"INVASIVE MARINE SPECIES: INTRODUCTION, IMPACT AND CONTROL"

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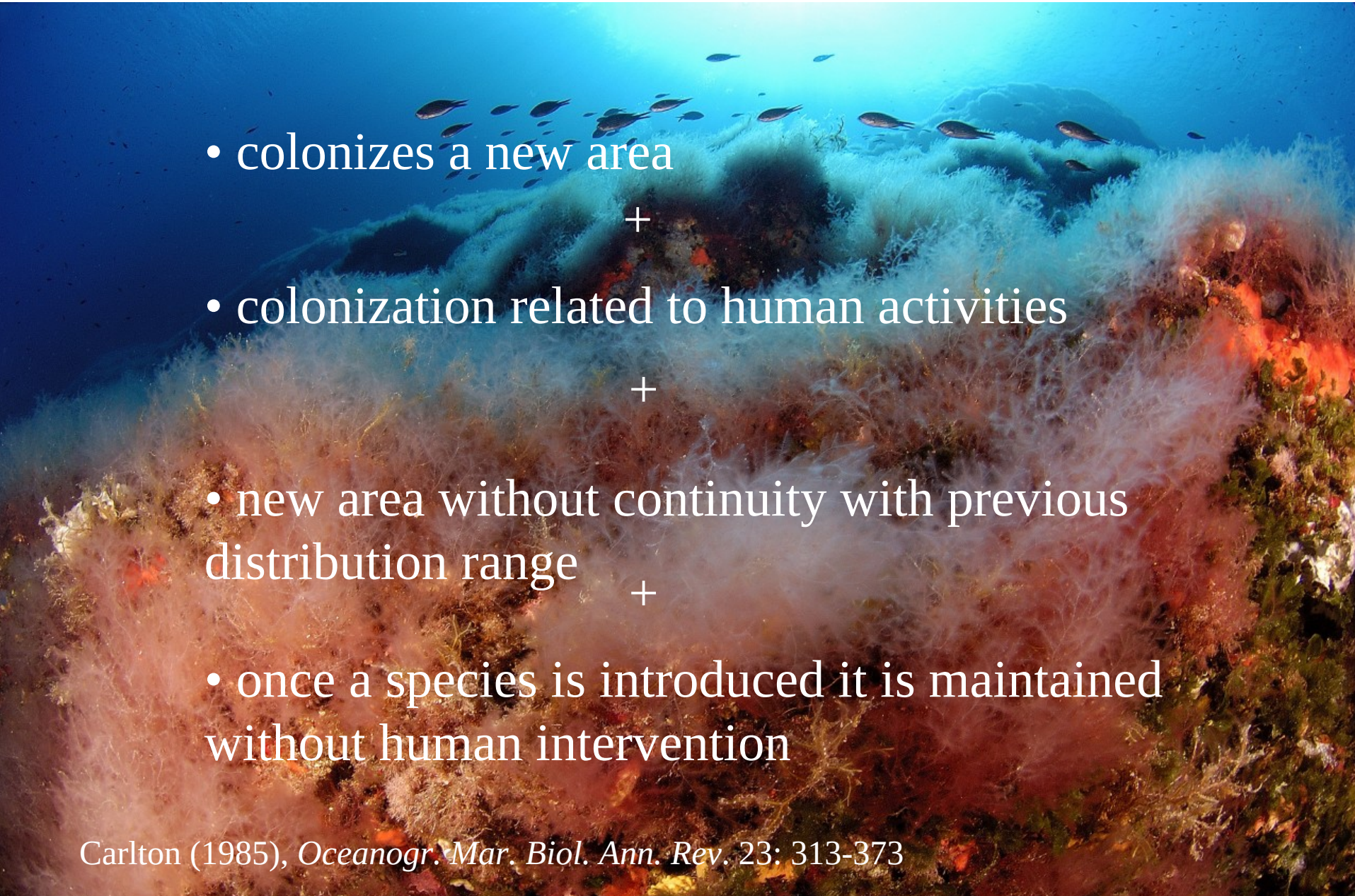
Centre d'Estudis Avançats de Blanes

Definition of **introduced** species



- colonizes a new area

+

- colonization related to human activities

+

- new area without continuity with previous distribution range

+

- once a species is introduced it is maintained without human intervention

Carlton (1985), *Oceanogr. Mar. Biol. Ann. Rev.* 23: 313-373

Definition of **invasive** species

- introduced
- abundant
- is dangerous for native species/communities
- is ecologically/economically harmful

10s[1] rule: one of each 10 introduced species becames invasive

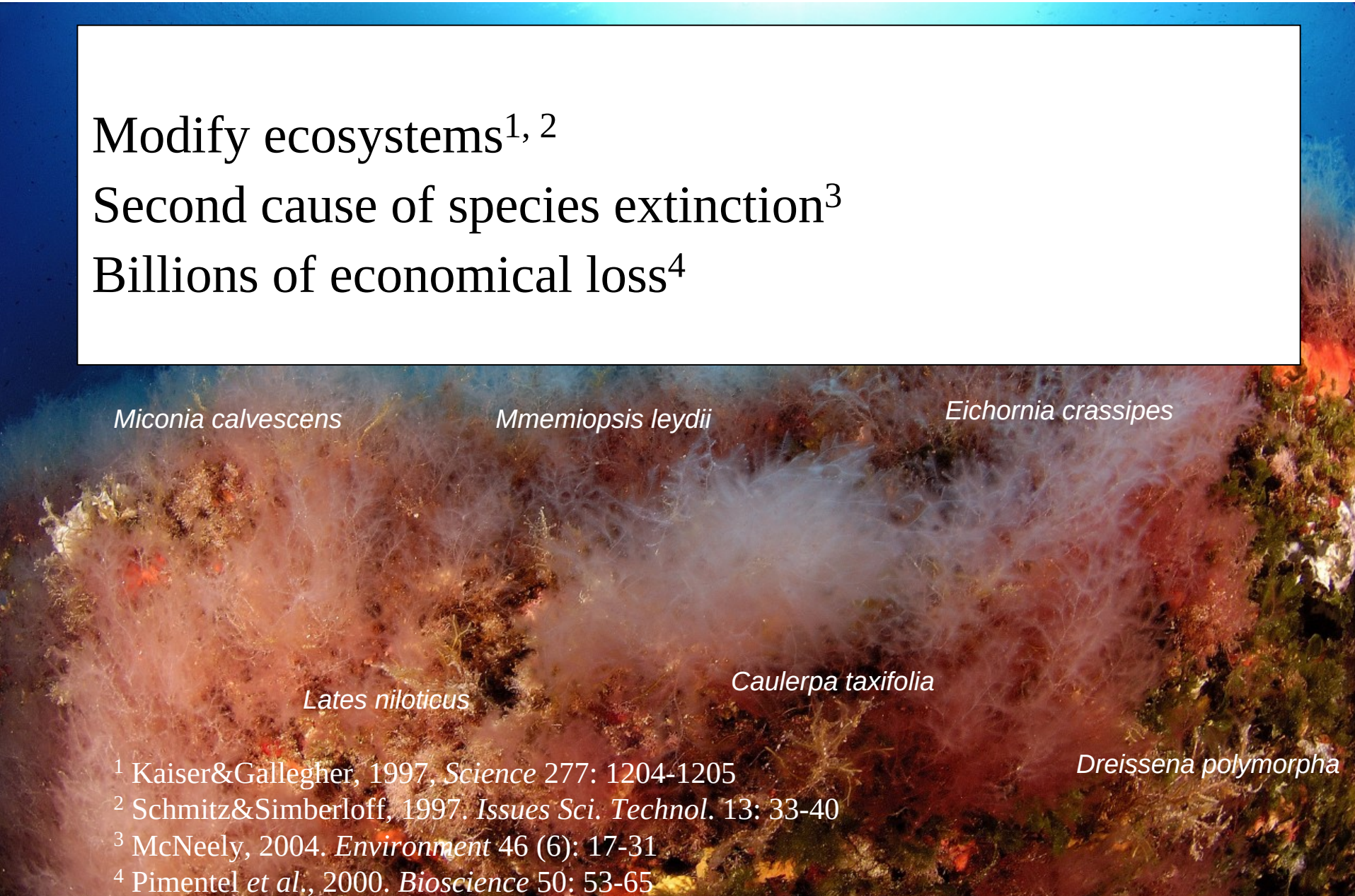
[1] Williamson & Fitter (1996), *Ecology* 77: 1661-1666

Invasive species

Modify ecosystems[1, 2]

Second cause of species extinction[3]

Billions of economical loss[4]



[1] Kaiser&Gallegher, 1997, *Science* 277: 1204-1205
[2] Schmitz&Simberloff, 1997. *Issues Sci. Technol.* 13: 33-40
[3] McNeely, 2004. *Environment* 46 (6): 17-31
[4] Pimentel *et al.*, 2000. *Bioscience* 50: 53-65

What happens in marine ecosystems?

