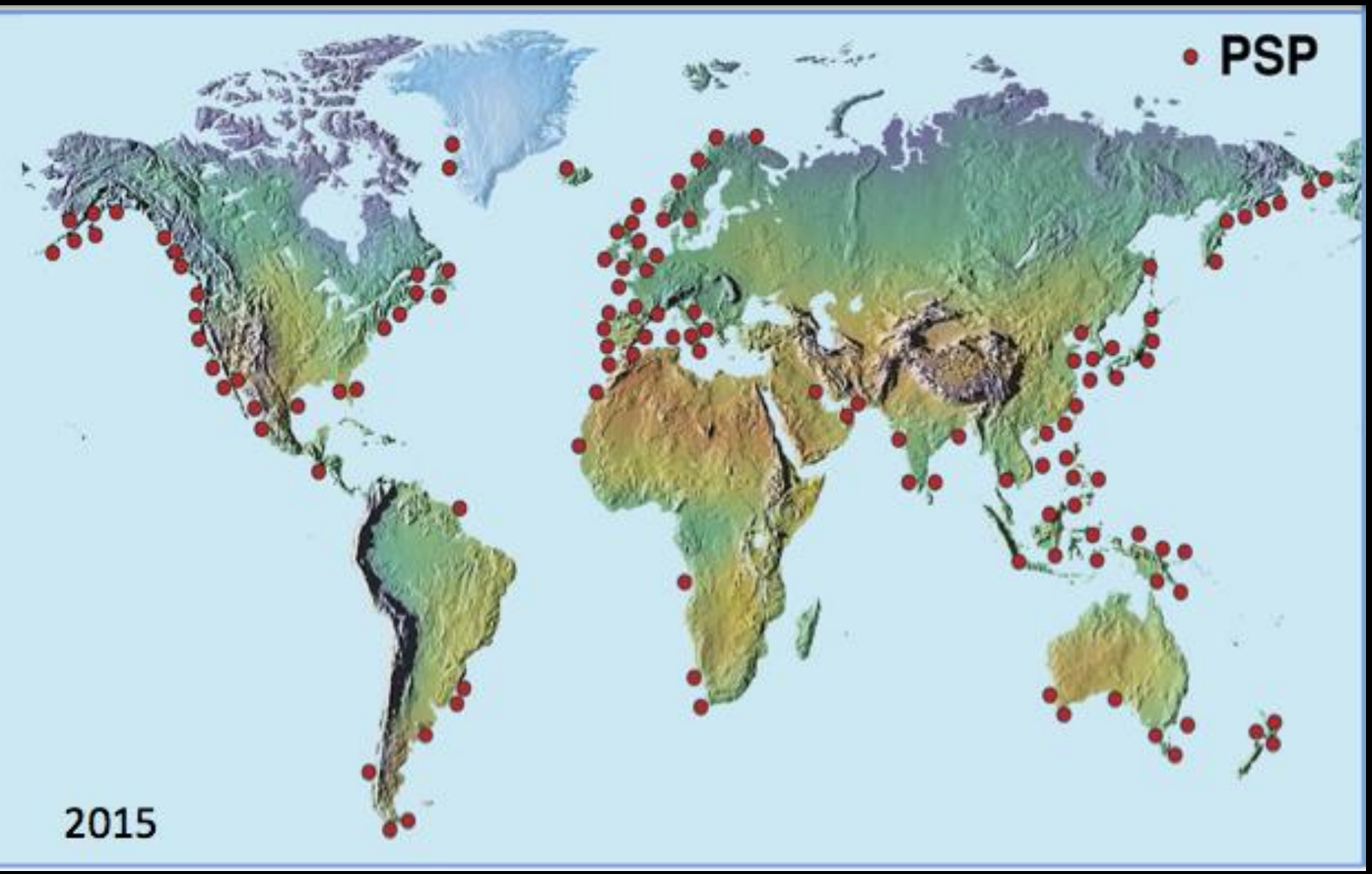
Land-based

- Estuary flow
- Excess fertilizer
- Animal waste
- Septic tanks
- Vegetation

HABs worldwide



Woods Hole Oceanographic Institution



Blue-green algae on Lake Okeechobee

Photo:TCPalm

Blue-green algae

- *Microcystis aeruginosa* – a cyanobacterium

Photo- Univ of FL

Blue-green algae

- *Microcystis aeruginosa* – a cyanobacterium
- Primary Lake Okeechobee algae

Photo- Univ of FL

Blue-green algae

- *Microcystis aeruginosa* – a cyanobacterium
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- Feeds on nitrogen and phosphorus

