Dinoflagellate Toxins and Their Mode of Action

1. Gonyaulacales, Gymnodiniales

2. Dinophysiales, Peridiniales, Prorocentrales

3. Diatoms, Cyanobacteria and Others

Gonyaulacales

Gymnodiniales

Gonyaulacales:

Alexandrium	
andersonii	Paralytic shellfish poisoning toxins (PSP)
catenella	Paralytic shellfish poisoning toxins (PSP)
fundyense	Paralytic shellfish poisoning toxins (PSP)
minutum	Paralytic shellfish poisoning toxins (PSP)
monilatum	Goniodomin-A
ostenfeldii	Spirolide
peruvianum	Paralytic shellfish poisoning toxins (PSP)
pseudogoniaulax	Goniodomin-A
tamarense	Paralytic shellfish poisoning toxins (PSP)
tamiyavanichii	Paralytic shellfish poisoning toxins (PSP)
Gambierdiscus	
australes	Ciguatera fish poisoning toxins (CTX)
pacificus	Ciguatera fish poisoning toxins (CTX)
toxicus	Ciguatera fish poisoning toxins (CTX)
yasumotoi	Ciguatera fish poisoning toxins (CTX)

Gonyaulacales (continuation):

Gonyaulax	
spinifera	Yessotoxins (YTX)
Lingulodinium	
polyedrum	Yessotoxins (YTX)
Protoceratium	
reticulatum	Yessotoxins (YTX)
Pyrodinium	
bahamense	Paralytic shellfish poisoning toxins (PSP)

Gymnodiniales:

Gymnodinium	
catenatum	Paralytic shellfish poisoning toxins (PSP)
Karenia	
brevis	Brevetoxins (PbTx)
mikimotoi	Gymnocin-A
selliformis	Gymnodimine (GYM)

Toxin classes

brevetoxins

ciguatoxins

goniodomin-A

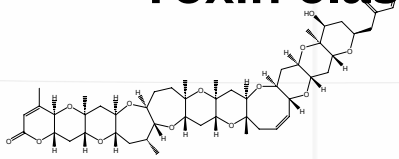
gymnocin-A

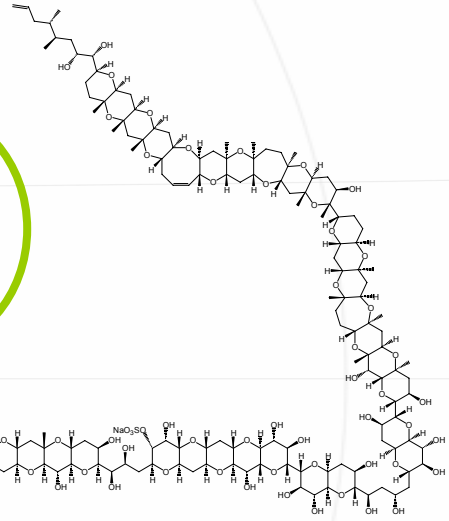
gymnodimine

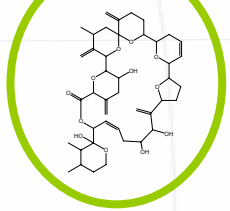
PSP

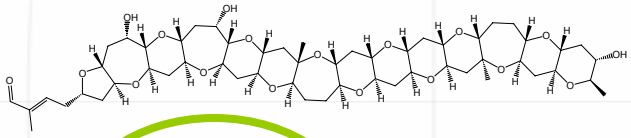
spirolides

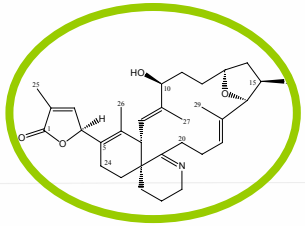
yessotoxins

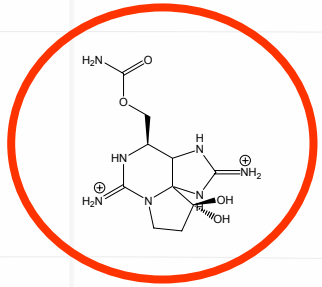


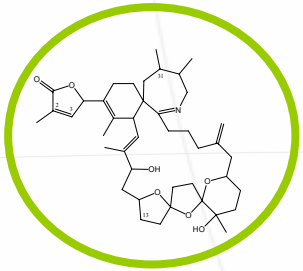






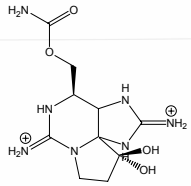




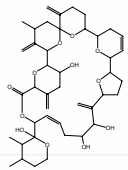


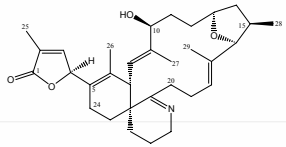
Main Groups of Toxins

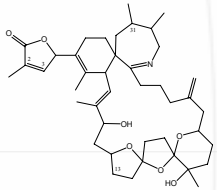
1. Tetrahydropurine derivatives (PSP)



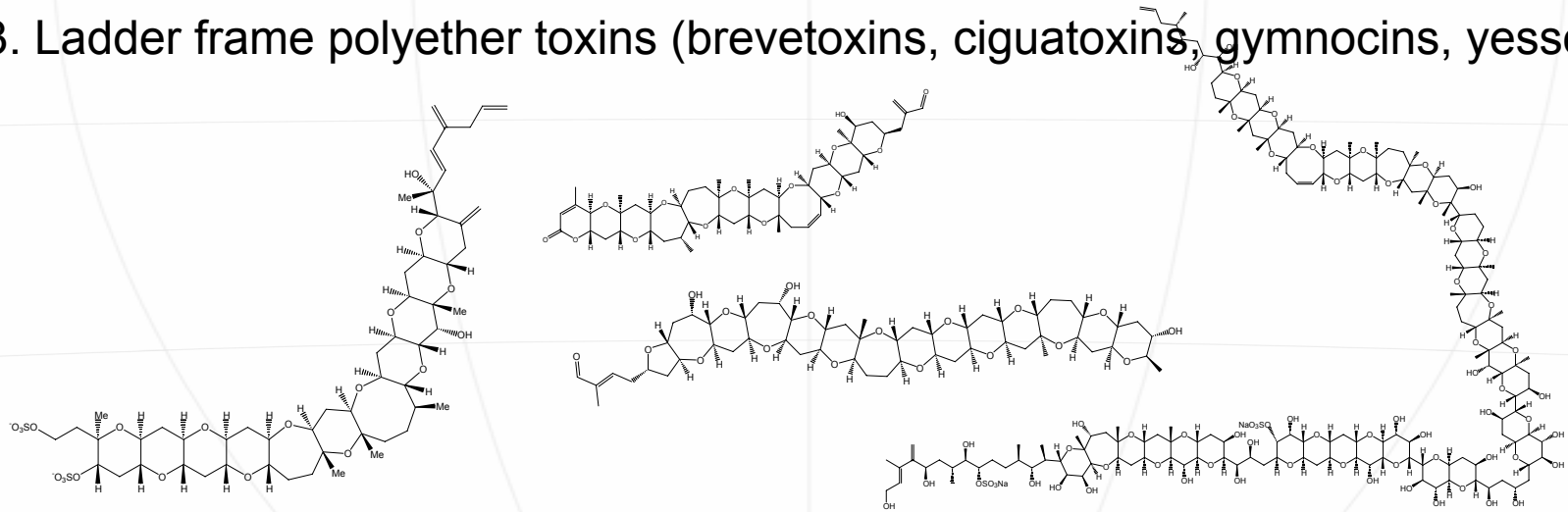
2. Macrolide toxins (goniodomins, gymnodimines, spirolides)



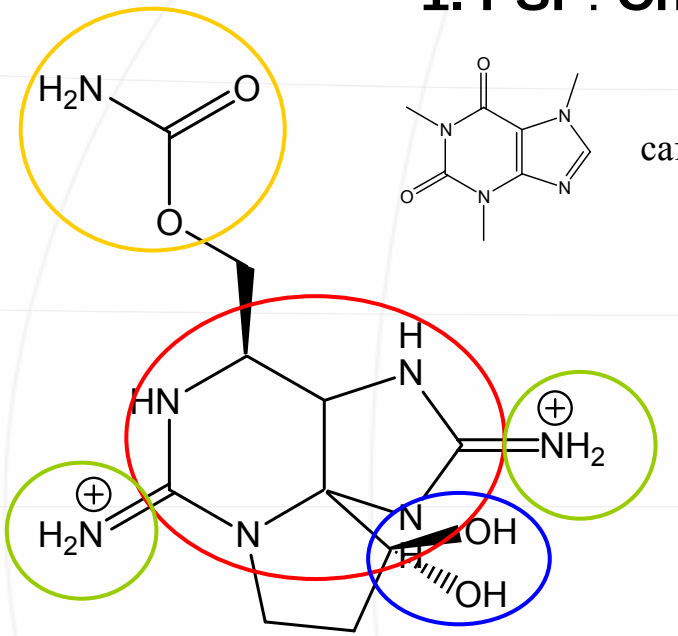




3. Ladder frame polyether toxins (brevetoxins, ciguatoxins, gymnocins, yessotoxins)



1. PSP: Chemical Structures



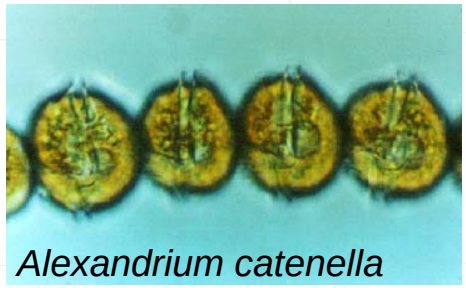
caffeine

Tetrahydropurine

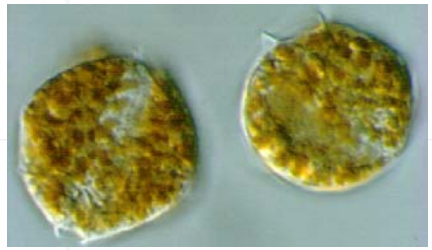
2 imino functions

Acetal moiety

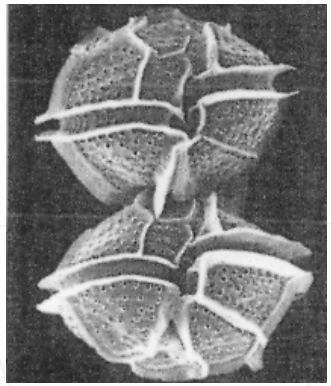
Carbamoyl group



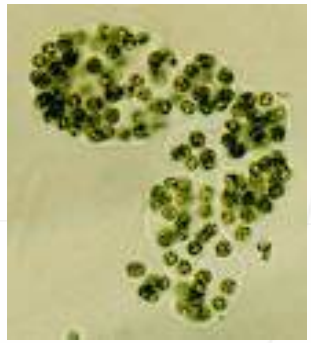
Alexandrium catenella



Alexandrium tamarense



Pyrodinium bahamense



Microcystis aeruginosa

Alexandrium
- *andersonii*
- *catenella*
- *fundyense*
- *minutum*
- *peruvianum*
- *tamarense*
- *tamiyavanichii*