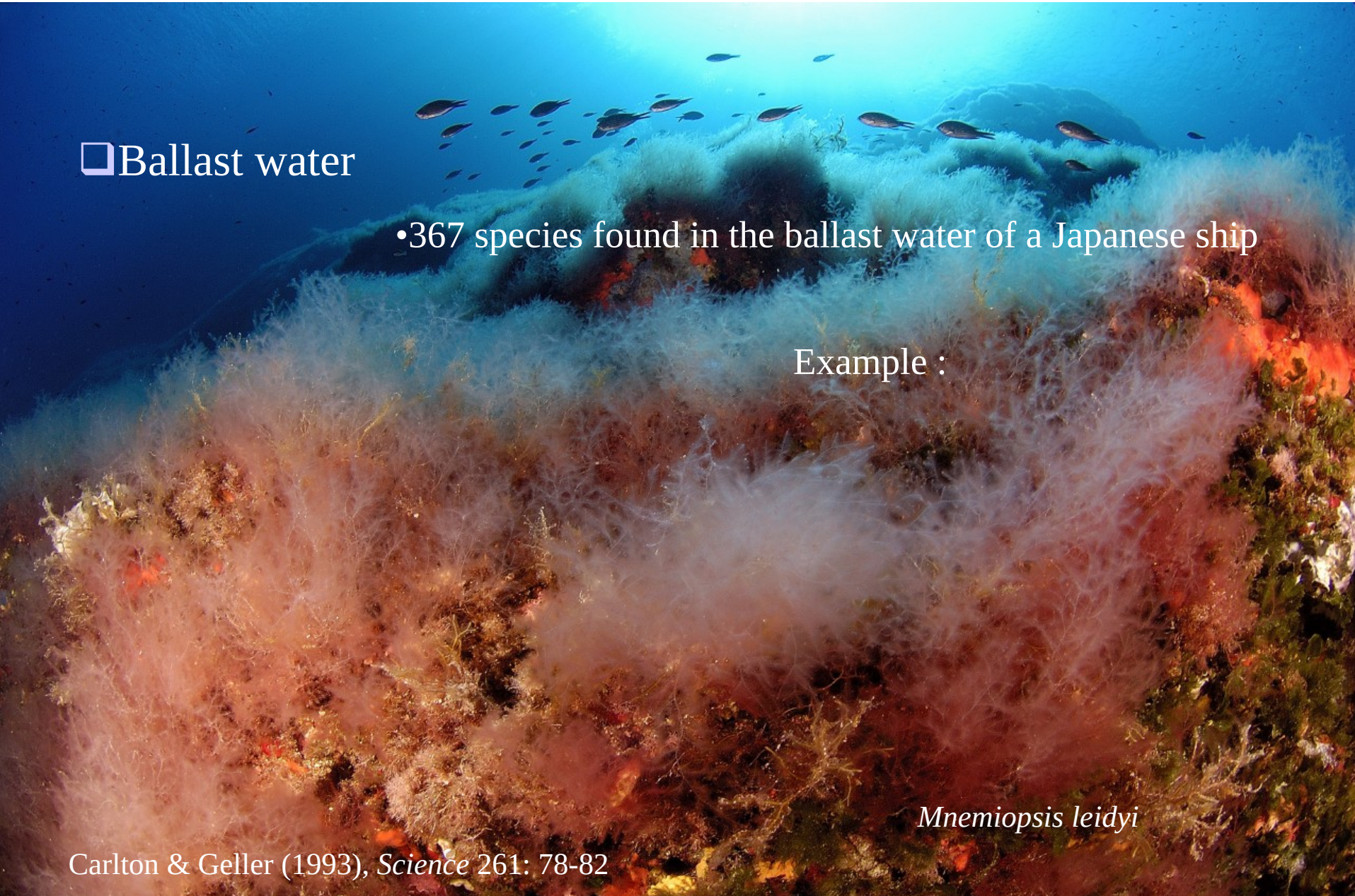
- Far less known and studied than in terrestrial ecosystems
- Very important ecologically and economically

Examples:

- *Mnemiopsis leidyi (Black Sea)*
- San Francisco Bay (California): 234 introduced species

- Well identified vectors

Vectors



- Ballast water
  - •367 species found in the ballast water of a Japanese ship
  - Example :

Mnemiopsis leidyi

Carlton & Geller (1993), *Science* 261: 78-82

Vectors

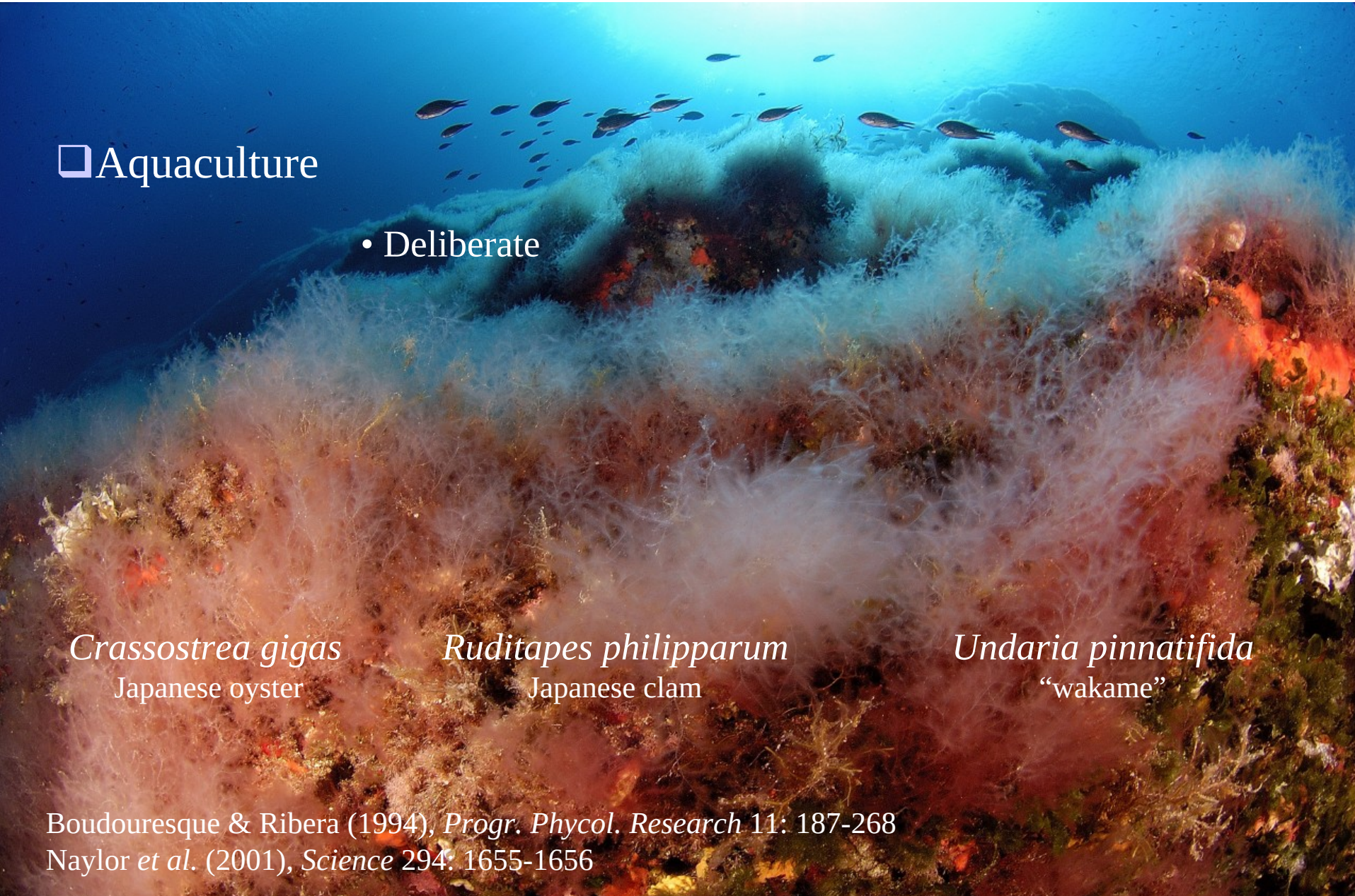
- Fouling

Probably cosmopolitan species correspond to ancient introductions attached to ship hulls

Example: *Ficopomatus enigmaticus*

Zibrowius (1994), *in Introduced Species in European Coastal Waters*: 44-49 EEC Publ.