Photo- Univ of FL

Blue-green algae

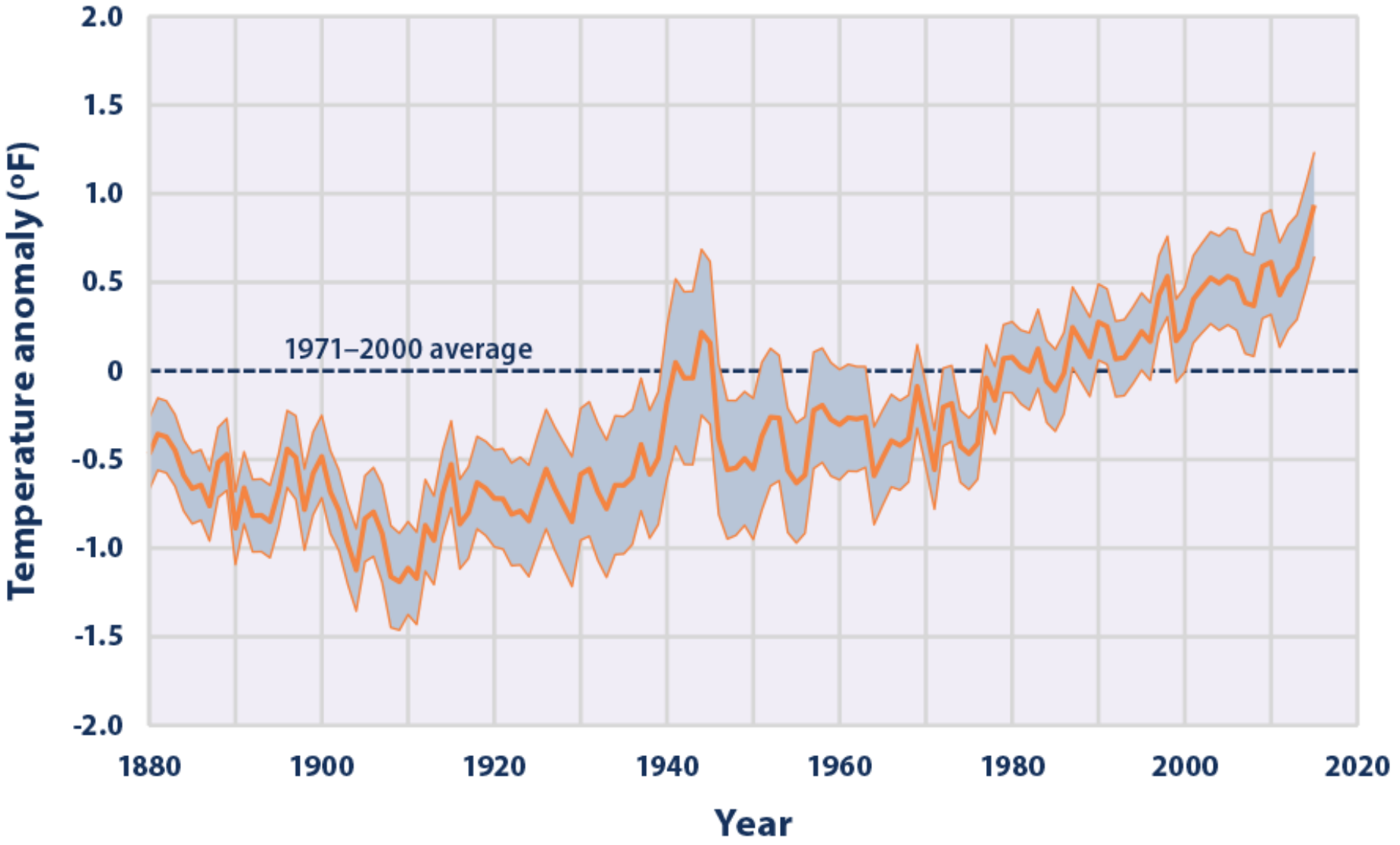
- *Microcystis aeruginosa* – a cyanobacterium
- Primary Lake Okeechobee algae
- Feeds on nitrogen and phosphorus
- Needs fresh water