Pyrodinium
- *bahamense*

Gymnodinium
- *catenatum*

Anabaena
- *circinalis*
- *lemmermannii*

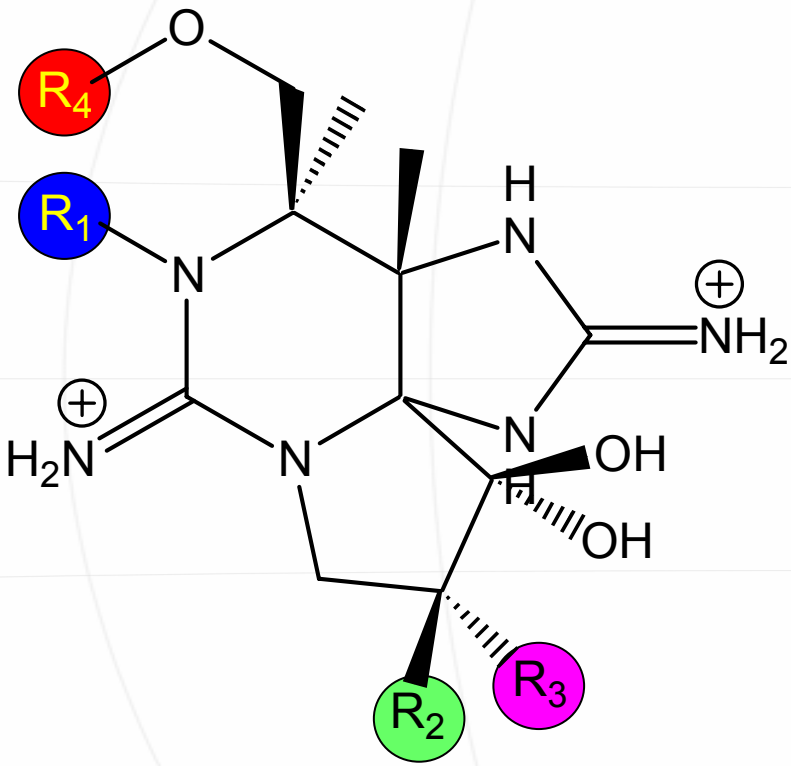
Aphanizomenon
- *flos-aquae*

Cylindrospermopsis
- *raciborskii*

Lyngbya
- *wollei*

Microcystis
- *aeruginosa*

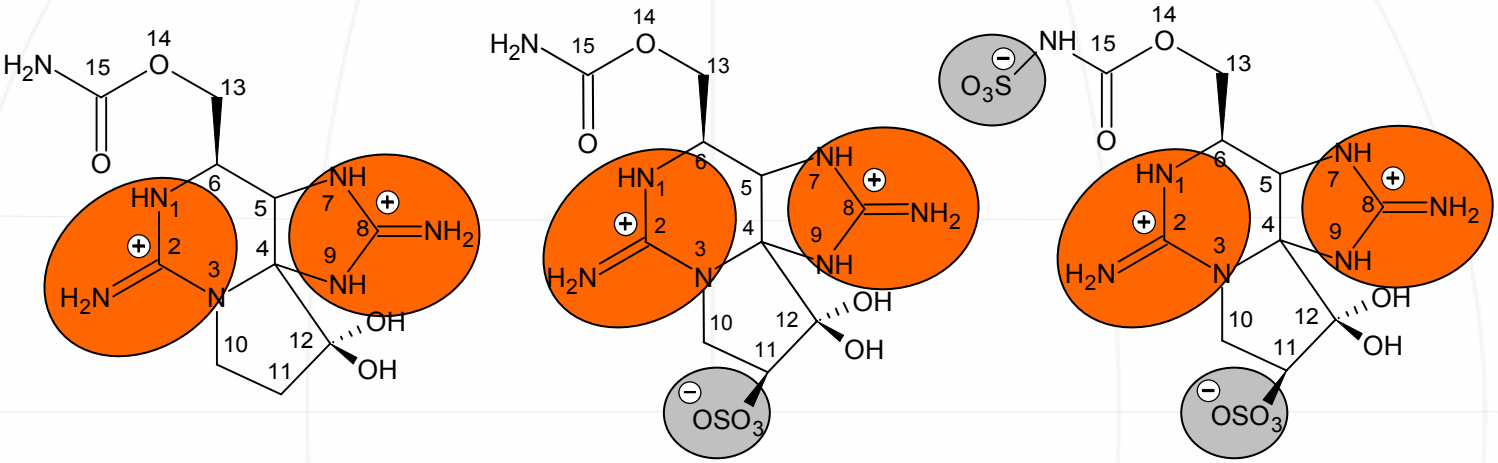
1. PSP: Chemical Structures

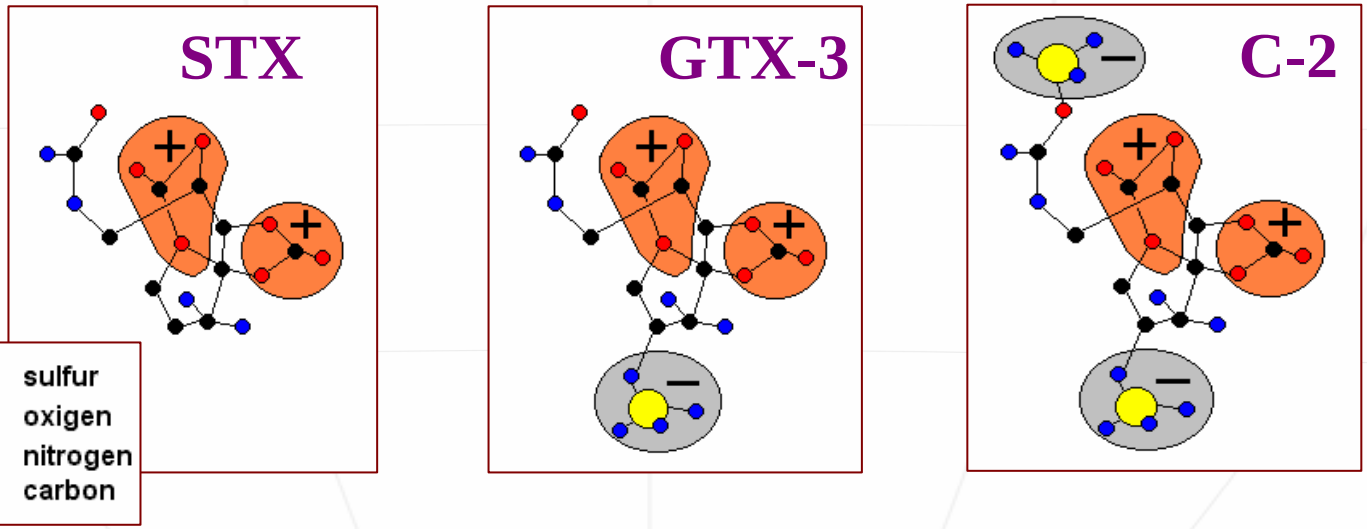


STX = Saxitoxin
NEO = Neosaxitoxin
GTX = Gonyautoxin

Toxin	R1	R2	R3	R4
STX	H	H	H	$CO-NH_2$ (Carbamoyl-)
NEO	OH	H	H	
GTX1	OH	H	OSO_3^-	
GTX2	H	H	OSO_3^-	
GTX3	H	OSO_3^-	H	
GTX4	OH	OSO_3^-	H	
B1= GTX5	H	H	H	$CO-NH-SO_3^-$ (N-Sulfocarbamoyl-)
B2= GTX6	OH	H	H	
C3	OH	H	OSO_3^-	
C1	H	H	OSO_3^-	
C2	H	OSO_3^-	H	
C4	OH	OSO_3^-	H	
dc-STX	H	H	H	H (Decarbamoyl-)
dc-NEO	OH	H	H	
dc-GTX1	OH	H	OSO_3^-	
dc-GTX2	H	H	OSO_3^-	
dc-GTX3	H	OSO_3^-	H	
dc-GTX4	OH	OSO_3^-	H	

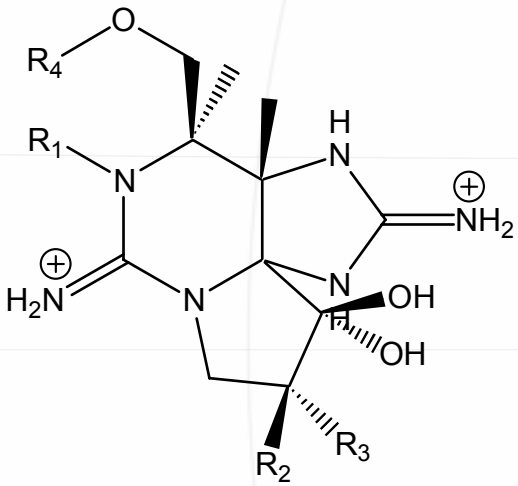
1. PSP: Charges and Toxicity





1. PSP: Charges and Toxicity

LD_{50}(STX): 8 µg/kg



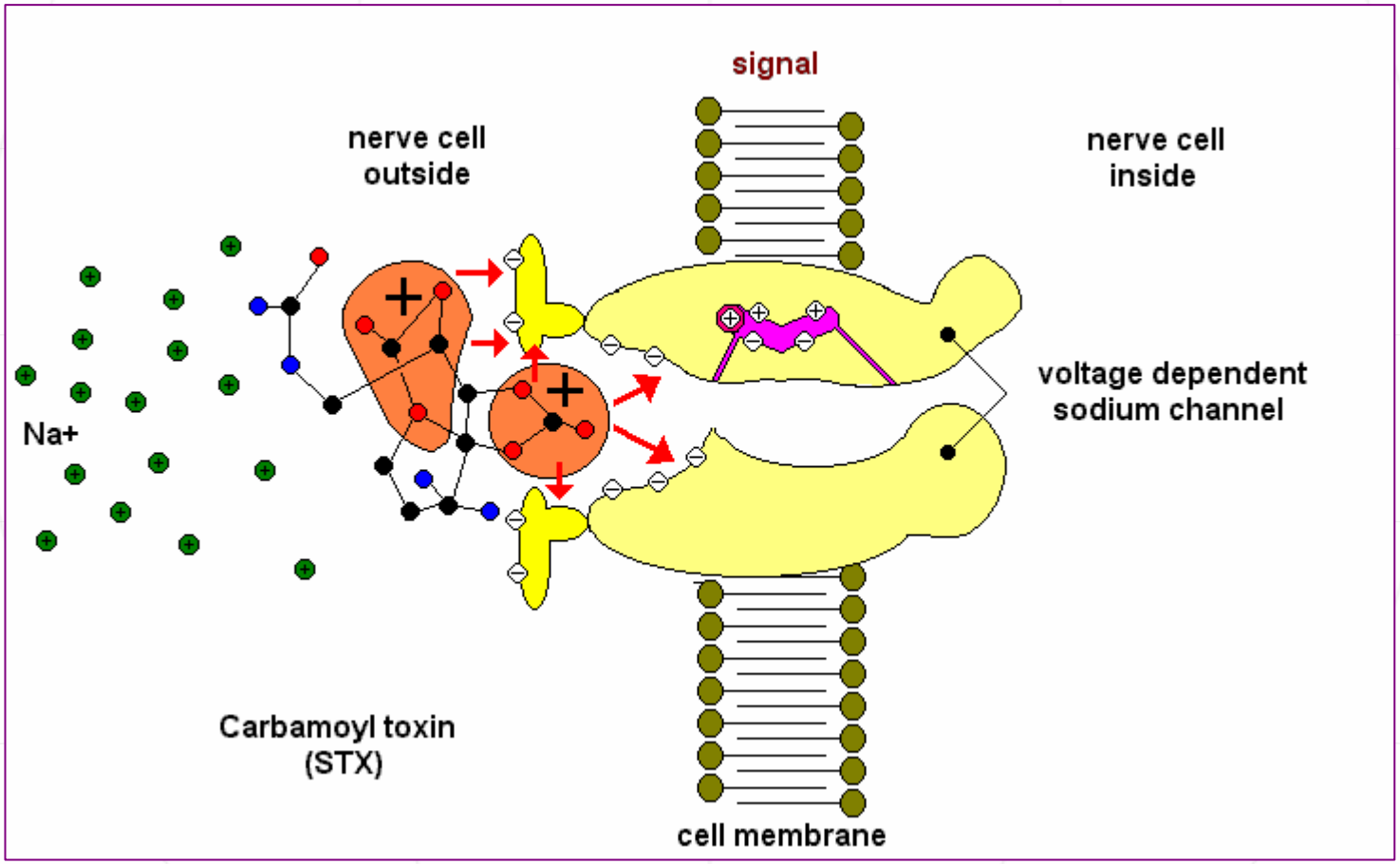
Double charged PSP-toxins (no sulfonyl group)

Single charged PSP-toxins (1 sulfonyl group)

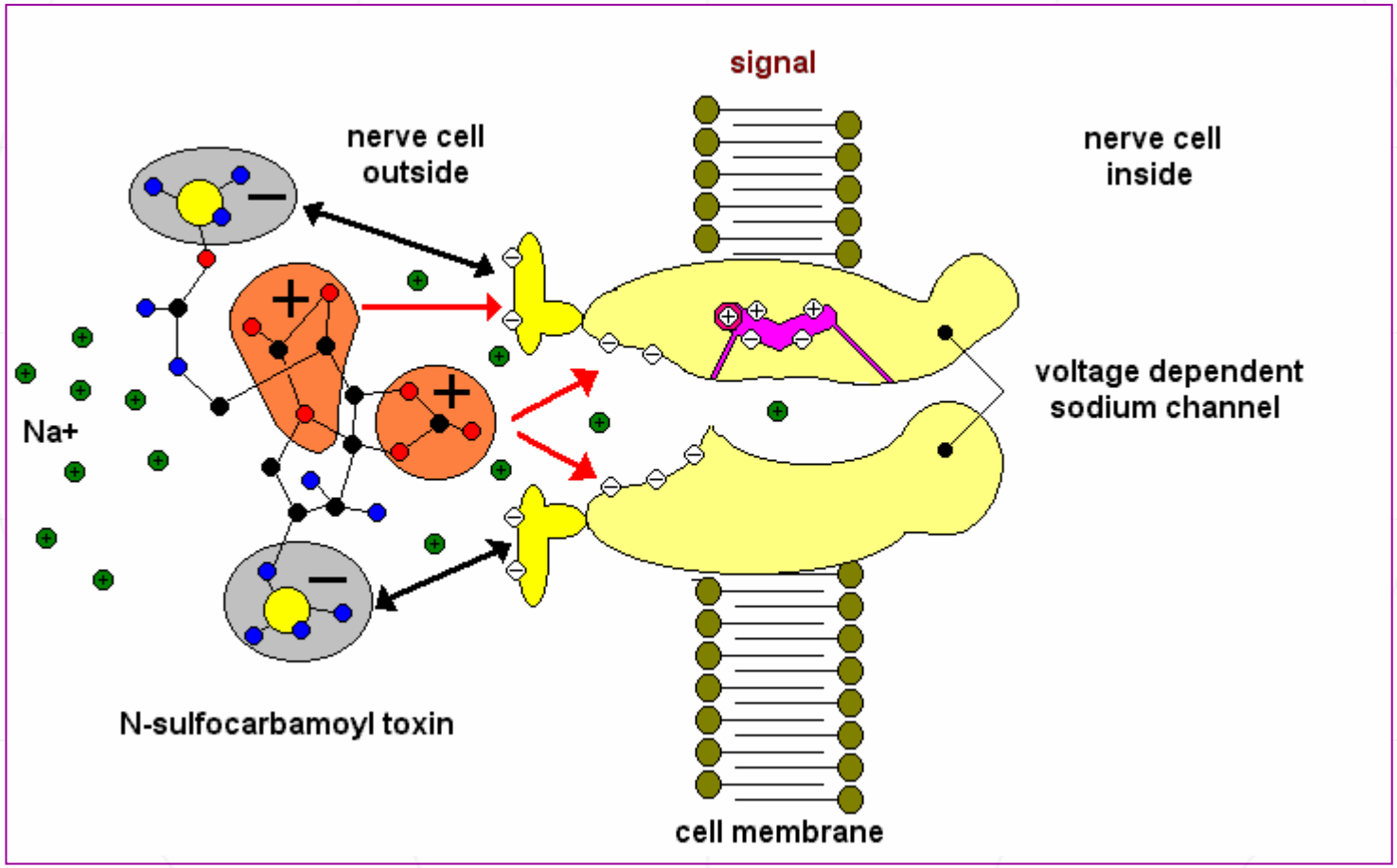
Neutral PSP-toxins (1 sulfonyl & 1 sulfate group)