Vectors



- Aquaculture
  - Deliberate

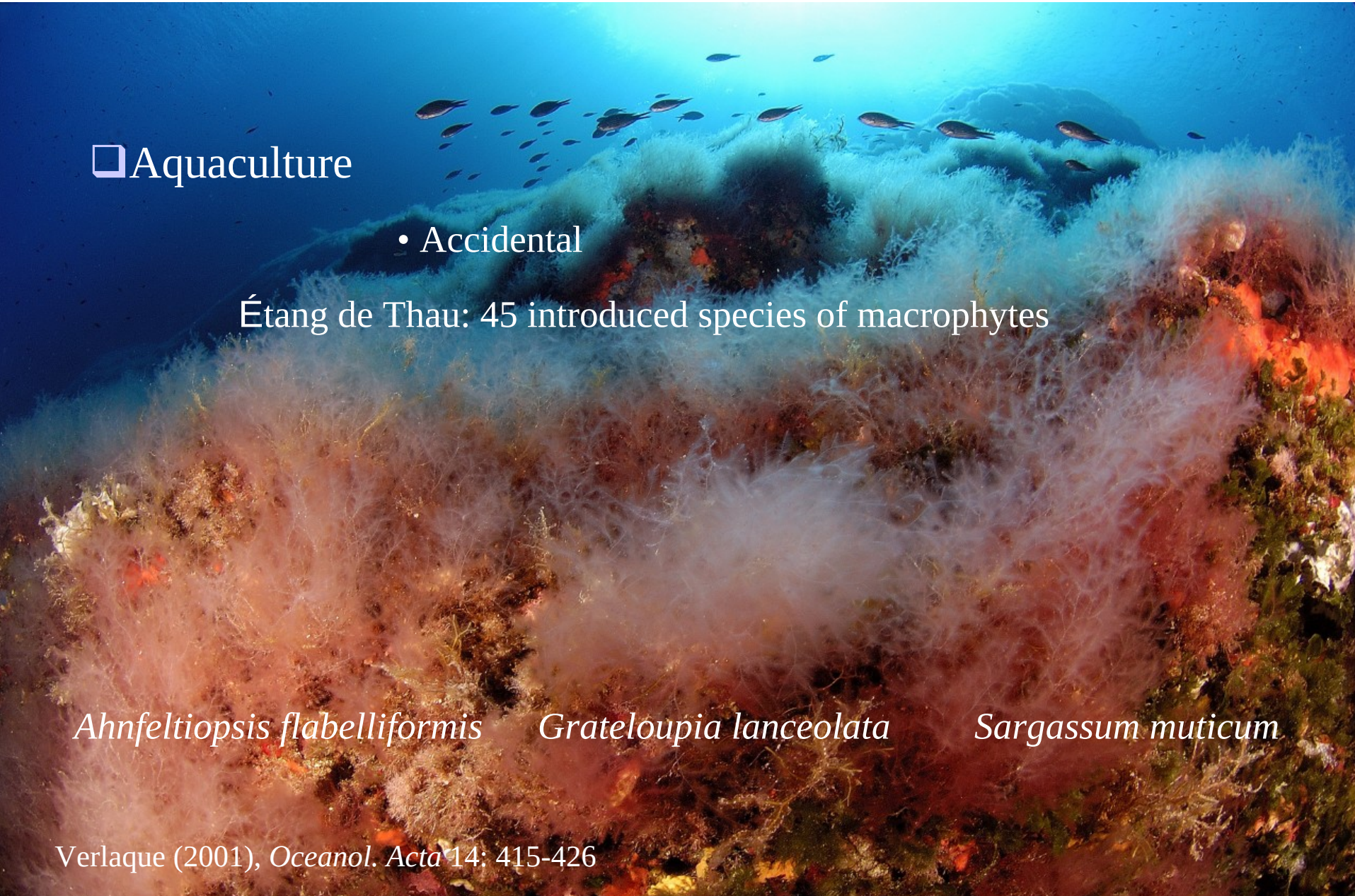
Crassostrea gigas
Japanese oyster

Ruditapes philipparum
Japanese clam

Undaria pinnatifida
“wakame”

Boudouresque & Ribera (1994), *Progr. Phycol. Research* 11: 187-268
Naylor *et al.* (2001), *Science* 294: 1655-1656

Vectors



- Aquaculture
  - Accidental

Étang de Thau: 45 introduced species of macrophytes

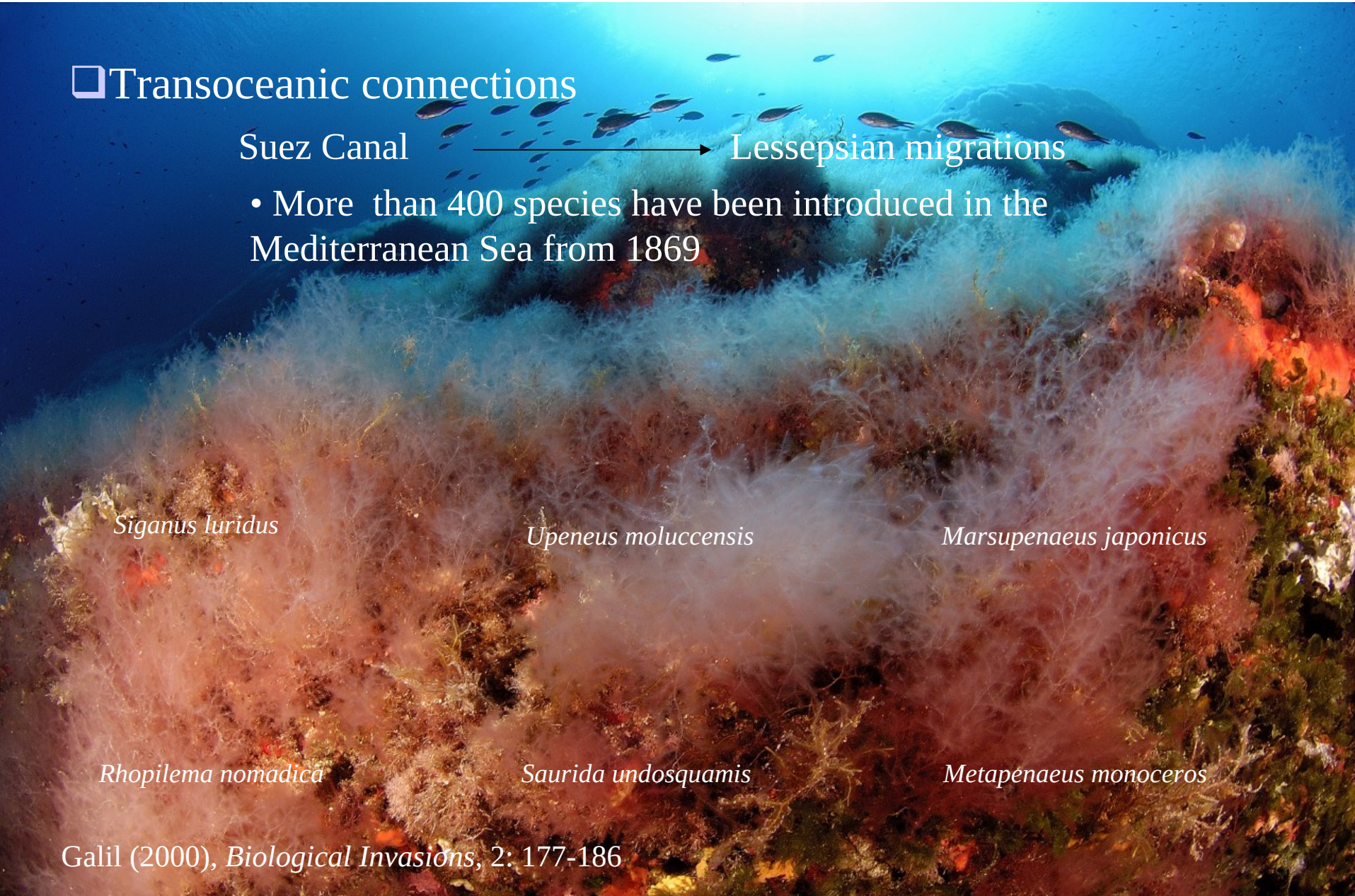
Ahnfeltiopsis flabelliformis *Grateloupia lanceolata* *Sargassum muticum*