Photo- Univ of FL

Red tide on shoreline

Photo: Joshua Hehe, A Medium Corporation

Temperature variations



www.epa.gov/climate-indicators/climate-change-indicators-sea-surface-temperature

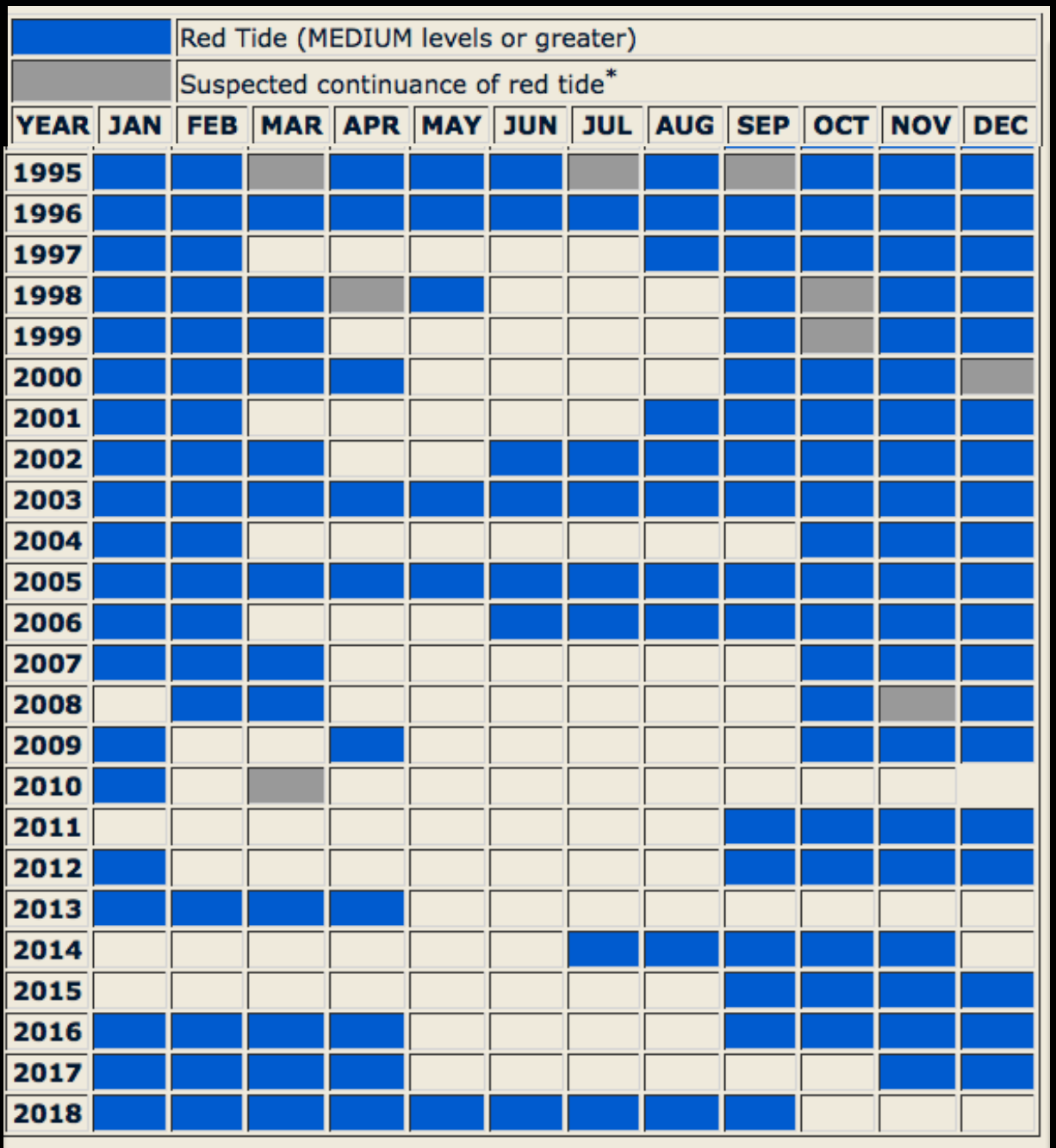
Dr. Karen A. Steidinger

Karenia brevis

Photo: Dale S. Beaumariage

- *Tricodesmium* fixes ~ 80 M Kg/yr N_2 in tropical waters

K. brevis concentrations 1995 - 2018



Source: Florida Fish and Wildlife Conservation Commission

	#/yr	Duration	Ave/yr
1995	12		
1996	12		
1997	7	26	
1998	9	10	
1999	7	7	
2000	8	8	
2001	7	6	
2002	10	8	7.6
2003	12	21	
2004	5	17	
2005	12	10	
2006	9	3	
2007	6	2	
2008	5	4	
2009	5	1	
2010	2	4	
2011	4	5	
2012	5	8	
2013	4		
2014	5	5	5.6
2015	4	8	
2016	8	8	
2017	6	11	
2018	9		

“Traditional” stream pollution issues

Photo: Laura Johnson, Scientific American

“Traditional” stream pollution issues

- Insertion of agricultural waste and excess fertilizer into streams

Photo: Laura Johnson, Scientific American

Result of higher CO_2 concentrations

At the predicted pCO_2 levels for 2100, growth rate of *K. brevis* Wilson clone increased substantially by 46% at 25 °C (0.43 ± 0.01 d−1) compared to recent and pre-industrial levels (0.29 ± 0.01 d−1). When grown at a higher temperature (30 °C), growth rates for the Wilson clone significantly decreased at all three pCO_2 by approximately 30%. However, even at the higher temperature, *K. brevis* growth rate significantly increased by 30% (0.30 ± 0.01 d−1) at the 1000 ppm CO_2 level when compared to recent and pre-industrial CO_2 levels (0.21 ± 0.01 d−1).

R.M. Errera et al, Harmful Algae 38 (2014) 110 - 116

“Traditional” stream pollution issues

- Insertion of agricultural waste and excess fertilizer into streams
- Excess nitrogen (nitrates, ammonium ions, etc.) and phosphorus (as phosphates) cause blue-green algae (cyanobacteria) to bloom