Toxin	Toxicity factor
STX	1,00
NEO	1,10
GTX1	0,90
GTX2	0,48
GTX3	0,76
GTX4	0,90
B1= GTX5	0,07
B2= GTX6	0,07
C3	<0,01
C1	0,01
C2	-
C4	-
dc-STX	0,43
dc-NEO	0,43
dc-GTX1	0,45
dc-GTX2	0,18
dc-GTX3	0,18
dc-GTX4	0,45

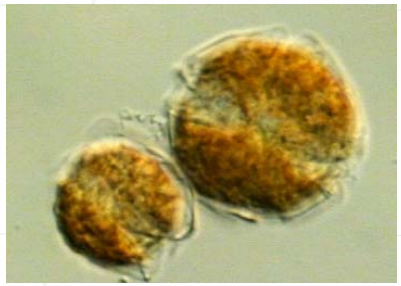
1. PSP: Charges and Toxicity



1. PSP: Charges and Toxicity

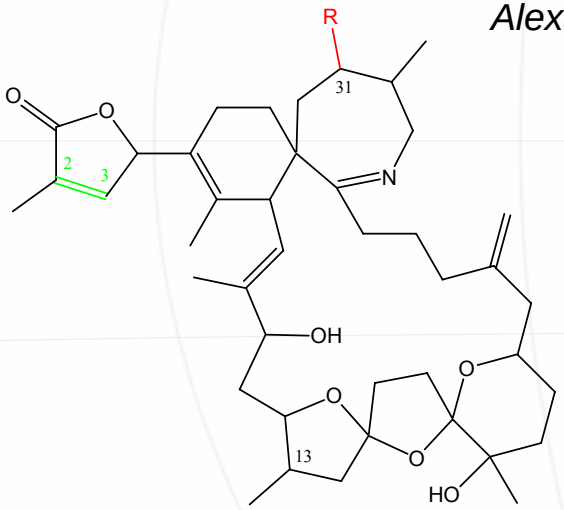


2. Macrolides: Spirolides – Chemical Structures

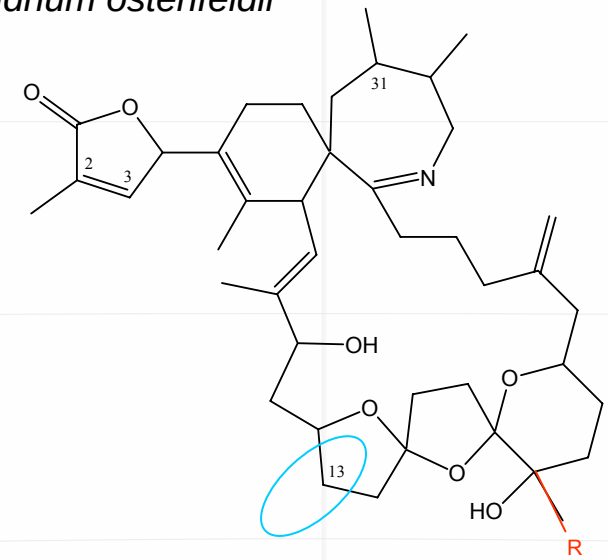


Alexandrium ostenfeldii

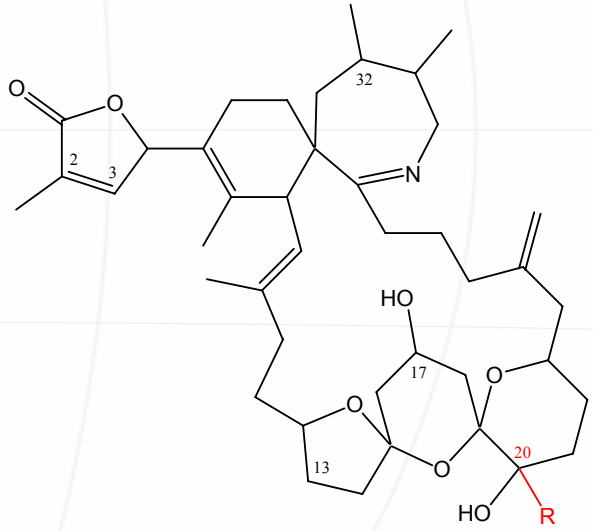
Alexandrium ostenfeldii



Spirolide A: R = H, $\Delta^{2,3}$
B: R = H
C: R = Me, $\Delta^{2,3}$
D: R = Me

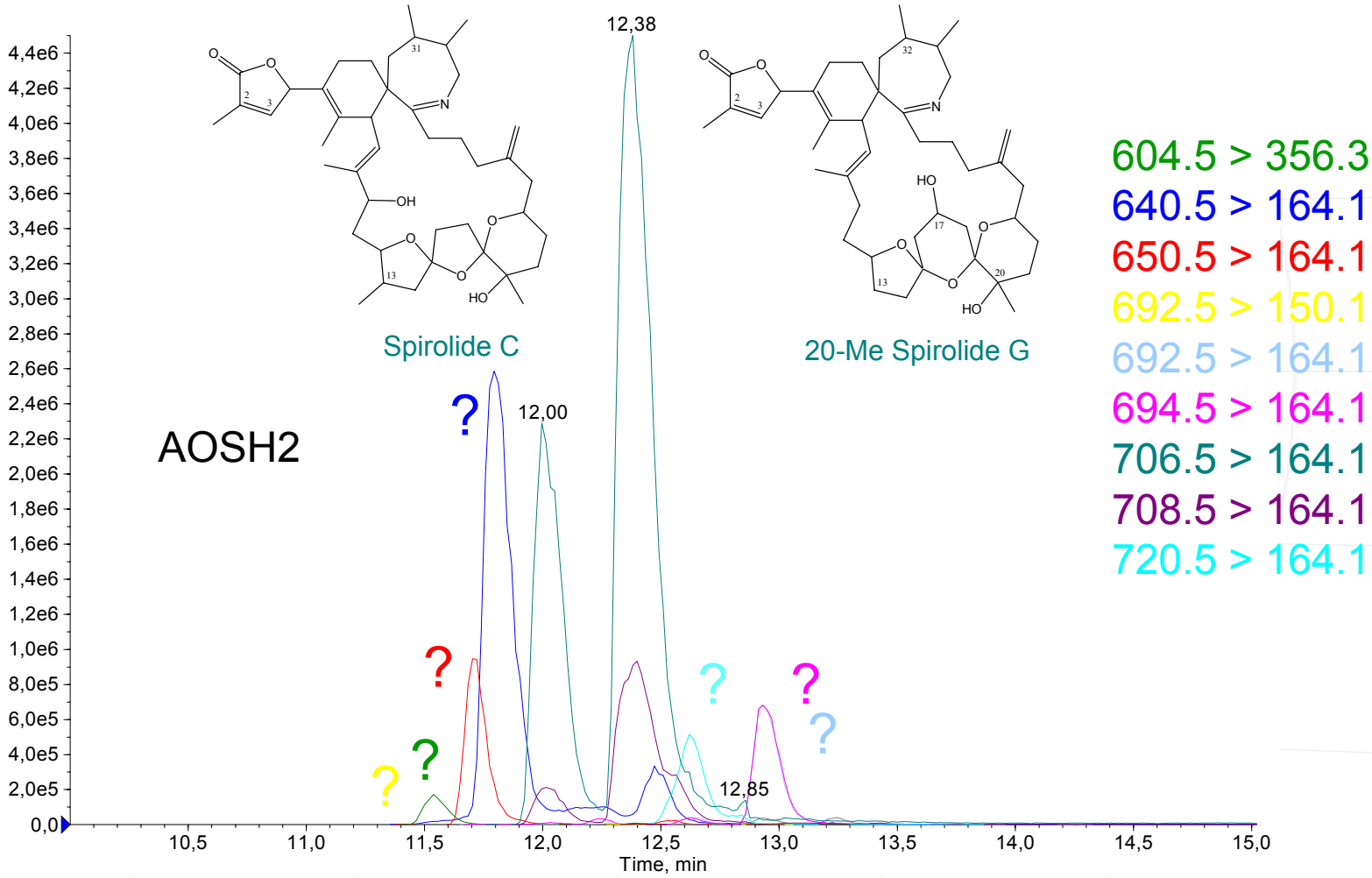


13-DesMe Spirolide C: R = Me
13,19-DidesMe Spirolide C: R = H



Spirolide G: R = H
20-Me Spirolide G: R = Me

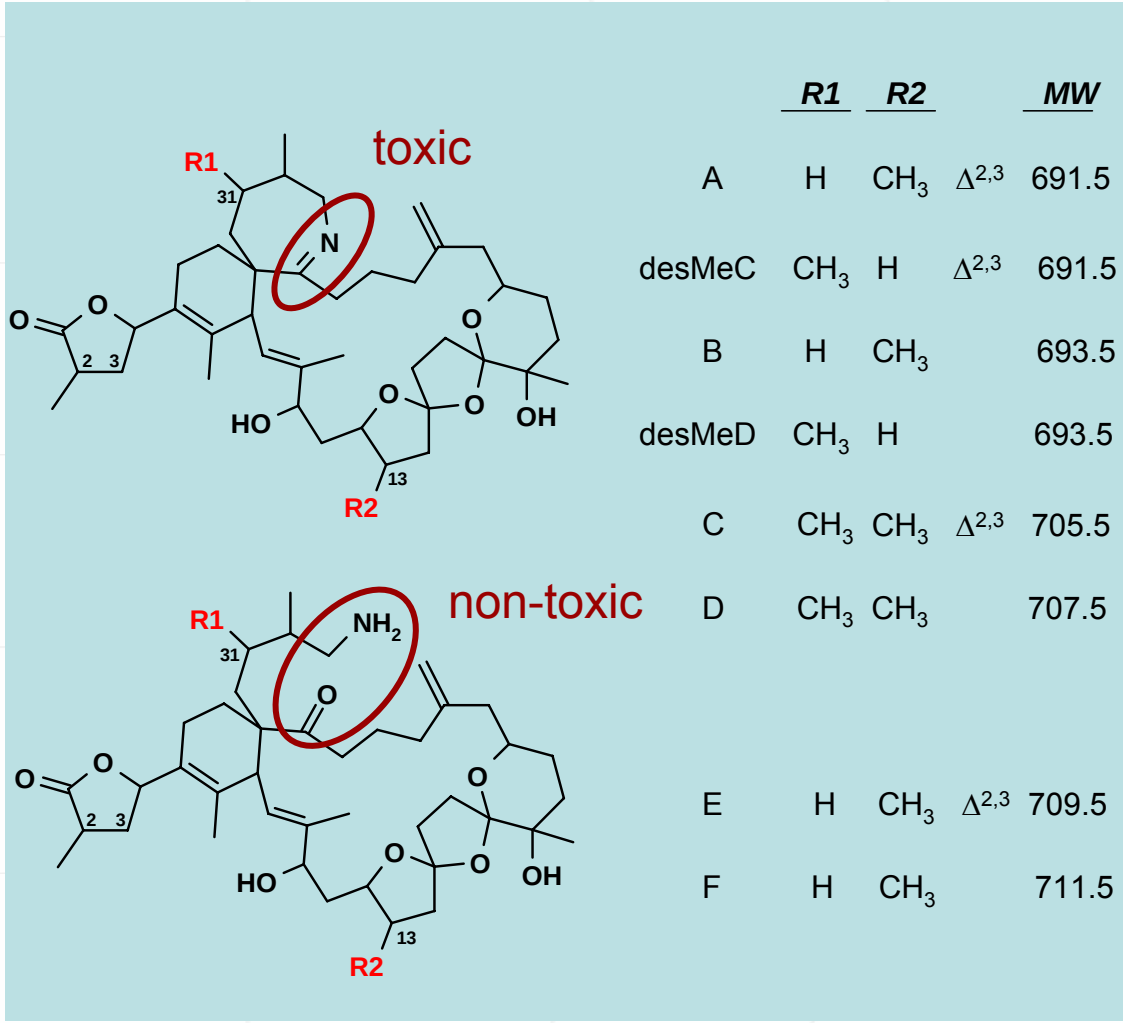
2. Macrolides: Spirolides – Chemical Structures