Verlaque (2001), *Oceanol. Acta* 14: 415-426

Vectors

Meinesz & Hesse (1991), *Oceanol. Acta* 14: 415-426

Vectors



- Transoceanic connections

  Suez Canal → Lessepsian migrations

  • More than 400 species have been introduced in the Mediterranean Sea from 1869

Siganus luridus

Upeneus moluccensis

Marsupenaeus japonicus

Rhopilema nomadica

Saurida undosquamis

Metapenaeus monoceros

Galil (2000), *Biological Invasions*, 2: 177-186

Invasive Mediterranean algae

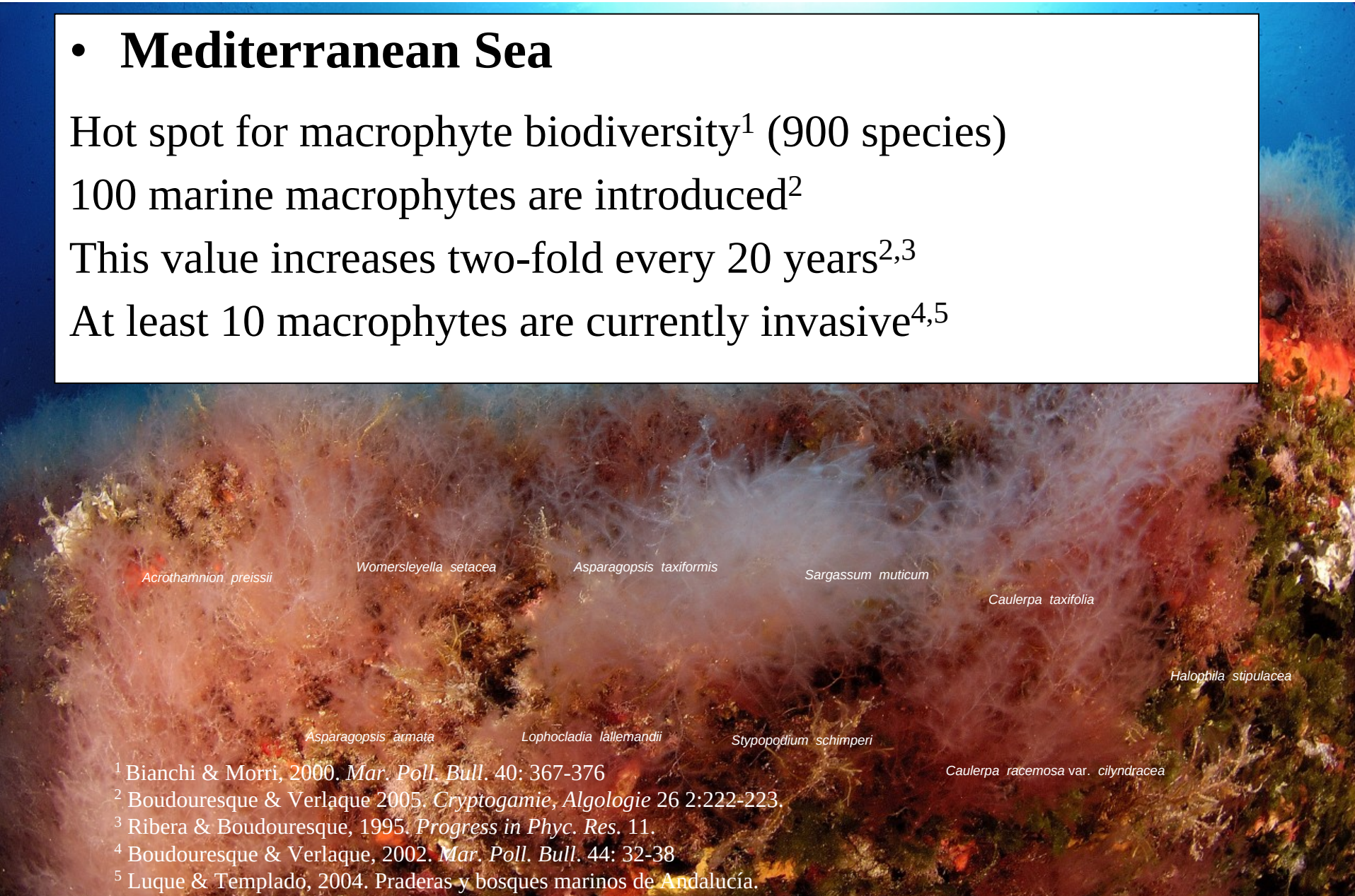
- **Mediterranean Sea**

Hot spot for macrophyte biodiversity[1] (900 species)

100 marine macrophytes are introduced[2]

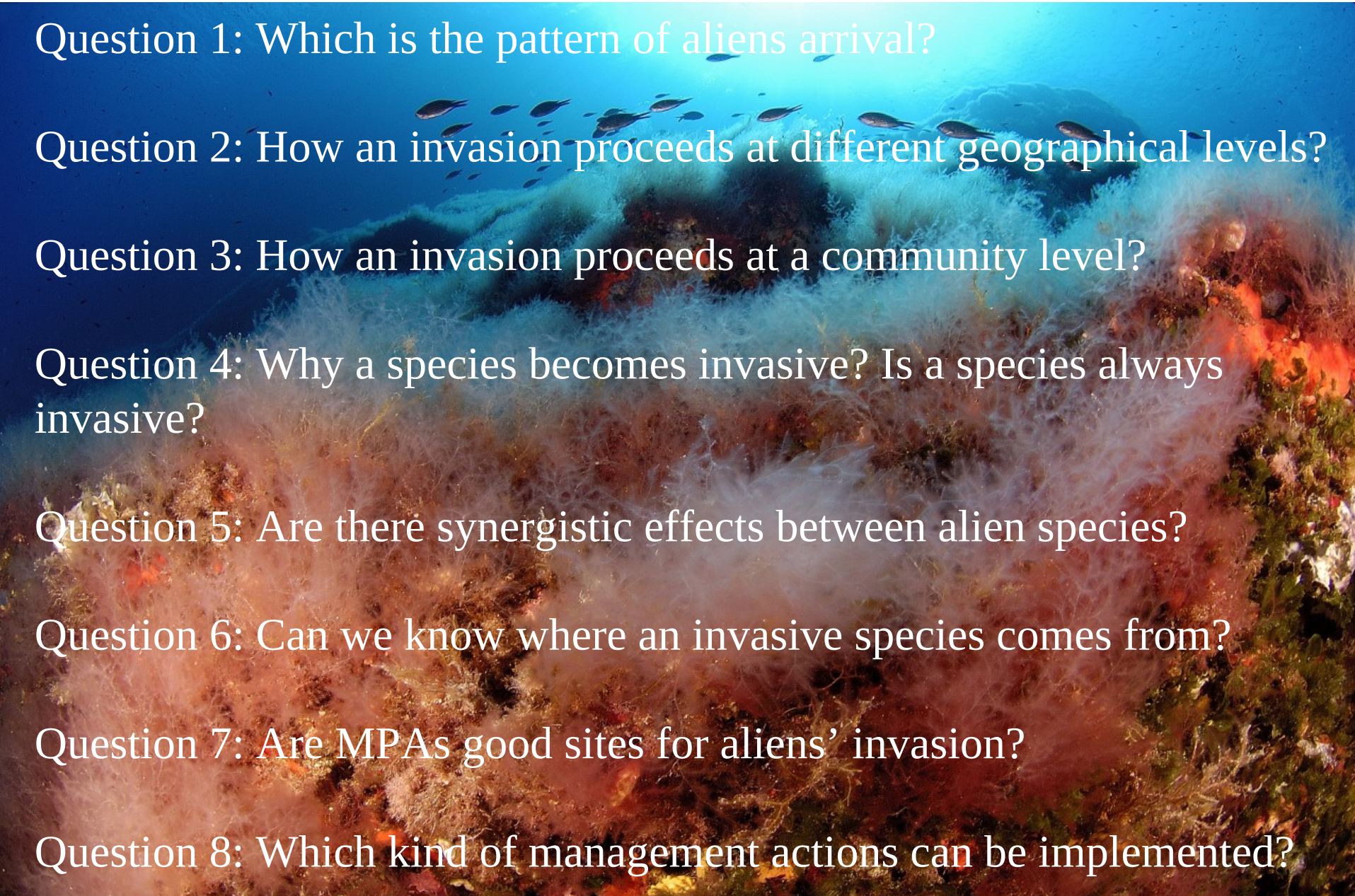
This value increases two-fold every 20 years[2,3]