Photo: Laura Johnson, Scientific American

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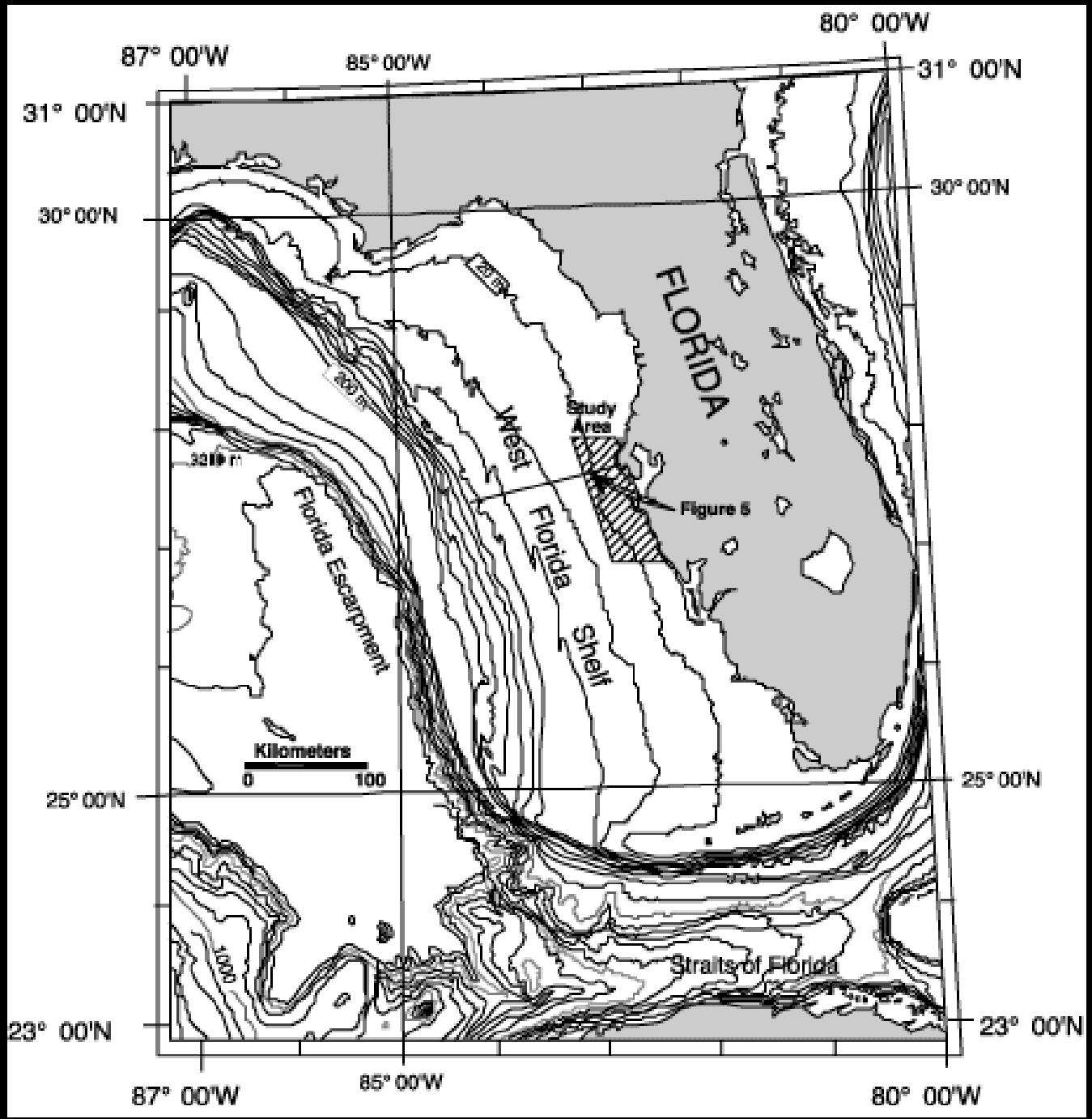
“Traditional” stream pollution issues

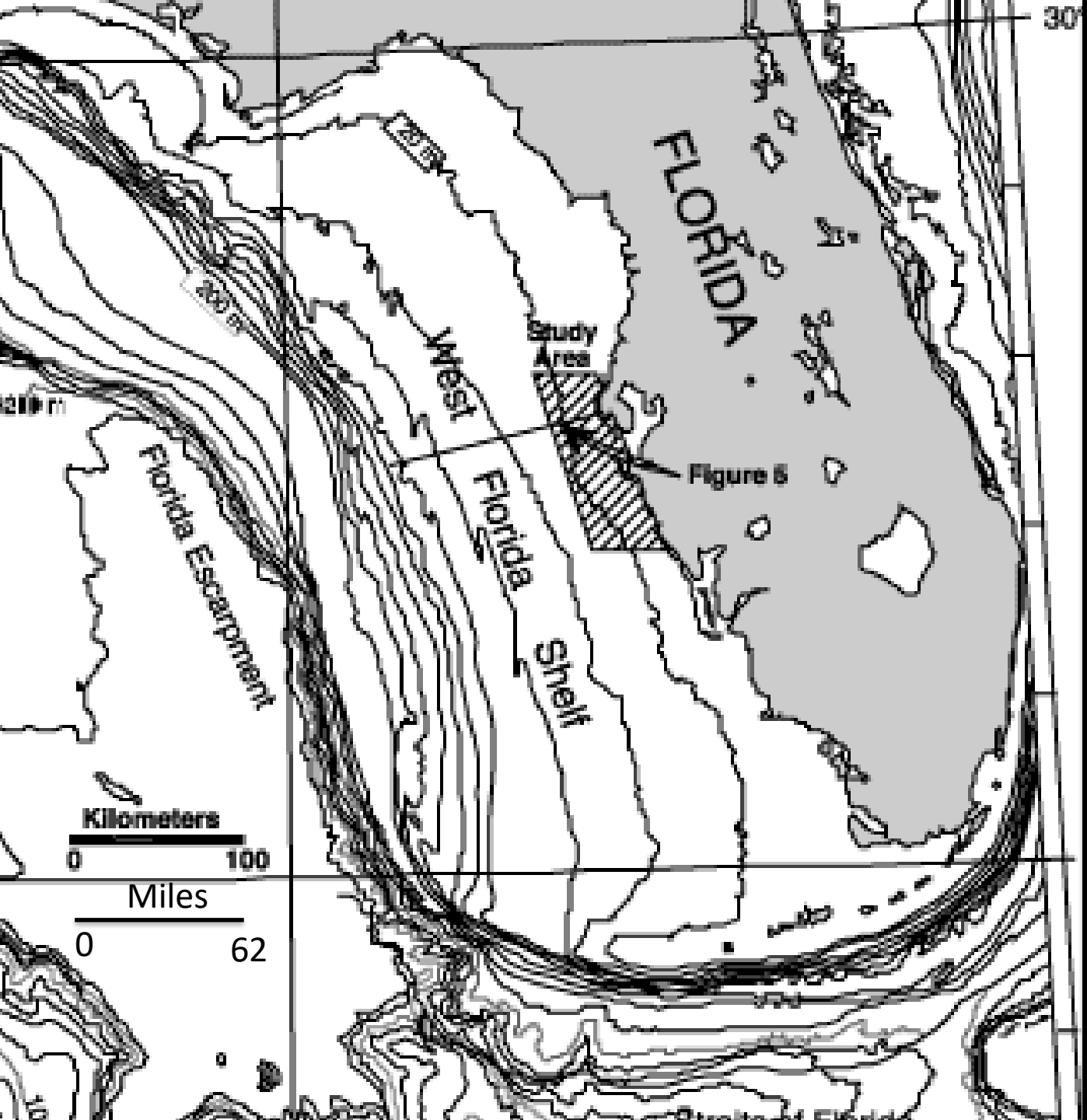
- Insertion of agricultural waste and excess fertilizer into streams
- Excess nitrogen (nitrates, ammonium ions, etc.) and phosphorus (as phosphates) cause blue-green algae (cyanobacteria) to bloom
- Upon dying, the algael mass depletes oxygen
- This creates a “dead zone” where fish cannot exist.