2. Macrolides: Spirolides – Cause of "Fast Acting Toxicity"

Novel compounds identified as "spirolides"

- macrocyclic imines
- structural similarity to pinnatoxin & gymnodimine
- pharmacologically active/inactive forms



	R1	R2		MW
A	H	CH_3	$\Delta^{2,3}$	691.5
desMeC	CH_3	H	$\Delta^{2,3}$	691.5
B	H	CH_3		693.5
desMeD	CH_3	H		693.5
C	CH_3	CH_3	$\Delta^{2,3}$	705.5
D	CH_3	CH_3		707.5
E	H	CH_3	$\Delta^{2,3}$	709.5
F	H	CH_3		711.5

2. Macrolides: Spirolides –Toxicity & Mode of Action

Toxicity:

40 µg/kg in mice (ip)
Oral toxicity: 1 mg/kg

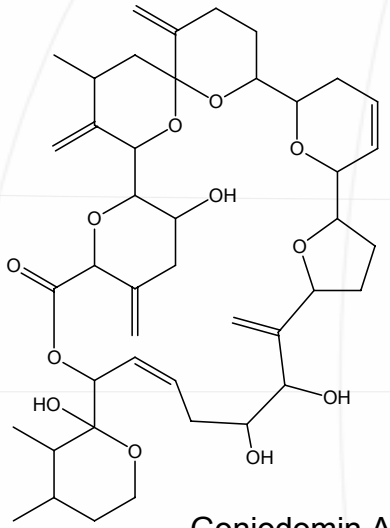
Mode of Action:

anticholinergic activity by blocking of muscarinic acetylcholin receptors

=> Paralysis of the parasympathetic nervous system

(few toxicological studies)

2. Macrolides: Gondiodomin



Goniodomin A

Alexandrium monilatum

Alexandrium
monilatum
pseudogoniaulax

Toxicity:

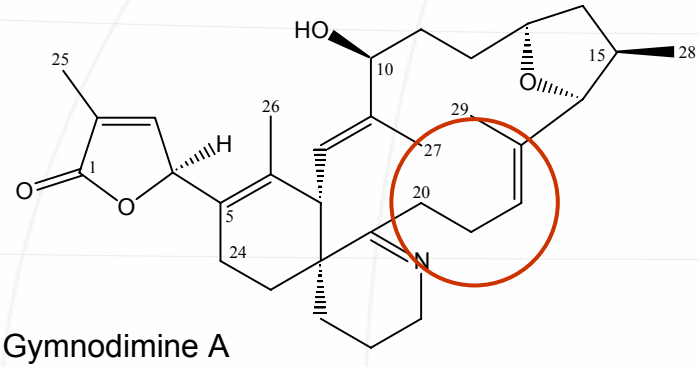
unknown

Mode of Action:

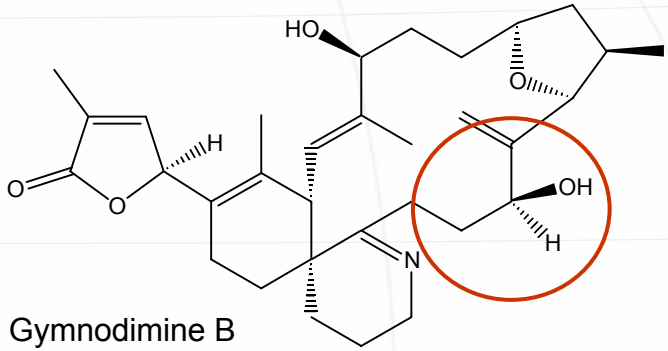
conformational change of actin leads to actomyosin ATPase activity

hemolytic, cytotoxic; mechanism unknown (few toxicological studies)

2. Macrolides: Gymnodimines



Gymnodimine A



Gymnodimine B

Toxicity:

Karenia selliformis

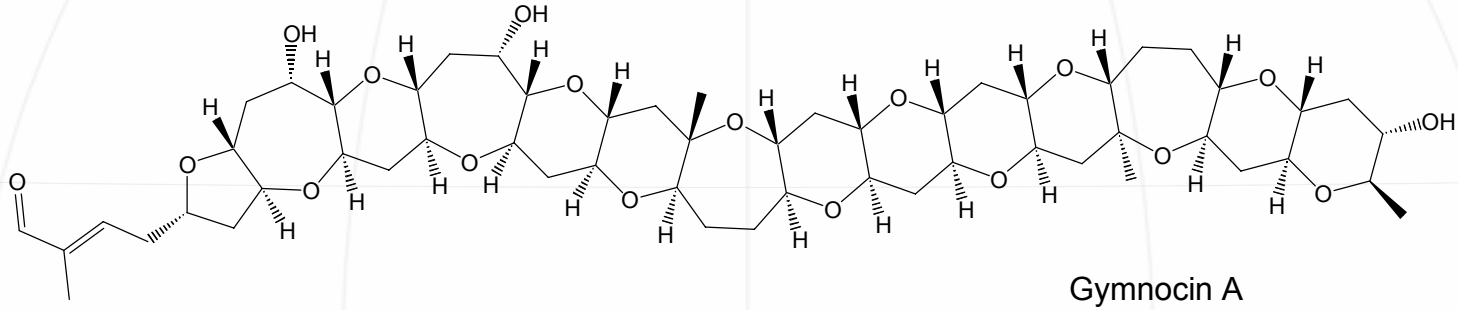
LD_{50} (ip) in mice: 96µg/kg

Mode of Action:

Competitive blocker of muscarinic receptors (similiar toxic effect as spirolides)

The potency to activate Na channels is much weaker than that of brevetoxins.

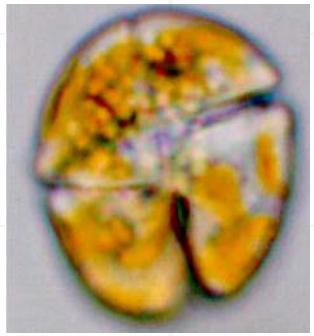
3. Ladder Frame Polyether Compounds: Gymnocin



Gymnocin A

Toxicity:

unknown



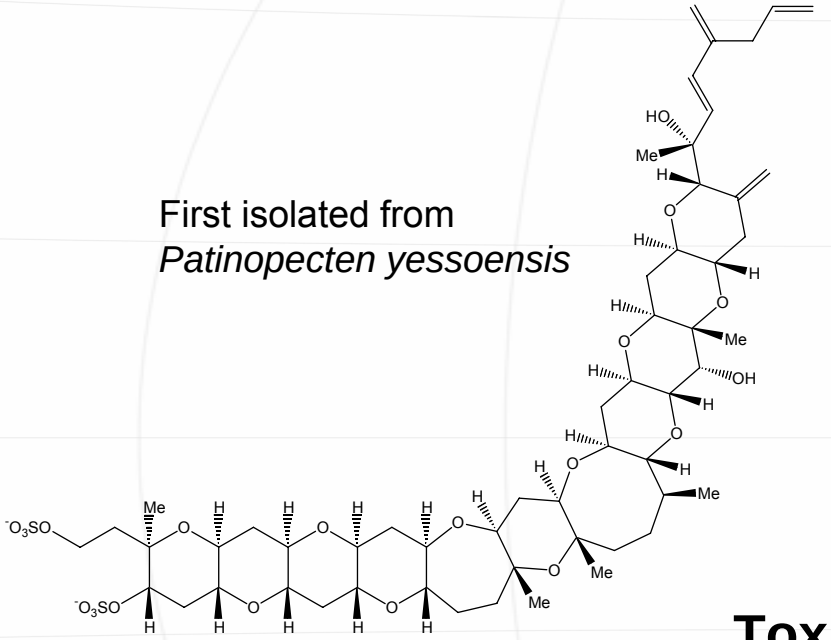
Karenia mikimotoi

Mode of Action:

mechanism unknown, cytotoxic, low ichthyotoxicity (even though *Karenia mikimotoi* blooms are extremely ichthyotoxic)

3. Ladder Frame Polyether Compounds: Yessotoxins

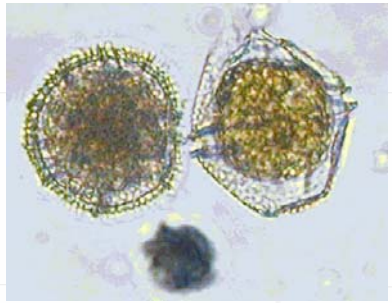
First isolated from
Patinopecten yessoensis



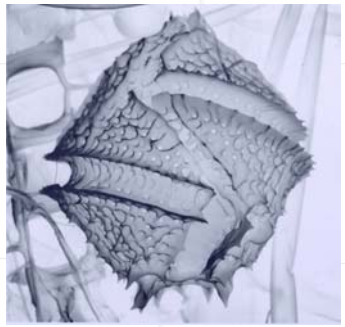
Yessotoxin

Protoceratium reticulatum

Gonyaulax
spinifera
Lingulodinium
polyedrum
Protoceratium
reticulatum



Lingulodinium polyedrum



Gonyaulax spinifera

Toxicity:

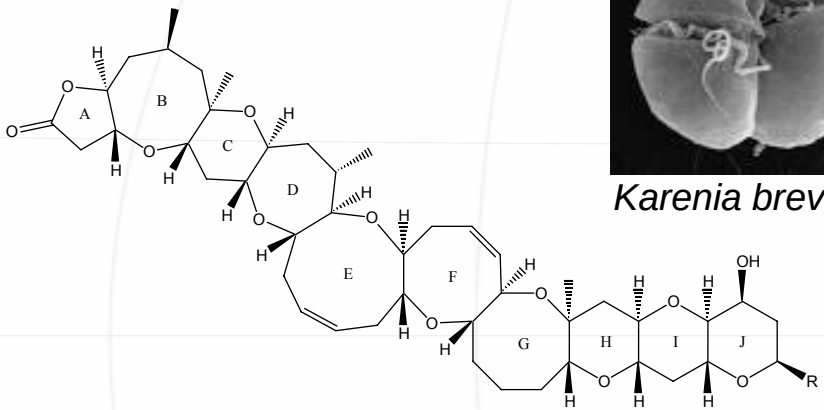
LD_{50} (ip): 286 µg/kg (mice)
LD_{50} (oral): > 54 mg/kg

Mode of Action:

mechanism unknown, no oral toxicity, not diarrheagenic, neurotoxic, causes cytological damage in the neuronal cell body

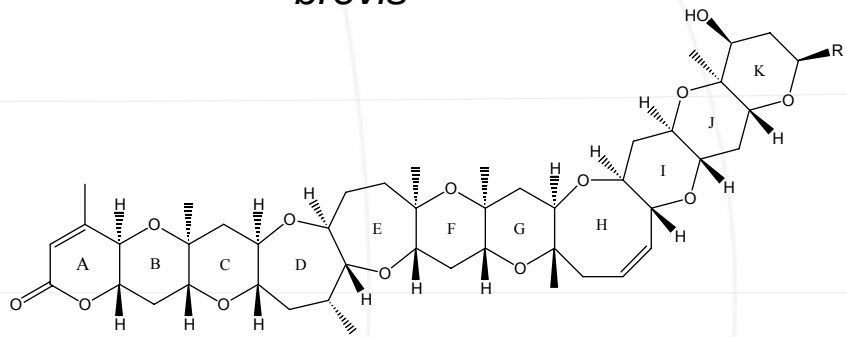
3. Ladder Frame Polyether Compounds: Brevetoxins – Structures

Karenia brevis



A-type brevetoxin skeleton

Karenia brevis



B-type brevetoxin skeleton

PbTx-1: R = $CH_2C(=CH_2)CHO$
PbTx-7: R = $CH_2C(=CH_2)CH_2OH$
PbTx-10: R = $CH_2CH(CH_3)CH_2OH$

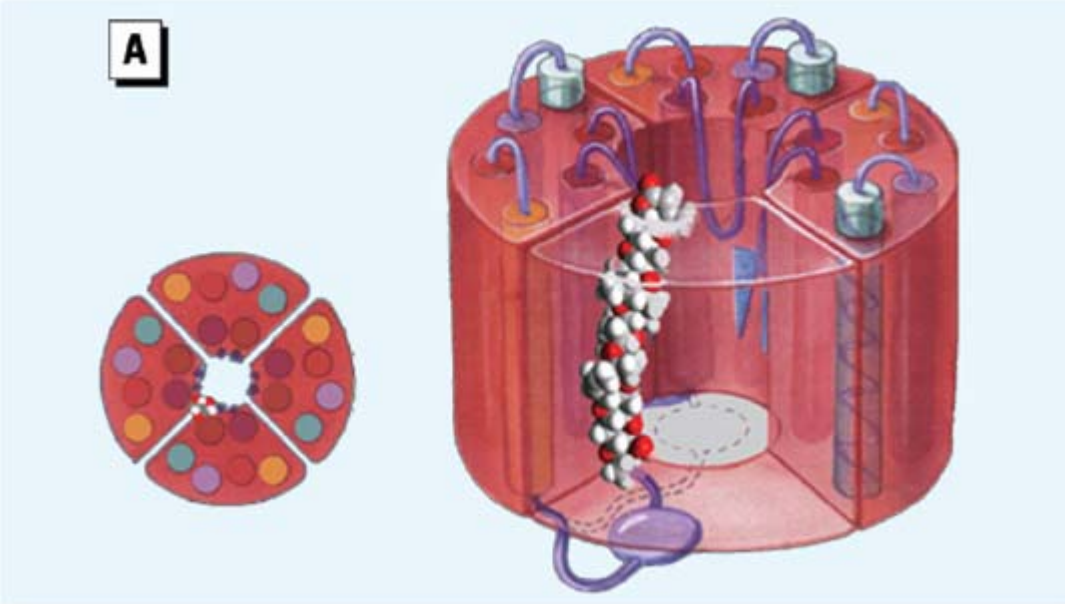
Karenia brevis was formely named *Ptychodiscus brevis*