At least 10 macrophytes are currently invasive[4,5]



[1] Bianchi & Morri, 2000. *Mar. Poll. Bull.* 40: 367-376
[2] Boudouresque & Verlaque 2005. *Cryptogamie, Algologie* 26 2:222-223.
[3] Ribera & Boudouresque, 1995. *Progress in Phyc. Res.* 11.
[4] Boudouresque & Verlaque, 2002. *Mar. Poll. Bull.* 44: 32-38
[5] Luque & Templado, 2004. Praderas y bosques marinos de Andalucía.

Important questions for managers and policy makers



Question 1: Which is the pattern of aliens arrival?

Question 2: How an invasion proceeds at different geographical levels?

Question 3: How an invasion proceeds at a community level?

Question 4: Why a species becomes invasive? Is a species always invasive?

Question 5: Are there synergistic effects between alien species?

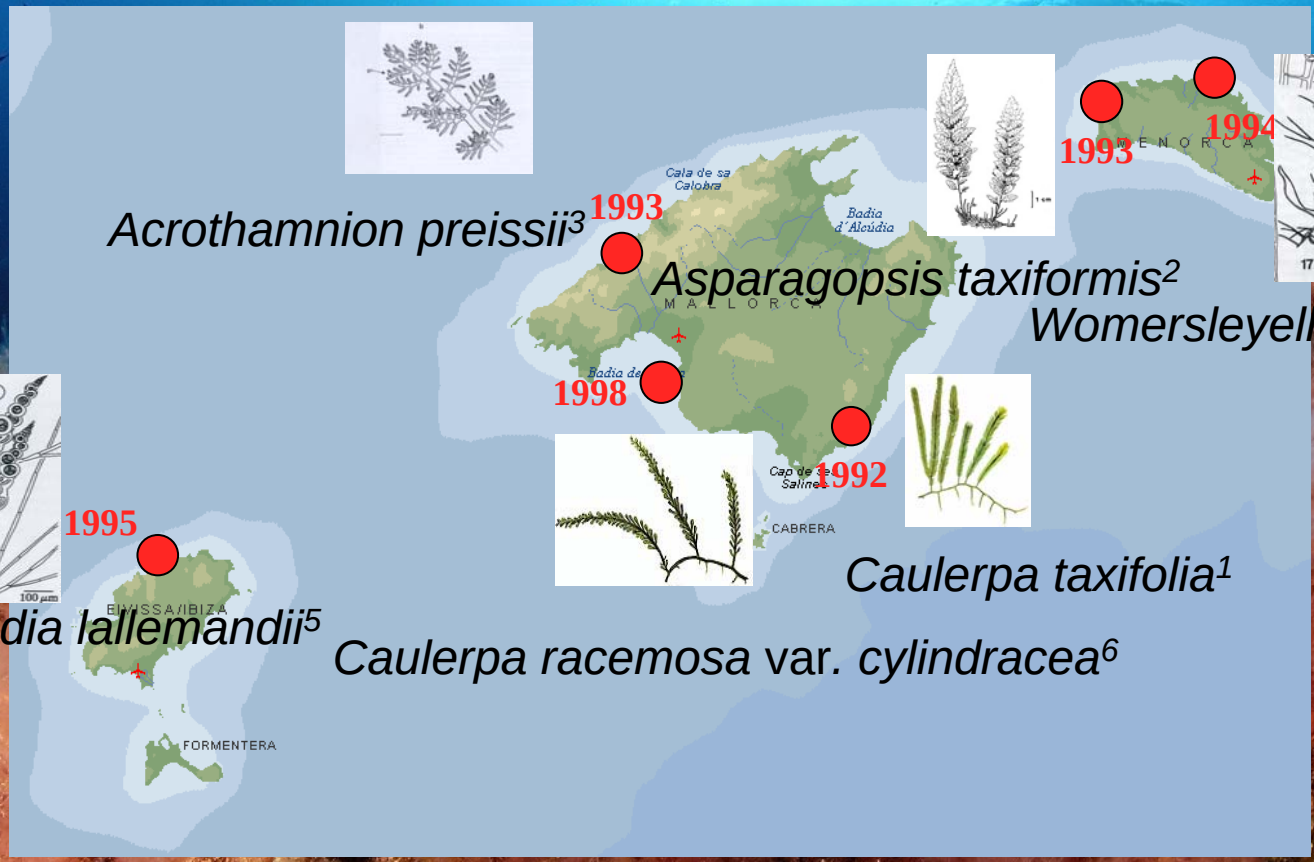
Question 6: Can we know where an invasive species comes from?

Question 7: Are MPAs good sites for aliens' invasion?

Question 8: Which kind of management actions can be implemented?

Question 1: Which is the pattern of aliens arrival?

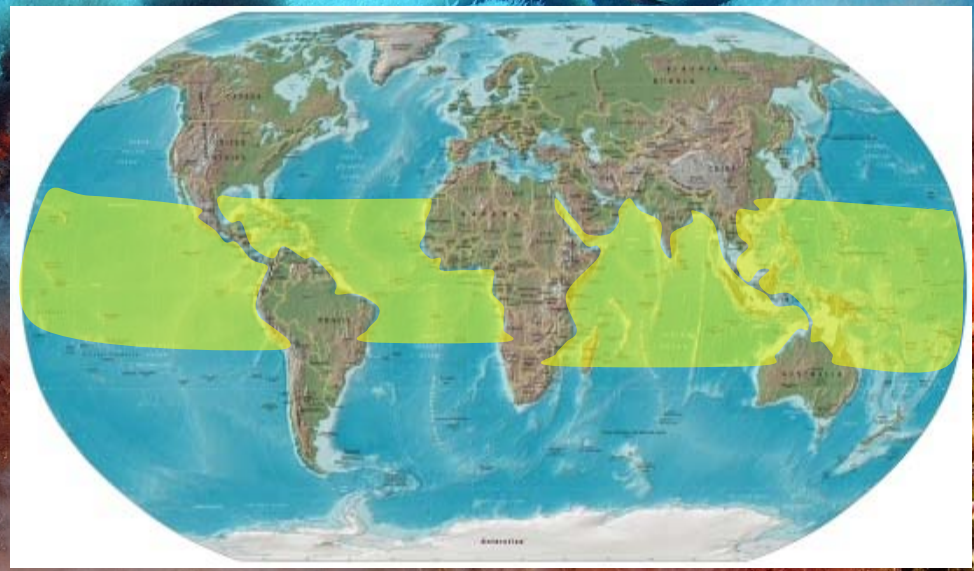
- **Example: Recent algal introductions in the Balearic Islands**



[1] Pou *et al.*,1993, *Boll. Soc. Hist. Nat. Balears*, 36: 83-90
[2] Ballesteros & Rodríguez-Prieto, 1996. *Boll. Soc. Hist. Nat. Balears* 39: 135-138
[3] Ferrer *et al.*, 1994. *Flora Mediterranea* 4: 163-166
[4] Ballesteros *et al.*, 1997. *Acta Bot. Barc.* 44: 29-37
[5] Patzner, 1998. *Boll. Soc. Hist. Nat. Balears*, 41: 75-80
[6] Ballesteros *et al.*, 1999. *Boll. Soc. Hist. Nat. Balears*, 42: 65-68

Question 2: How a invasion proceeds at a geographical level?