Photo: LG Sonic Corp.



West Florida shelf

Source: pubs.usgs.gov



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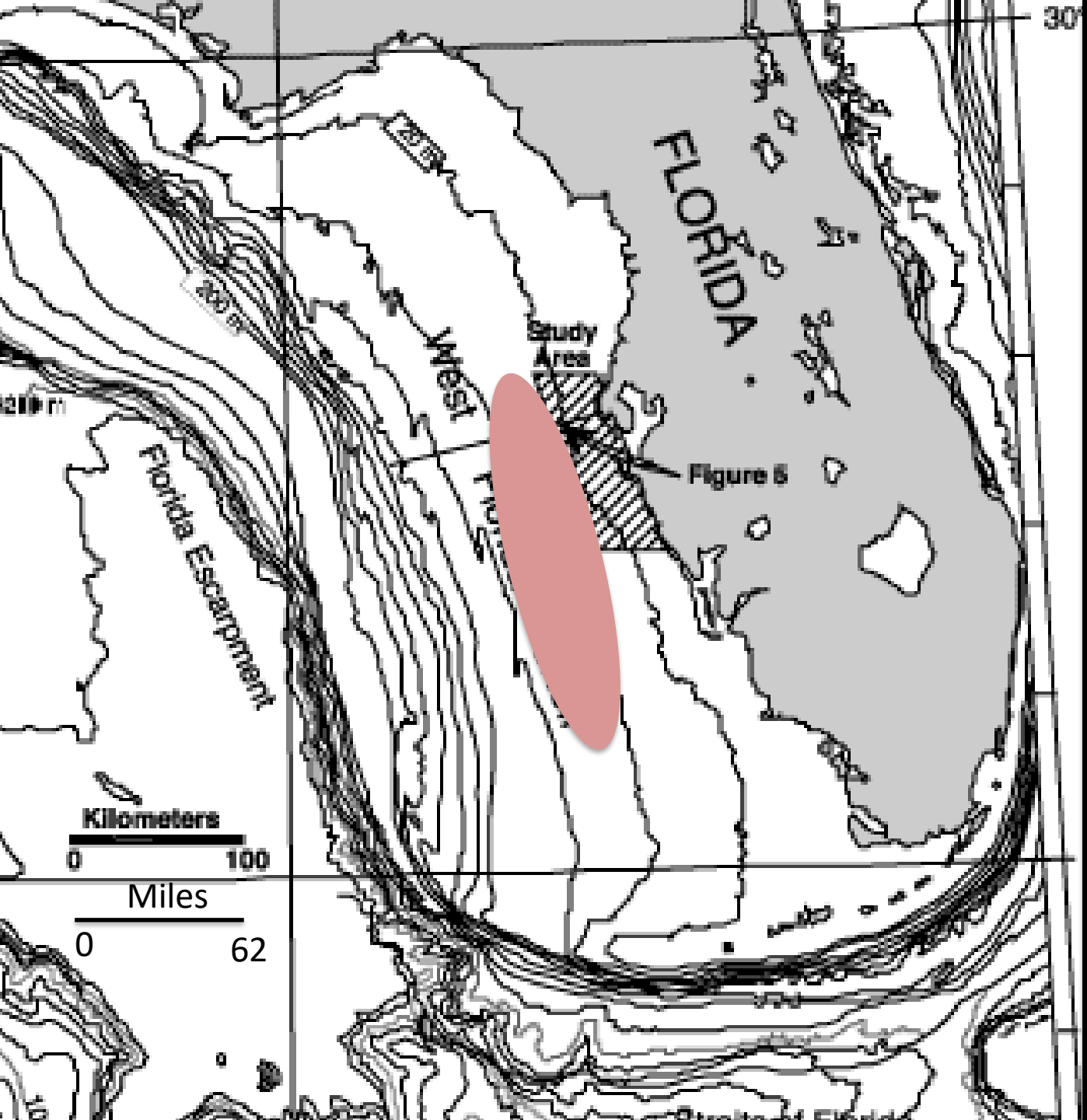
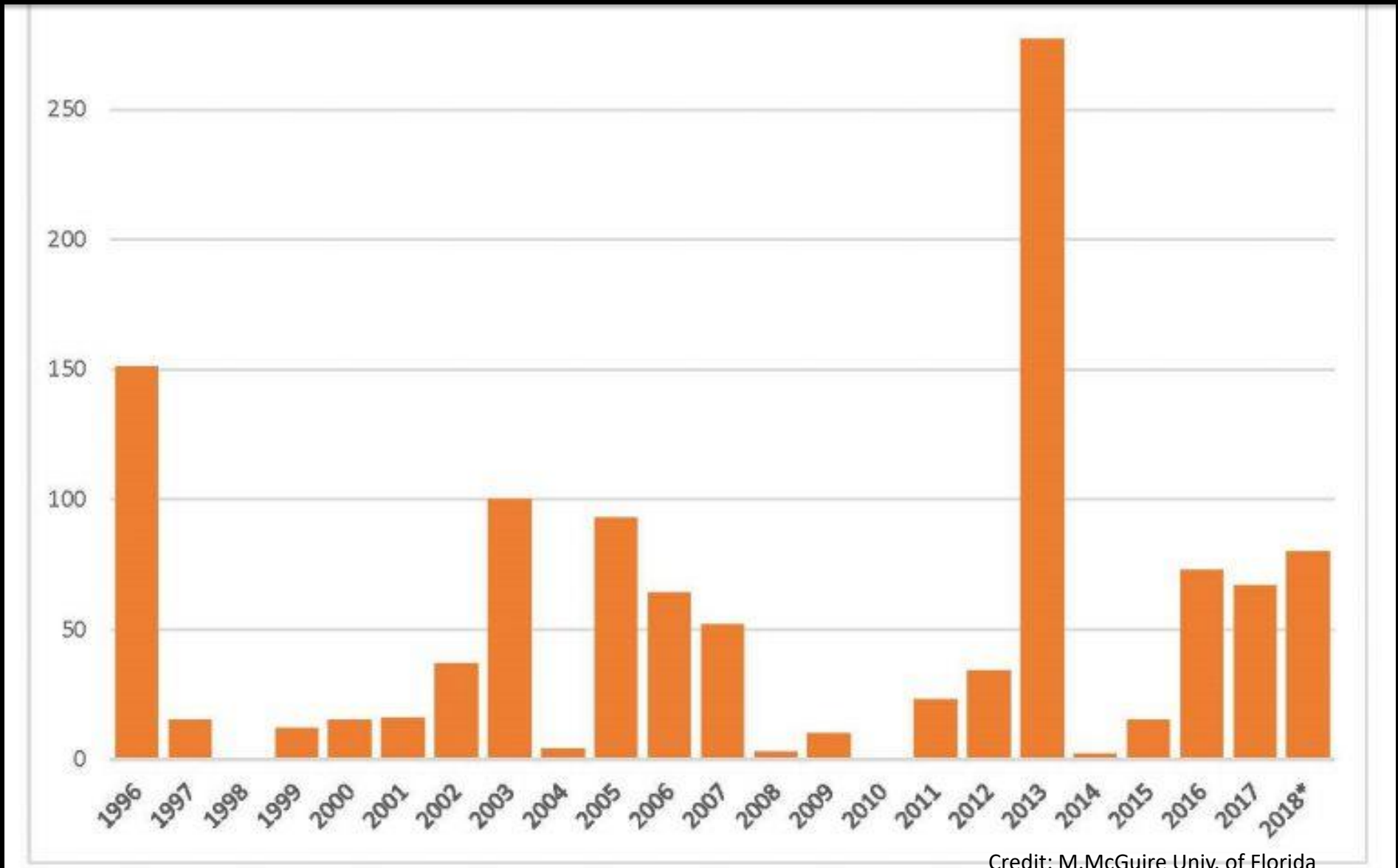