PbTx-2: R = $CH_2C(=CH_2)CHO$
PbTx-3: R = $CH_2C(=CH_2)CH_2OH$
PbTx-5: K-Ring acetate
PbTx-6: H-Ring epoxide
PbTx-8: CH_2COCH_2Cl
PbTx-9: R = $CH_2CH(CH_3)CH_2OH$

3. Ladder Frame Polyether Compounds: Brevetoxins – Toxicity & Mode of Action

Toxicity:

LD_{50} PbTx-1: 180 mg/kg (mice)



Baden et al (2005): Environmental Health Perspectives 113(5), 621-625

Mode of Action:

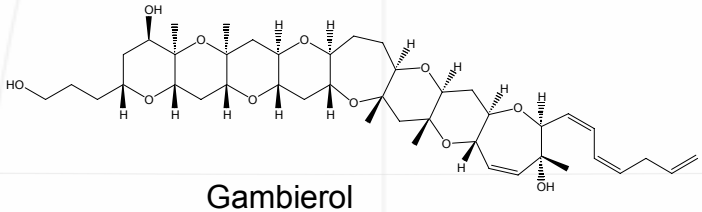
Bind on site 5 of the α-subunit of voltage sensitive sodium channels

Na channel activaters, repetitive neuronal firing until exhaustion of the nerve cell

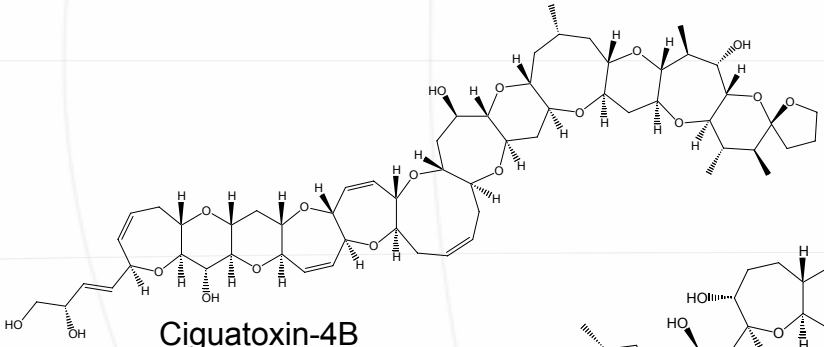
3. Ladder Frame Polyether Compounds: Ciguatoxins

Gambierdiscus toxicus

Gamberdiscus spp.

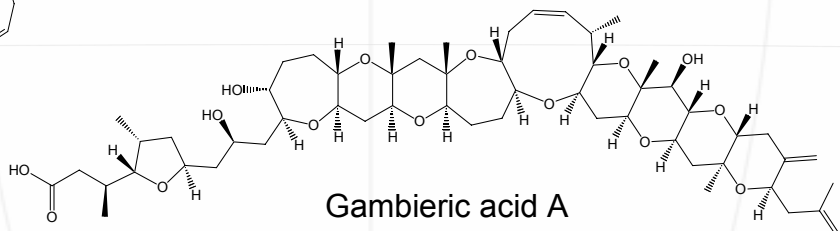


Gambierol

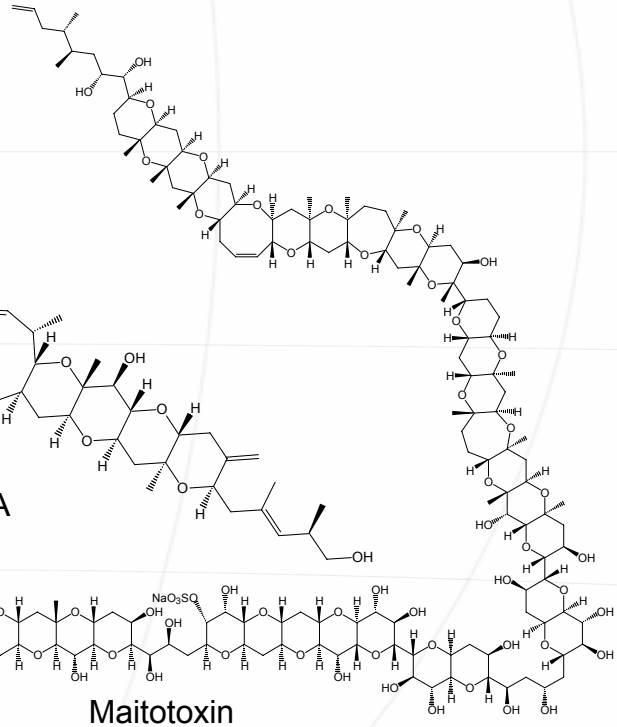


Ciguatoxin-4B

Named after Cigua
(caribbean snail)



Gambieric acid A



Maitotoxin

3. Ladder Frame Polyether Compounds: Ciguatoxins

Toxicity:

LD_{50} CTX-1:	0.25 µg/kg (mice)
LD_{50} MTX-1:	0.05 µg/kg (mice)
LD_{50} Gambierol:	50 µg/kg (mice)
LD_{50} Gambieric acid A:	> 1000 µg/kg (mice)

Mode of Action:

Same as Brevetoxins: Na channel activaters;
additionally block voltage gated potassium channels, prolongation of the duration of presynaptic action potentials, enhancing neurotransmitter release => strong convulsions

Dinophysiales

Peridiniales

Prorocentrales

Dinophysiales:

Dinophysis	
acuminata	Dinophysistoxins (DTX), Pectenotoxins (PTX)
acuta	Dinophysistoxins (DTX), Pectenotoxins (PTX)
caudata	Dinophysistoxins (DTX), Pectenotoxins (PTX)
fortii	Pectenotoxins (PTX)
miles	Dinophysistoxins (DTX)
mitra	Dinophysistoxins (DTX)
norvegica	Dinophysistoxins (DTX), Pectenotoxins (PTX)
rapa	Dinophysistoxins (DTX)
rotundata	Pectenotoxins (PTX)
sacculus	Dinophysistoxins (DTX)
tripos	Dinophysistoxins (DTX)

Peridiniales:

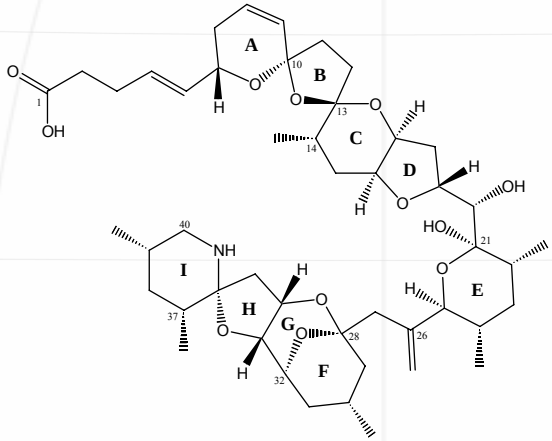
Heterocapsa	
circularisquama	Mussel toxins
Protoperidinium	
crassipes	Azaspiracids (AZA), Pectenotoxins (PTX)

Prorocentrales:

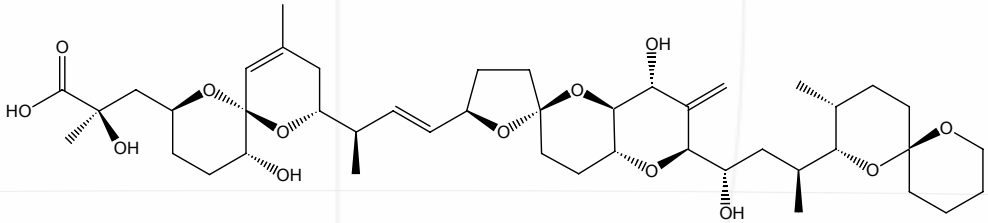
Prorocentrum	
arenarium	Dinophysistoxins (DTX)
belizeanum	Dinophysistoxins (DTX)
cassubicum	Dinophysistoxins (DTX)
faustiae	Dinophysistoxins (DTX)
hoffmannianum	Dinophysistoxins (DTX)
lima	Dinophysistoxins (DTX)
maculosum	Dinophysistoxins (DTX)