Example: *Lophocladia lallemandii*



Indo-Pacific distribution

Suez-Canal introduction

Verlaque (1994) *Oceanol. Acta* 17: 1-23
Gómez-Garreta *et al*. (2001), *Bot. Mar.* 44: 425-460
Patzner (1998), *Boll. Soc. Hist. Nat. Balears* 41: 75-80

Lophocladia lallemandii

Patzner (1998), *Boll. Soc. Hist. Nat. Balears*, 41:75-80

Lophocladia lallemandii

Patzner (1998), *Boll. Soc. Hist. Nat. Balears*, 41:75-80

Lophocladia lallemandii

Patzner (1998), *Boll. Soc. Hist. Nat. Balears*, 41:75-80

Lophocladia lallemandii

Ballesteros & Cebrián (unpublished data)

Lophocladia lallemandii

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Lophocladia lallemandii

Ballesteros & Cebrián (unpublished data)

Lophocladia lallemandii

Ballesteros & Cebrián (unpublished data)

Question 3: How an invasion proceeds at a community level?

- **Transects**

Transectos P. N. Cabrera
1: Cap Llebeig.0-47m
2: Freu Imperial. 0-50m
3: Ses Rates. 0-33m
4: Sa Carabassa. 0-45m
5. S'Olla. 0-5m
6: Estell d'Es Coll 0-50m
7: L'Imperial. 0-50m
8: Cova Verda. 0-12m
9: Illó Foradat. 0-40m
10: Cova Blava. 0-40m
11: Sa platgeta. 0-5m
12: Cap Llebeig. 0-48m
13: Port. 0-37m
14: Cala Sta. Maria. 0-11m
15: Na Redona 0-32m

Cabrera Archipelago

Cabrera Archipelago

- **Transects**

Transectos P. N. Cabrera	2001		
	W. set	*L. lall*	*C. rac.*
1: Cap Llebeig.0-47m	2%	0%	0%
2: Freu Imperial. 0-50m	17%	0%	0%
3: Ses Rates. 0-33m	0%	0%	0%
4: Sa Carabassa. 0-45m	22%	0%	0%
5. S'Olla. 0-5m	0%	0%	0%
6: Estell d'Es Coll 0-50m	10%	0%	0%
7: L'Imperial. 0-50m	9%	0%	0%
8: Cova Verda. 0-12m	0%	0%	0%
9: Illó Foradat. 0-40m	19%	0%	0%
10: Cova Blava. 0-40m	16%	0%	0%
11: Sa platgeta. 0-5m	0%	0%	0%
12: Cap Llebeig. 0-48m	15%	0%	0%
13: Port. 0-37m	12%	0%	0%
14: Cala Sta. Maria. 0-11m	0%	0%	0%
15: Na Redona 0-32m	3%	0%	0%
Promedio	**8%**	**0%**	**0%**

0% <30% 30-60% >60%

Cabrera Archipelago

- **Transects**

Transectos P. N. Cabrera	2001			2003		
	W. set	*L. lall*	*C. rac.*	*W. set*	*L. lall*	*C. rac.l*
1: Cap Llebeig.0-47m	2%	0%	0%	2%	58%	0%
2: Freu Imperial. 0-50m	17%	0%	0%	17%	10%	33%
3: Ses Rates. 0-33m	0%	0%	0%	0%	53%	11%
4: Sa Carabassa. 0-45m	22%	0%	0%	22%	22%	1%
5. S'Olla. 0-5m	0%	0%	0%	0%	2%	0%
6: Estell d'Es Coll 0-50m	10%	0%	0%	10%	2%	0%
7: L'Imperial. 0-50m	9%	0%	0%	9%	3%	0%
8: Cova Verda. 0-12m	0%	0%	0%	0%	1%	0%
9: Illó Foradat. 0-40m	19%	0%	0%	19%	56%	0%
10: Cova Blava. 0-40m	16%	0%	0%	16%	41%	1%
11: Sa platgeta. 0-5m	0%	0%	0%	0%	0%	0%
12: Cap Llebeig. 0-48m	15%	0%	0%	15%	31%	0%
13: Port. 0-37m	12%	0%	0%	12%	7%	1%
14: Cala Sta. Maria. 0-11m	0%	0%	0%	0%	1%	0%
15: Na Redona 0-32m	3%	0%	0%	3%	65%	0%
Promedio	**8%**	**0%**	**0%**	**8%**	**23%**	**3%**