West Florida shelf

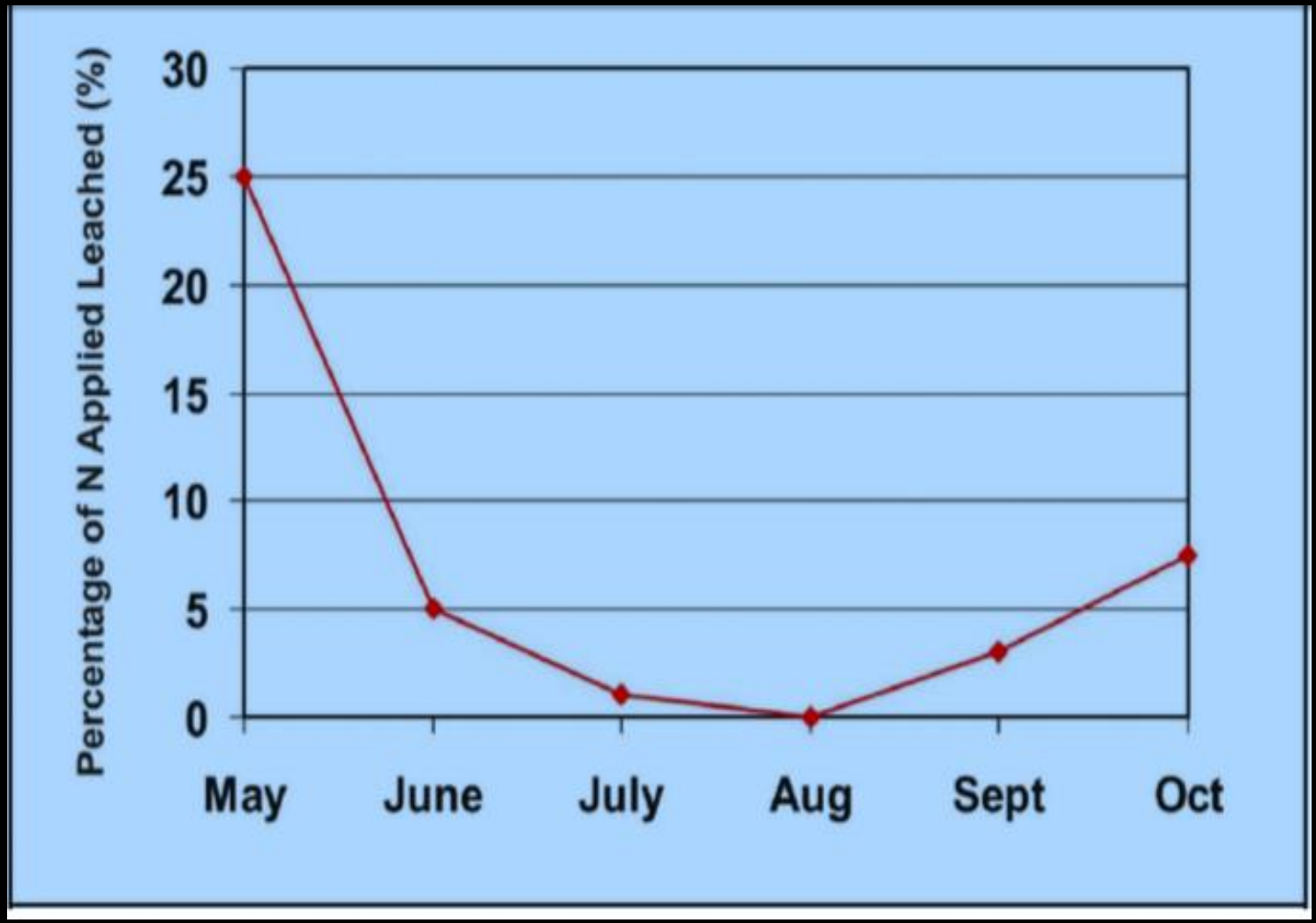
Source: pubs.usgs.gov

Red tide-related Florida manatee deaths 1996 – 7/19/2018



Credit: M.McGuire Univ. of Florida

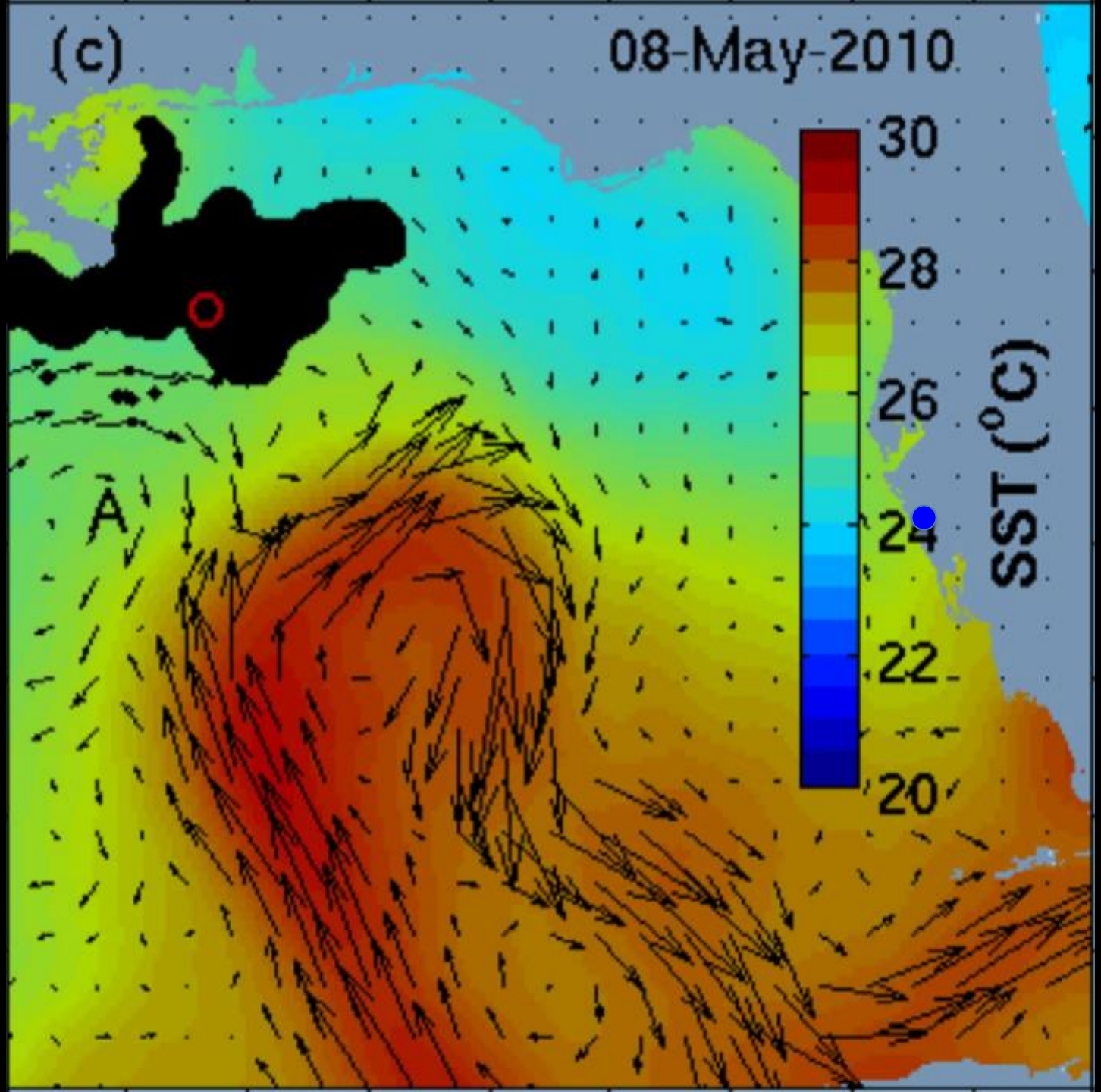
Percent Applied N Leached



Hochmuth *et al*, IFAS , UF, SL283

Temperature re *K. brevis* blooms

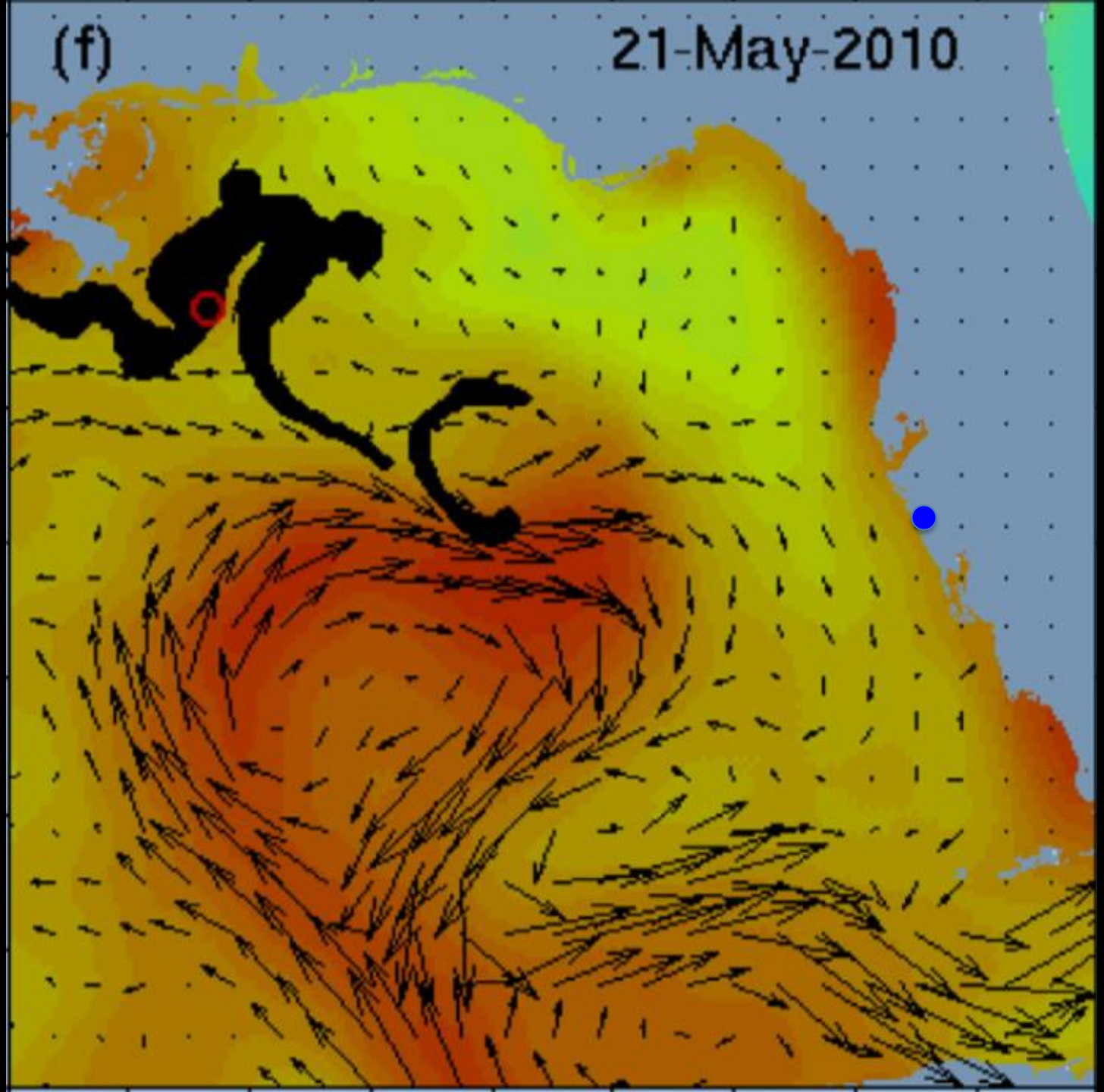
- Scientists have found, in particular, that the kinds of algae and bacteria that can produce toxins or cause disease proliferate greatly compared to other less harmful species when there is an increase in water temperature
- .
- K. Havens, UF/IFAS Extension SGEF216 Feb. 2018
.



Weisberg *et al*, Harrnful Algae 38, (2014) 119-126

Temperature re *K. brevis* blooms

- In 2014, when water temperatures in the Gulf of Mexico were at record highs, the Florida Fish and Wildlife Conservation Commission (FWC) recorded one of the largest red tide blooms ever, just northwest of Tampa. It threatened beaches from Clearwater to Sarasota, yet remained largely offshore due to prevailing winds.
- K. Havens, UF/IFAS Extension SGEF216 Feb. 2018
-



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