Toxin classes

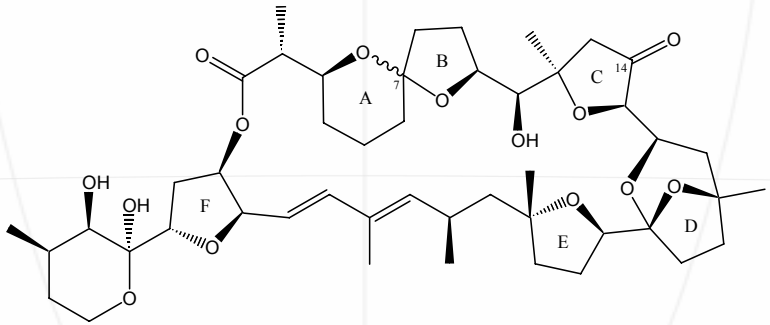
1. Azaspiracids



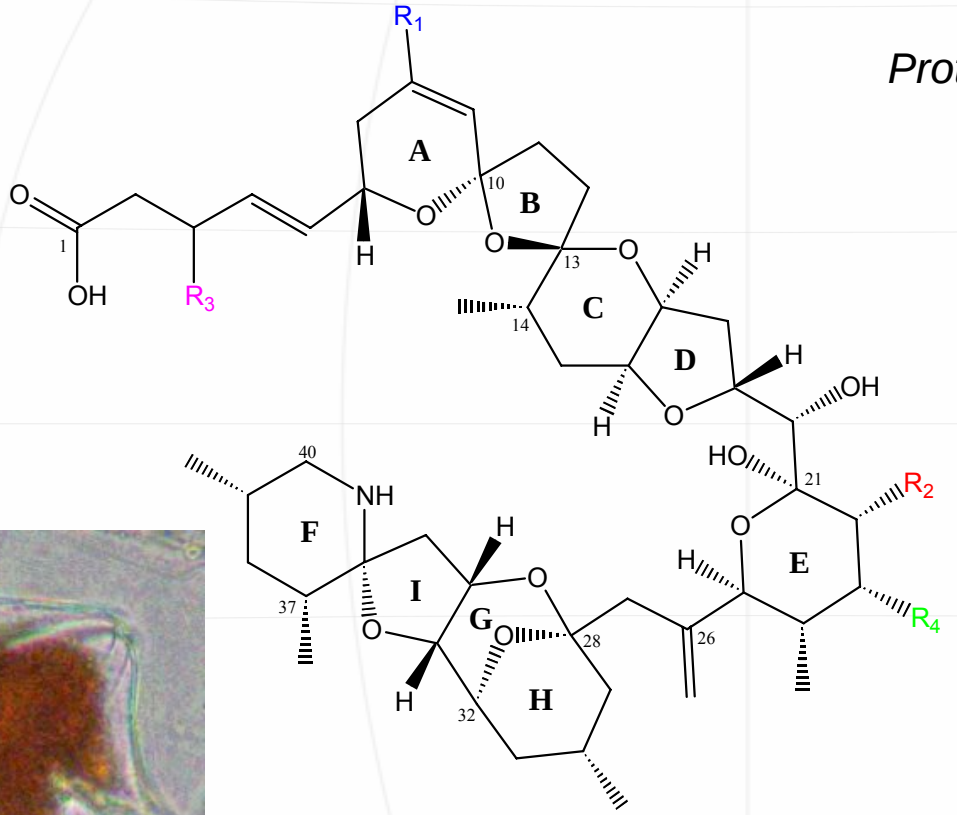
2. Dinophysistoxins



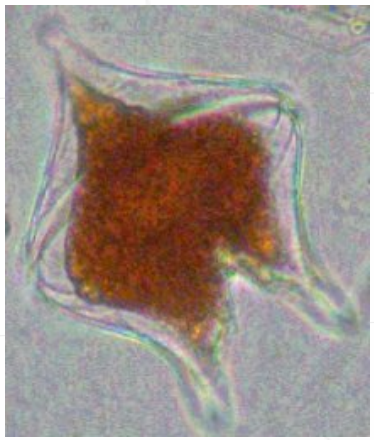
3. Pectenotoxins



1. Azaspiracids – Structures



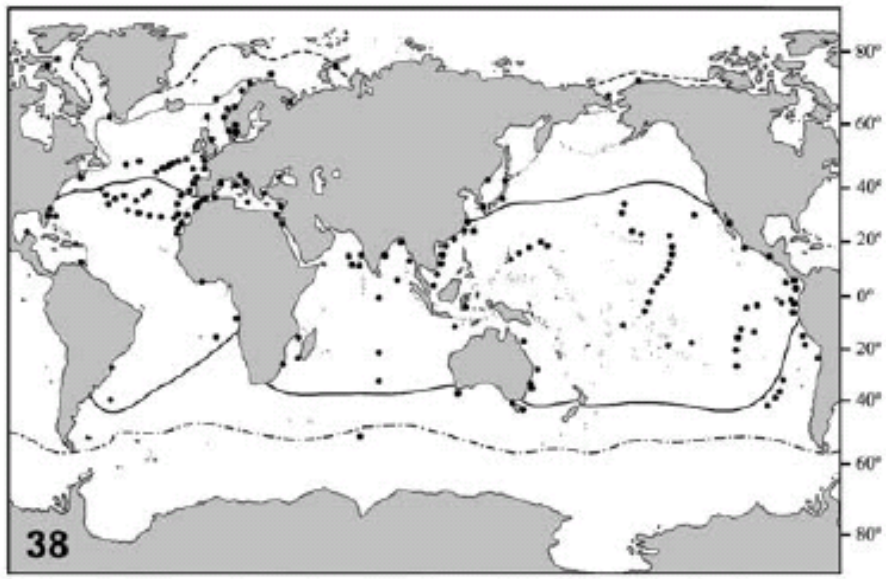
Protoperidinium crassipes



Protoperidinium crassipes

Toxin	R_1	R_2	R_3	R_4
AZA-1	H	CH_3	H	H
AZA-2	CH_3	CH_3	H	H
AZA-3	H	H	H	H
AZA-4	H	H	OH	H
AZA-5	H	H	H	OH
AZA-6	CH_3	H	H	H
AZA-7	H	CH_3	OH	H
AZA-8	H	CH_3	H	OH
AZA-9	CH_3	H	OH	H
AZA-10	CH_3	H	H	OH

1. Azaspiracids – Structures



Distribution of *P. crassipes*

1. Azaspiracids – Toxicity and Mode of Action

Toxicity:

LD_{50} AZA-1: 0.2 µg/kg (mice)

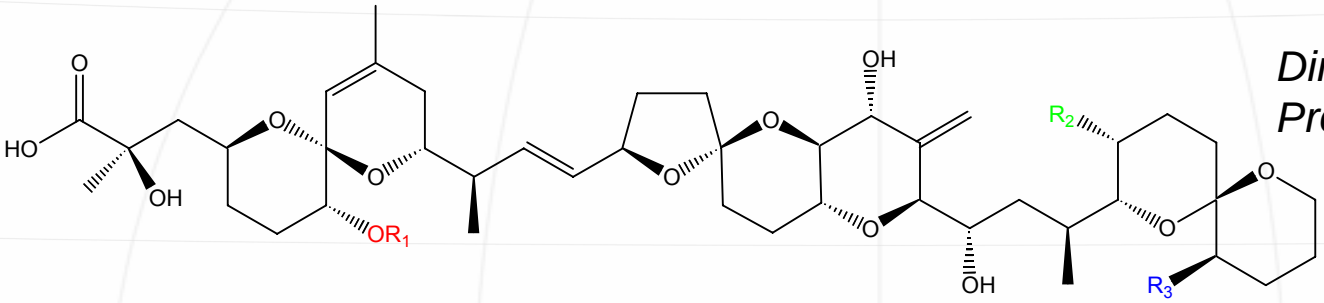
Mode of Action:

effects of AZA-1 on the arrangement of F-actin
⇒concurrent loss of pseudopodia, cytoplasmic extensions that function in mobility and chemotaxis; effects on cytoskeleton

Increases cytosolic calcium levels in lymphocytes

diarrheagenic, tumorigenic

2. Dinophysistoxins – Structures



Dinophysis spp.
Prorocentrum spp.

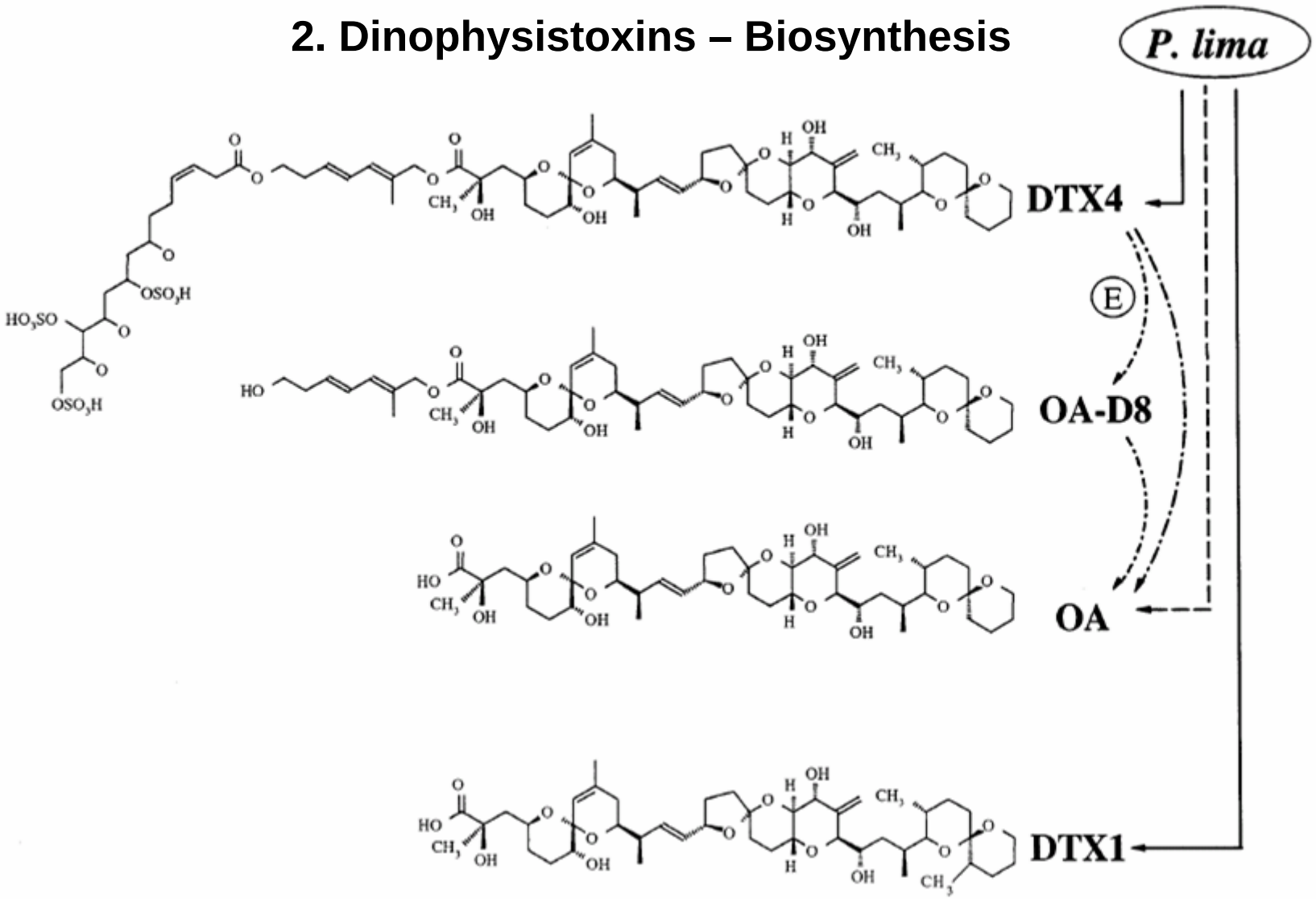
	R1	R2	R3
OA	H	CH_3	H
DTX1	H	CH_3	CH_3
DTX2	H	H	CH_3
DTX3	CH_3CO	CH_3	CH_3
Acyl-OA	CH_3CO	CH_3	H

Dinophysis acuminata

Prorocentrum lima

OA: Okadaic acid (first isolated from the sponge *Halichondria okadaii*)

2. Dinophysistoxins – Biosynthesis



Pan, Y. et al. Marine Biology (1999) 134: 541-549

2. Dinophysistoxins – Toxicity & Mode of Action

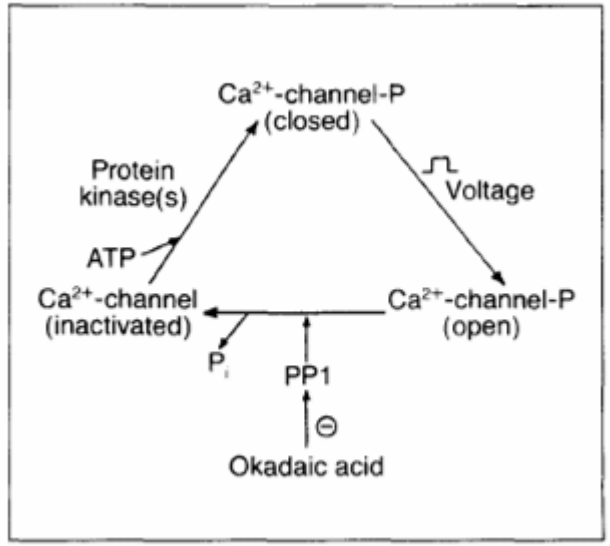
Toxicity:

LD_{50} OA: 192 µg/kg (mice)

Mode of Action:

specific inhibitor of protein phosphatases 1 and 2a (inhibition of dephosphorylation of serine and threonine) => Long lasting contractions of smooth muscles

diarrheagenic, tumorigenic

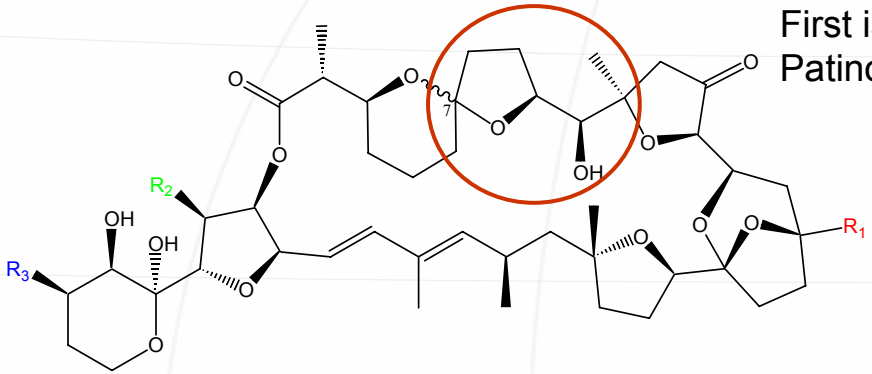


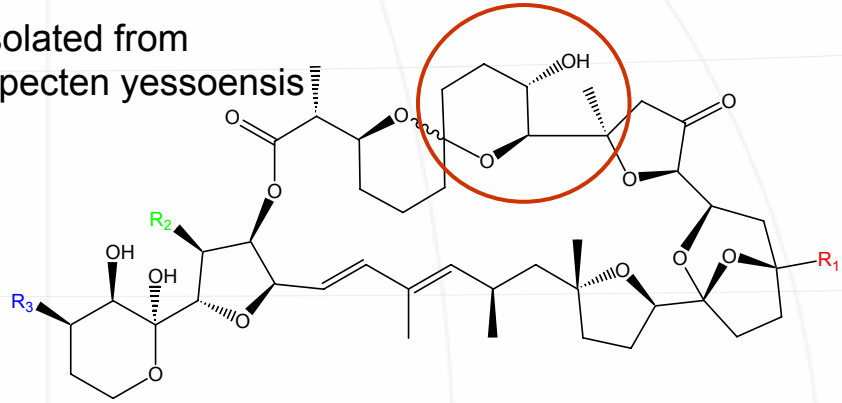
Cohen et al. (1990) TIBS 15(3), 98-102

backward swimming of protozoa

3. Pectenotoxins – Structures

First isolated from
Patinopecten yessoensis





	R1	R2	R3	C7
PTX2	CH_3	H	CH_3	R
PTX2b	CH_3	H	CH_3	S
PTX1	CH_2OH	H	CH_3	R
PTX4	CH_2OH	H	CH_3	S
PTX3	CHO	H	CH_3	R
PTX6	COOH	H	CH_3	R
PTX7	COOH	H	CH_3	S
PTX11	CH_3	OH	CH_3	R
PTX11b	CH_3	OH	CH_3	S
PTX12	CH_3	H	$=CH_2$	R

	R1	R2	R3	C7
PTX2c	CH_3	H	CH_3	S
PTX8	CH_2OH	H	CH_3	S
PTX9	COOH	H	CH_3	S
PTX11c	CH_3	OH	CH_3	S

Dinophysis acuminata

Dinophysis
acuminata
acuta
caudata
fortii
norvegica
rotundata

3. Pectenotoxins – Toxicity and Mode of Action

Toxicity:

LD_{50} PTX2: 219 µg/kg (mice)