0% <30% 30-60% >60%

Cabrera Archipelago

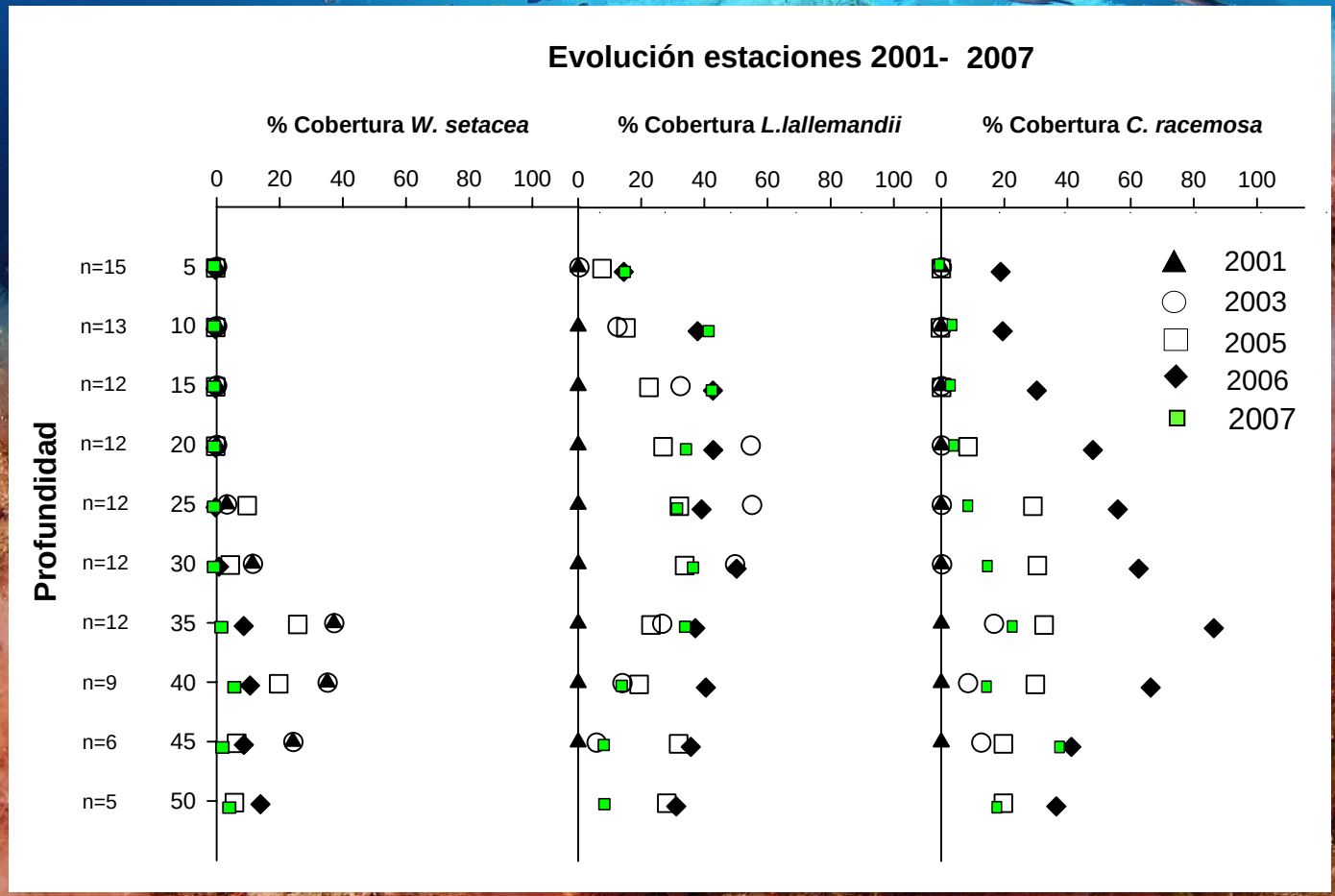
- **Transects**

Transectos P. N. Cabrera	2001			2003			2005		
	W. set	*L. lall*	*C. rac.*	*W. set*	*L. lall*	*C. rac.l*	*W. set*	*L. lall.*	*C. rac.*
1: Cap Llebeig 0-47m	2%	0%	0%	2%	58%	0%	9%	12%	9%
2: Freu Imperial 0-50m	17%	0%	0%	17%	10%	33%	0%	71%	61%
3: Ses Rates 0-33m	0%	0%	0%	0%	53%	11%	0%	26%	46%
4: Sa Carabassa 0-45m	22%	0%	0%	22%	22%	1%	4%	22%	25%
5. S'Olla 0-5m	0%	0%	0%	0%	2%	0%	0%	60%	0%
6: Estell d'Es Coll 0-50m	10%	0%	0%	10%	2%	0%	15%	1%	0%
7: L'Imperial 0-50m	9%	0%	0%	9%	3%	0%	2%	36%	6%
8: Cova Verda 0-12m	0%	0%	0%	0%	1%	0%	0%	20%	0%
9: Illó Foradat 0-40m	19%	0%	0%	19%	56%	0%	23%	10%	23%
10: Cova Blava 0-40m	16%	0%	0%	16%	41%	1%	18%	14%	5%
11: Sa Platgeta 0-5m	0%	0%	0%	0%	0%	0%	0%	0%	0.1%
12: Cap Llebeig 0-48m	15%	0%	0%	15%		0%	5%	23%	0%
13: Port 0-37m	12%	0%	0%	12%		1%	4%	9%	1%
14: Cala Sta. Maria 0-11m	0%	0%	0%	0%		0%	0%	5%	0%
15: Na Redona 0-32m	3%	0%	0%	3%		0%	9%	37%	10%
Promedio	**8%**	**0%**	**0%**	**8%**	**23%**	**3%**	**6%**	**24%**	**12%**

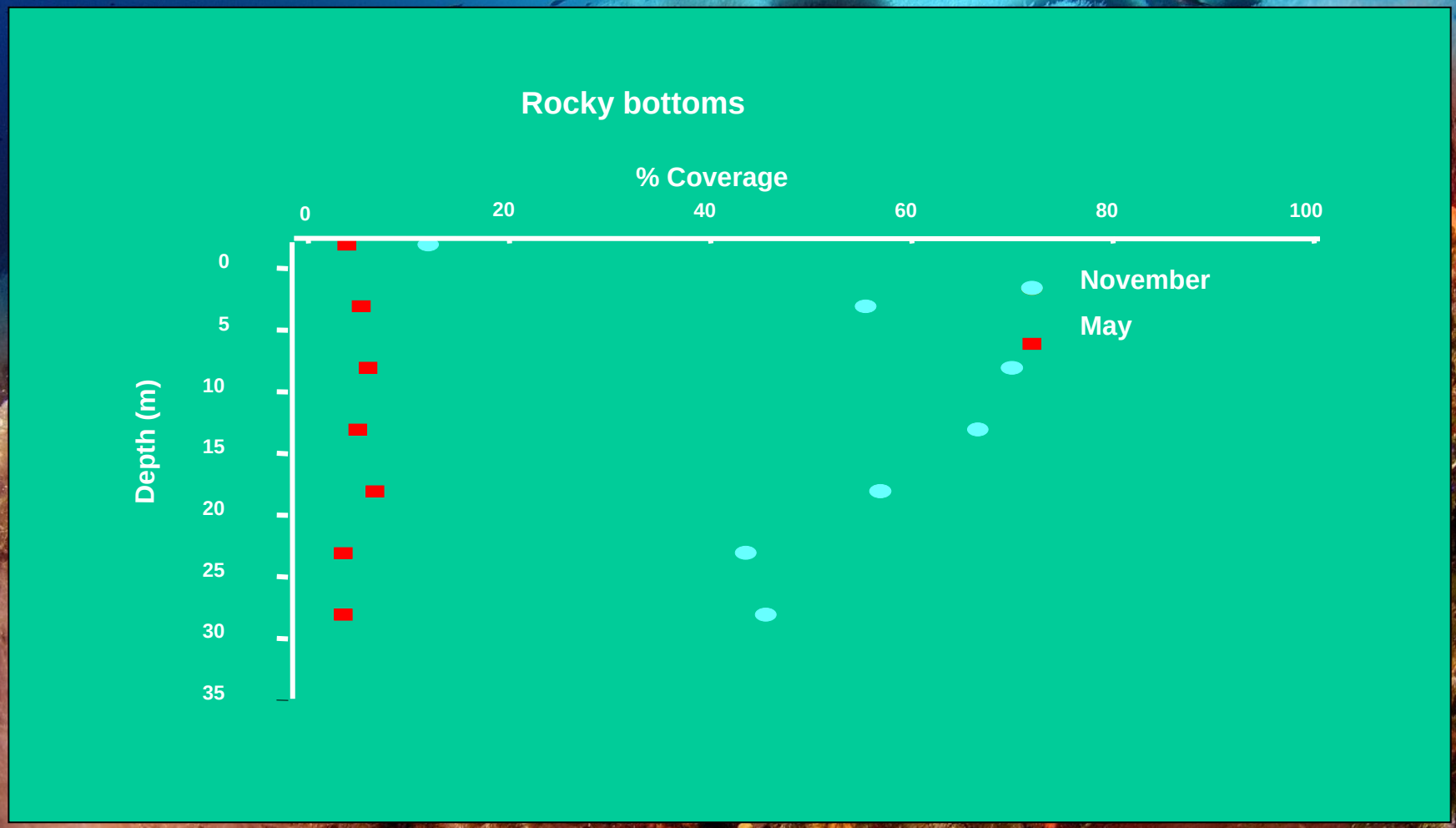
0% <30% 30-60% >60%

Cabrera Archipelago

- **Depth pattern of colonization**



Es Freus Marine Reserve: Seasonality



Es Freus Marine Reserve: differences between communities

Photophilic seaweeds (10 m)