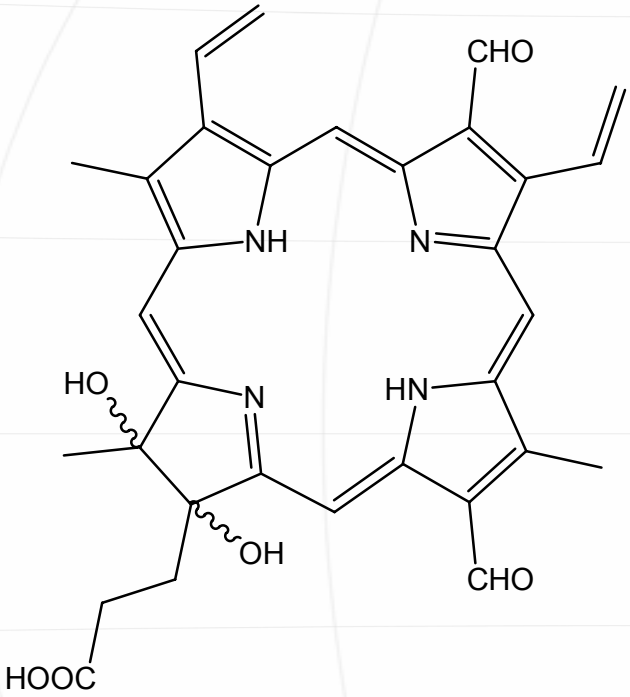
Mode of Action:

causes actin depolymerization => characteristic liver injuries. Within 1 hr after the injection of pectenotoxin-1 numerous non-fatty vacuoles appeared in the hepatocytes around the periportal regions of the hepatic lobules

increased permeability of capillaries in the digestive tract and liver

nondiarrheagenic

Mussel Toxins



H2-a

Heterocapsa circularisquama


Heterocapsa circularisquama

Toxic to shellfish but not ichthyotoxic

Light dependent hemolytic effect

Diatoms

Cyanobacteria

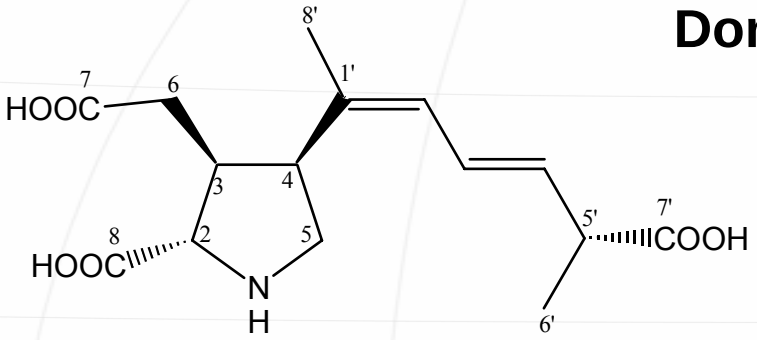
and Others

Diatoms:

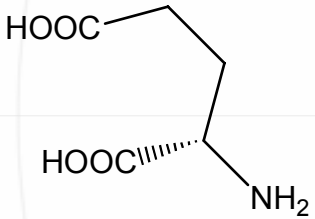
Nitzschia	
varis-varingica	Domoic Acid (ASP)
Pseudo-Nitzschia	
australis	Domoic Acid (ASP)
calliantha	Domoic Acid (ASP)
delicatissima	Domoic Acid (ASP)
multiseries	Domoic Acid (ASP)
multistriata	Domoic Acid (ASP)
seriata	Domoic Acid (ASP)
turgidula	Domoic Acid (ASP)

ASP: **A**mnesic **S**hellfish **P**oisoning

Domoic Acid



Domoic acid



Glutamic acid

Pseudonitzschia spp.

Toxicity:

LD_{50} : 2.4 mg/kg (mice)

Mode of Action:

Glutamic acid agonist, binds to certain glutamic acid receptors (kainate receptors) in the brain and causes neuronal firing due to the inability of glutamate transporters to clear DA from the synaptic cleft, thus prolonging neuronal excitation.

Neurotoxic, causes neurobehavioural effects, loss of short term memory

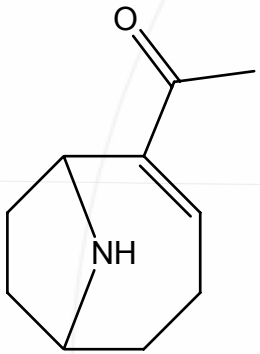
Freshwater Cyanobacteria:

Anabaena	
circinalis	Anatoxin-a, Microcystins (MC), PSP
flos-aquae	Anatoxin-a, Anatoxin-a(s), Microcystins (MC)
lemmermannii	Anatoxin-a(s), PSP
Anabaenopsis	
milleri	Microcystins (MC)
Aphanizomenon	
flos-aquae	Anatoxin-a, PSP, Cylindrospermopsins (CYN)
gracile	PSP
ovalisporum	Cylindrospermopsins (CYN), Microcystins (MC)
Cylindrospermopsis	
raciborskii	Cylindrospermopsins (CYN), PSP
Lyngbya	
wollei	PSP

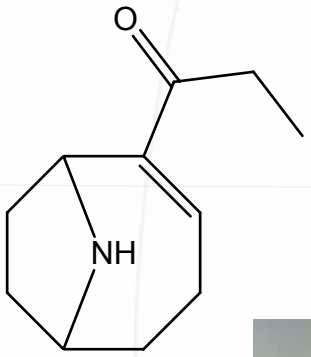
Freshwater Cyanobacteria (contiunation):

Microcystis		
	aeruginosa	Microcystins (MC), PSP
	botrys	Microcystins (MC)
	viridis	Microcystins (MC)
Planktothrix		
	agardhii	Microcystins (MC)
	formosa	Anatoxin-a
	mugeotii	Microcystins (MC)
	rubescens	Microcystins (MC)
Nodularia		
	spumigena	Nodularins (NOD)
Nostoc spp.		Microcystins (MC)
Umezakia		
	natans	Cylindrospermopsins (CYN)

Anatoxin-a



Anatoxin-a

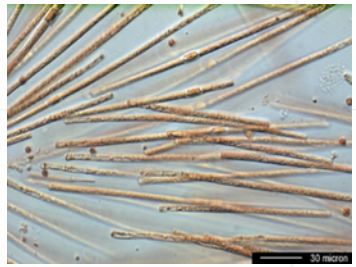


Homoanatoxin-a

Anabaena circinalis

Anabaena
circinalis
flos-aquae
Aphanizomenon
flos-aquae
Planktothrix
formosa

Anabaena flos-aquae



Aphanizomenon flos-aquae

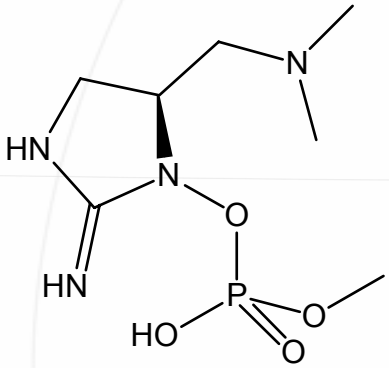
Mode of Action:

Binds to nicotinic acetylcholin receptor (nAChR)
⇒ Opening of the postsynaptic sodium channels
⇒ generation of action potentials until exhaustion of the nerve cell
neurotoxic

Toxicity:

LD_{50}: 200 µg/kg (mice)

Anatoxin-a(s)



Anatoxin-a(s)

Anabaena flos-aquae

Anabaena
flos-aquae
lemmermannii

Anabaena lemmermannii

Toxicity:

LD_{50}: 50 µg/kg (mice)

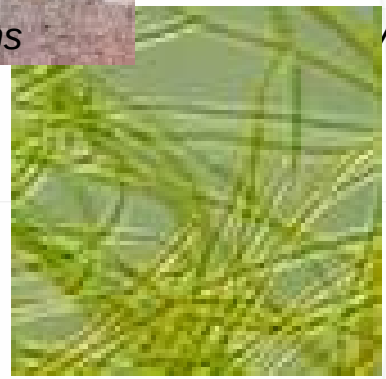
Mode of Action:

Acetylcholin esterase (AChE) inhibitor
=> Opening of the postsynaptic sodium channels
⇒generation of action potentials until exhaustion of the nerve cell
neurotoxic

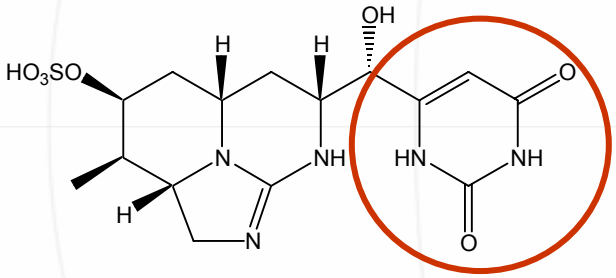
Cylindrospermopsins – Structures

Umezakia natans

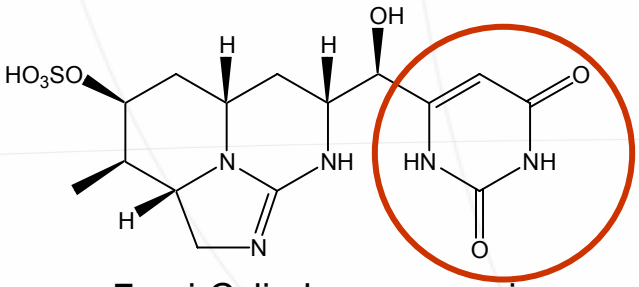
Aphanizomenon
flos-aquae
ovalisporum
Cylindrospermopsis
raciborskii
Umezakia
natans



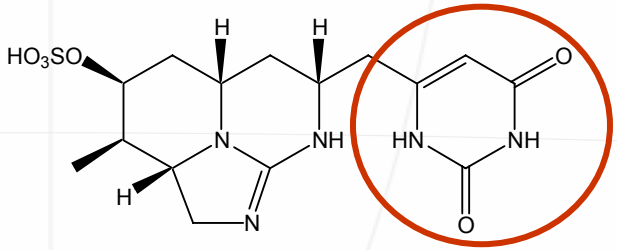
Cylindrospermopis raciborskii



Cylindrospermopsin



7-epi-Cylindrospermopsin



deoxy-Cylindrospermopsin

Cylindrospermopsins – Mode of Action

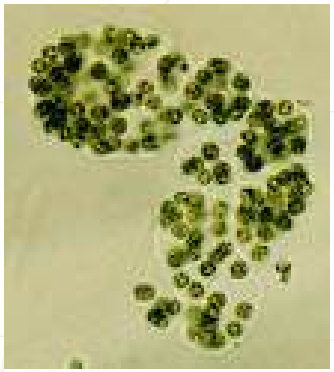
Toxicity:

LD_{50}: 2 mg/kg (mice)

Mode of Action:

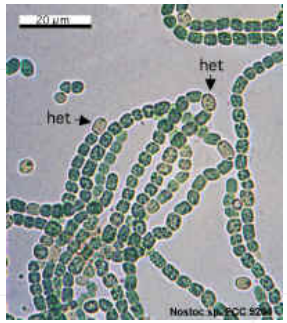
competitive binding of the toxin to a catalytic site(s) involved in the synthesis of pyrimidine nucleotides (i.e., uridine)
Inhibition in a noncompetitive manner of the in vitro activity of uridine monophosphate (UMP) synthase complex
hepatotoxic

Microcystins – Structures



Microcystis aeruginosa

Planktothrix agardhii



Nostoc

Anabaena
- *circinalis*
- *flos-aquae*

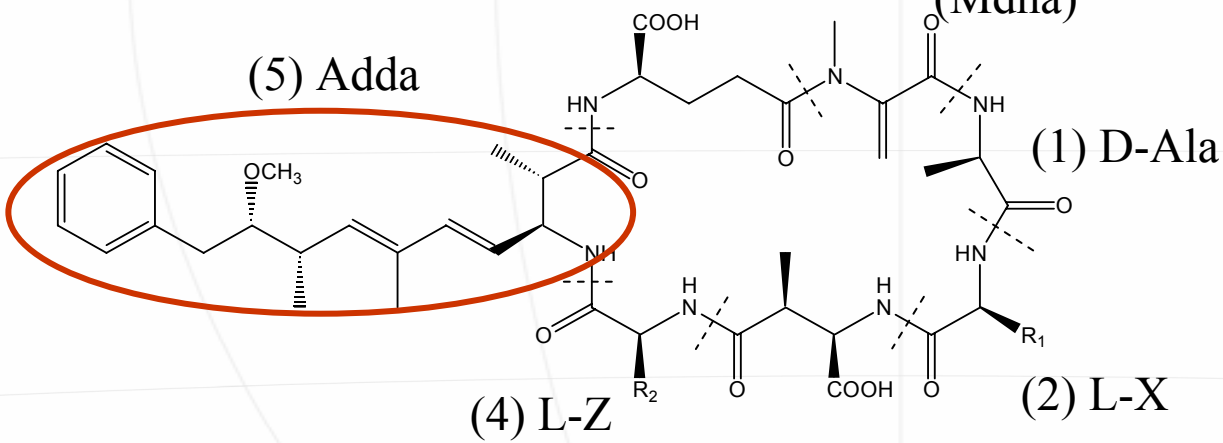
Anabaenopsis
- *milleri*

Aphanizomenon
- *ovalisporum*

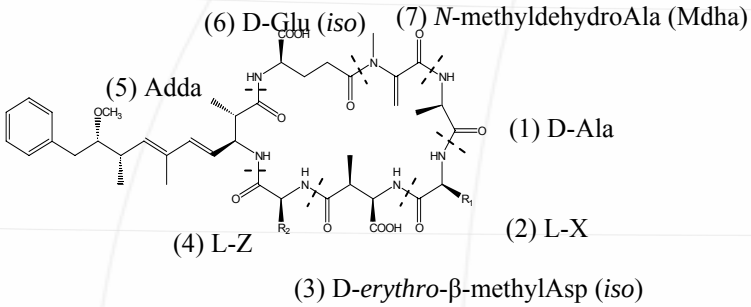
Microcystis
- *aeruginosa*
- *botrys*
- *viridis*

Planktothrix
- *agardhii*
- *mugeotii*
- *rubescens*

Nostoc spp.

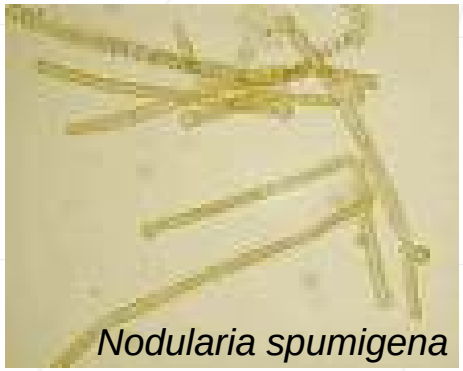


Microcystins – Structures

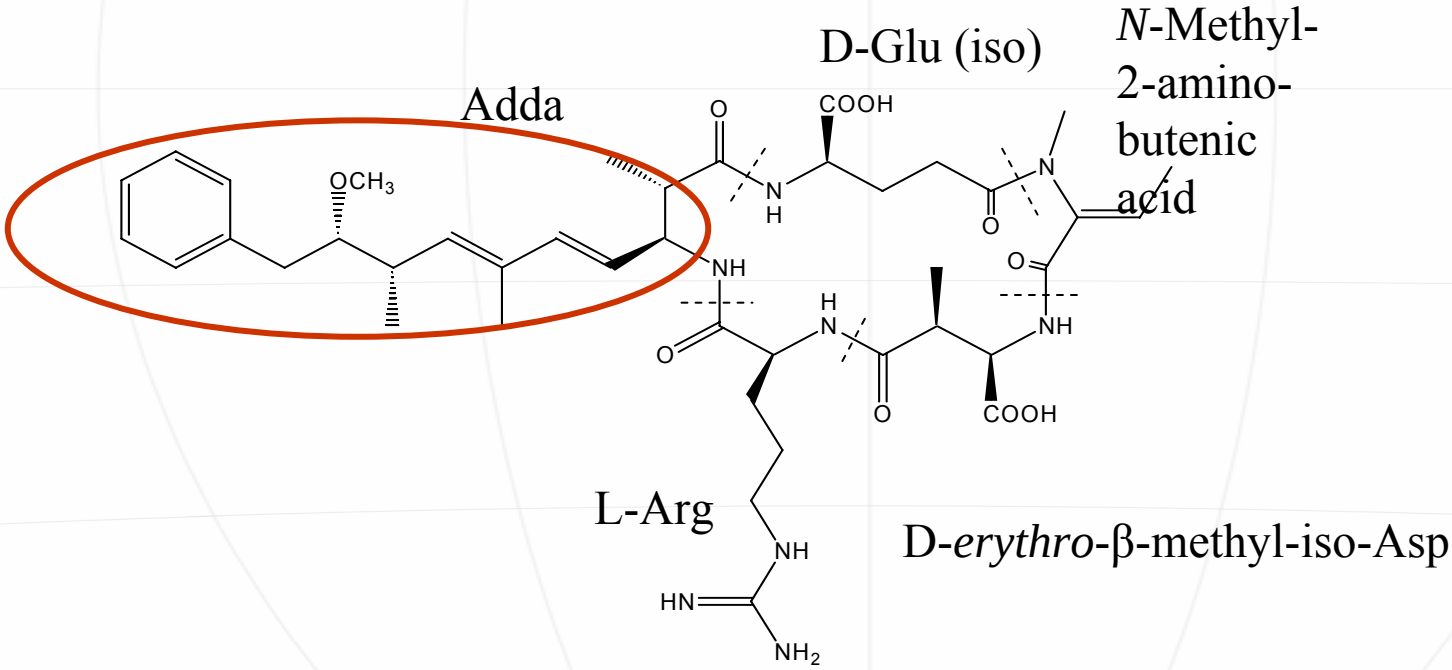


AA 1	AA 2	AA 3	AA 4	AA 5	AA 6	AA 7
D-Ala	**L-Leu**	**D-MeAsp**	**L-Arg**	**Adda**	**D-Glu**	**Mdha**
D-Ser	L-Ala	D-Asp	L-Aib	ADMAdda	D-MeGlu	Dha
	L-Glu		L-Ala	DMAdda	$OC_2H_3(CH_3)$OH-Glu	Dhb
	L-GluMe		L-Glu	(6Z)Adda		L-Ala
	L-Har		L-GluMe			L-MeSer
	L-Hil		L-Har			L-Ser
	L-Hph		L-Hph			Mdhb
	L-Hty		L-Hty			MeLan
	L-Met		L-Leu			
	L-Met(O)		L-Met			
	L-Phe		L-Met(O)			
	L-ThTyr		L-Phe			
	L-Trp		L-Trp			
	L-Tyr		L-Tyr			
			L-Val			

Nodularins – Structures



Nodularia spumigena



Microcystins/Noduarins – Toxicity and Mode of Action

Toxicity:

LD_{50} MC-LR/NOD: 50 µg/kg (mice)

Mode of Action:

ADDA blocks the catalytic site of protein serine/threonine phosphatases PP1 and PP2A
=> Hyperphosphorylation => cytoskeletal rearrangements => changes in whole-cell morphology

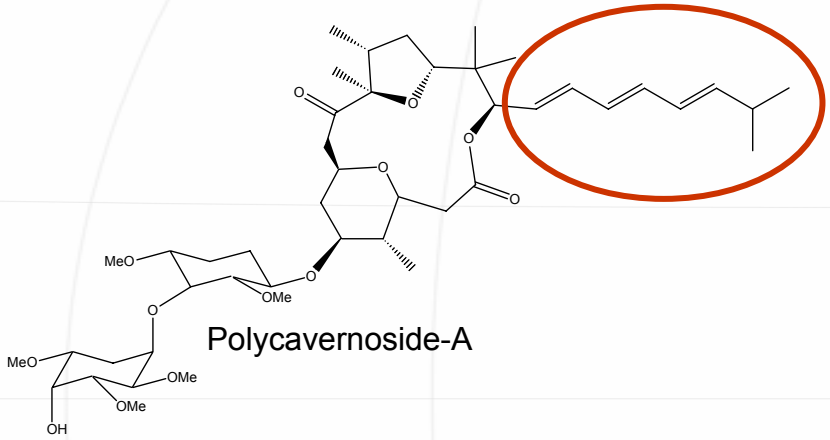
Tumor promotion is attributed also to PP inhibition

Oxidative stress by formation of ROS stimulated by MCs

Marine Cyanobacteria:

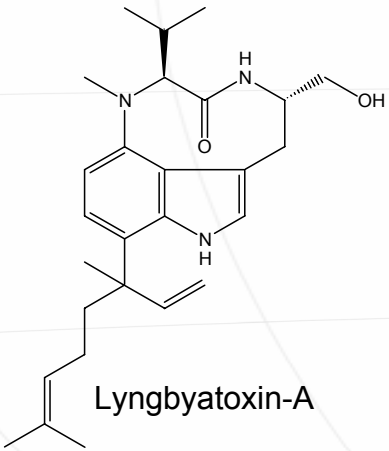
Lyngbya	
majuscula	Aplysiatoxins, Lyngbyatoxins
Oscillatoria	
nigroviridis	Aplysiatoxins
Schizothrix	
calcicola	Aplysiatoxins, Lyngbyatoxins
Gracilaria (Polycavernosa tsudai)	
edulis ??	Polycavernoside-A

Marine Cyanobacterial toxins – Structures

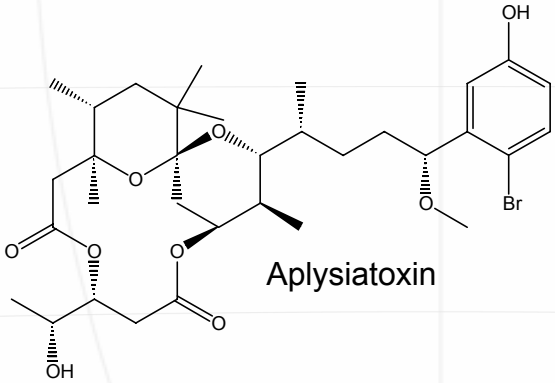


Polycavernoside-A

Schizothrix calcicola



Lyngbyatoxin-A



Aplysiatoxin

Aplysia - seaslug

Lyngbya majuscula

Marine Cyanobacterial toxins – Toxicity

Polycavernoside-A

Oral toxicity

Aplysiatoxin:

Swimmer‘s itch (contactdermatitis)
diarrheagenic, vomiting
Bleeding of the small intestine
Tumor promotin (potentiation of protein kinase C)

Lyngbyatoxin-A

Dermonecrotic
Tumor promoting

Haptophytes:

Chrysocromulina	
leadbeateri	Ichthyotoxins
polylepis	Ichthyotoxins
Phaeocystis	
pouchetii	Ichthyotoxins (?)
Prymnesium	
calathiferum	Ichthyotoxins
faveolatum	Ichthyotoxins
parvum	Ichthyotoxins, prymnesins (PRM)
patelliferum	Ichthyotoxins
zebrinum	Ichthyotoxins

Prymnesins

Prymnesin-1

Ichthyotoxic
Hemolytic
Direct action on cell membrane

Raphidophyceans:

Chattonella	
antiqua	Ichthyotoxins
globosa	Ichthyotoxins
marina	Ichthyotoxins
subsalsa	Ichthyotoxins
verruculosa	Ichthyotoxins
Fibrocapsa	
japonica	Ichthyotoxins
Heterosigma	
akashiwo	Ichthyotoxins

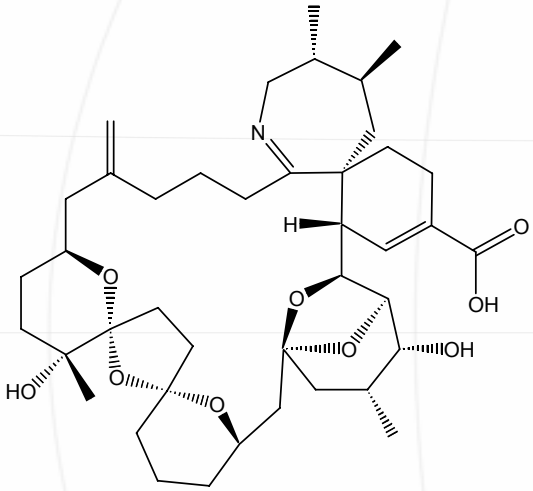
Chattonella antiqua

Heterosigma akashiwo

Toxins and mode of action unknown

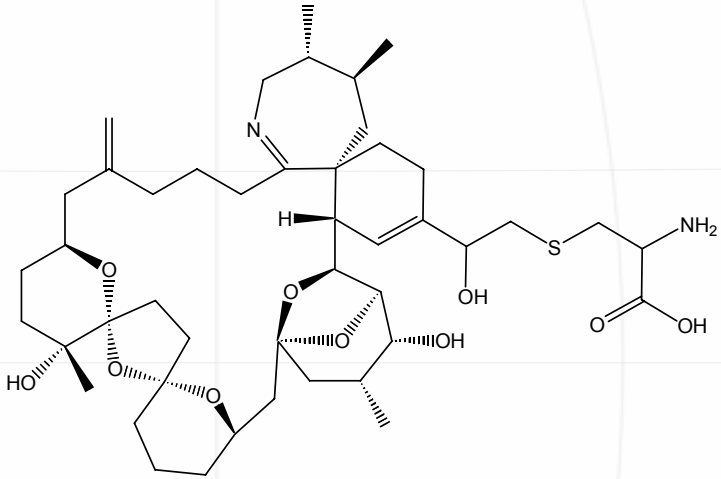
Fibrocapsa japonica

Phycotoxins of Unknown Origin – Structures



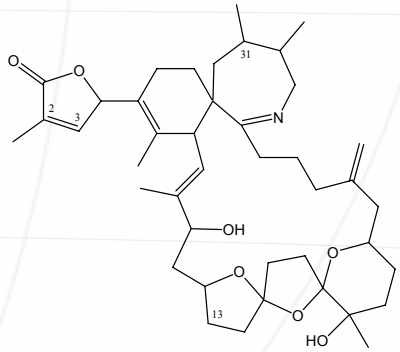
Pinnatoxin-A

Bivalve *Pinna muricata*



Pteriatoxin-A

Bivalve *Pteria penguin*



13-desMe Spirolide C

Phycotoxins of Unknown Origin – Toxicity

Pinnatoxins

Diarrhea, convulsions, paralysis
Calcium channel activators?

Pteriatoxins

?