Native species

L. lallemandii

May

November

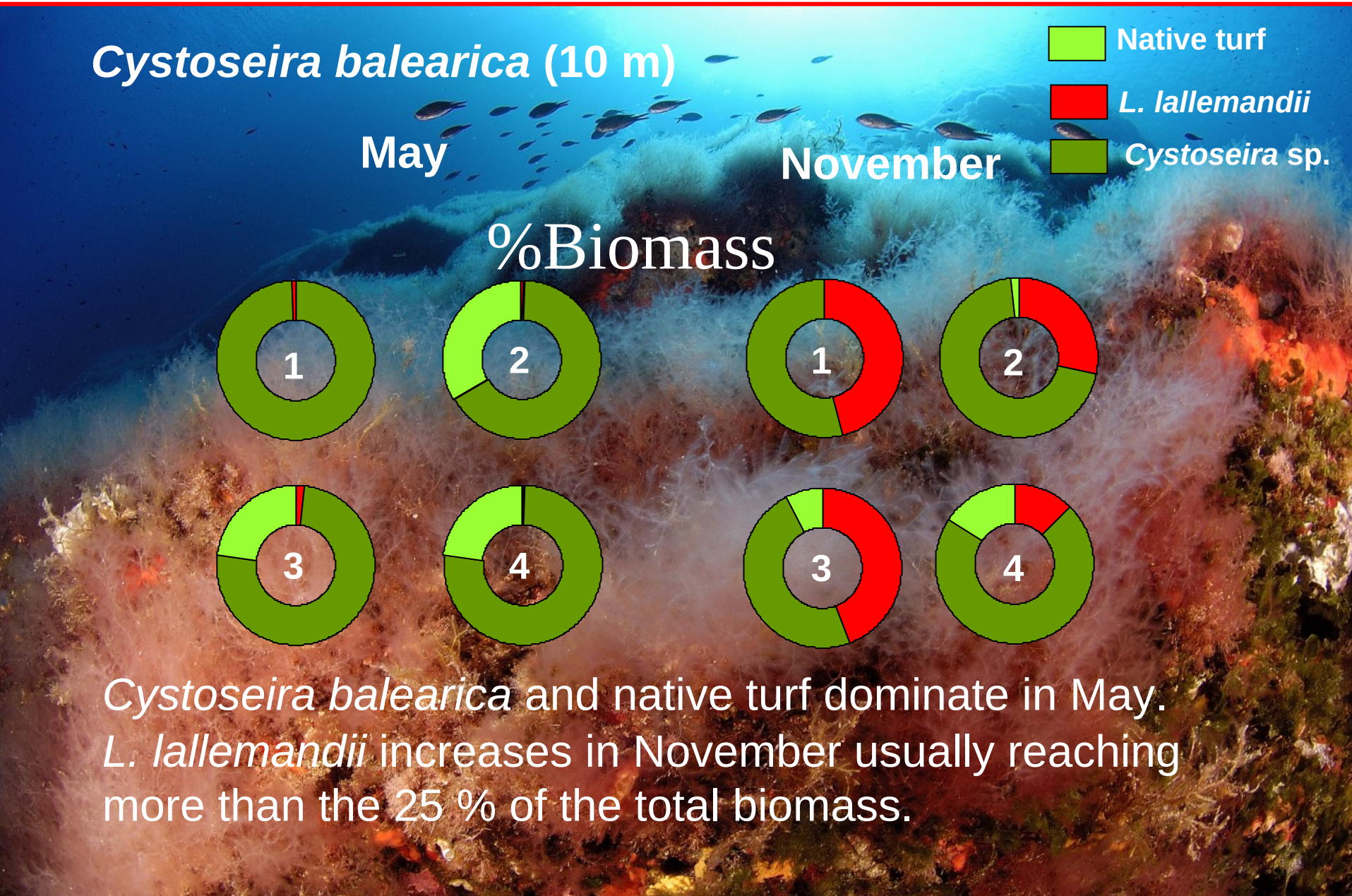
%Biomass

Erect algae

Photophilic algal community is absolutely dominated by native seaweeds in May but...

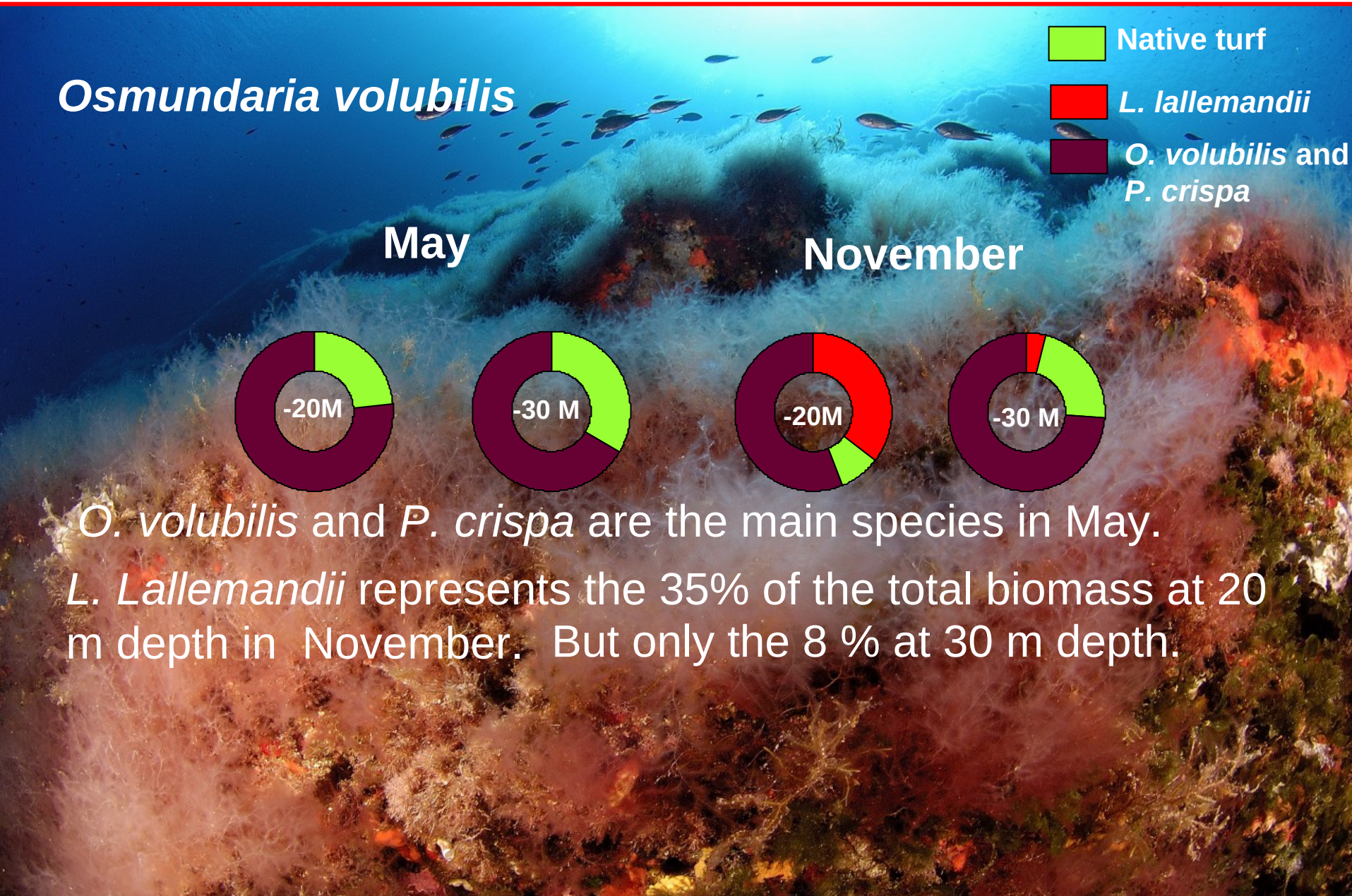
L. lallemandii represents the main percentage of the total biomass in November.

Es Freus Marine Reserve: differences between communities



Cystoseira balearica and native turf dominate in May. *L. lallemandii* increases in November usually reaching more than the 25 % of the total biomass.

Es Freus Marine Reserve: differences with depth



O. volubilis and *P. crispa* are the main species in May.

L. Lallemandii represents the 35% of the total biomass at 20 m depth in November. But only the 8 % at 30 m depth.

Es Freus Marine Reserve

Comunity	Nº samples	Nº sp (May)	Nº sp (November)
Photophilic algae	1	23	15
Cystoseira balearica	4	43	14
Cystoseira spinosa	2	37	5
Osmundaria volubilis	2	45	12

The total number of species is usually at least 2 x in May than in November

In some cases the total number of species in May can be 5 x higher than in November

Question 4: Why a species becomes invasive?

The success of an invasive species is determined by:

physical environment
resources
enemies

and their spatial and seasonal variation

Shea & Chesson (2002), *TREE* 17(4): 170-176

Why there are so many invasive algae in the Mediterranean?

- According to the "Lack of enemies" theory, populations are usually limited by their predators or pathogens.

Tropical seas → High herbivory

Mediterranean → Low herbivory pressure

↓

This could explain the abundance of invasive algae in the Mediterranean

Darwin (1859), *The Origin of Species by means of natural selection*. John Murray
Elton (1958), *The ecology of invasions*. Methuen

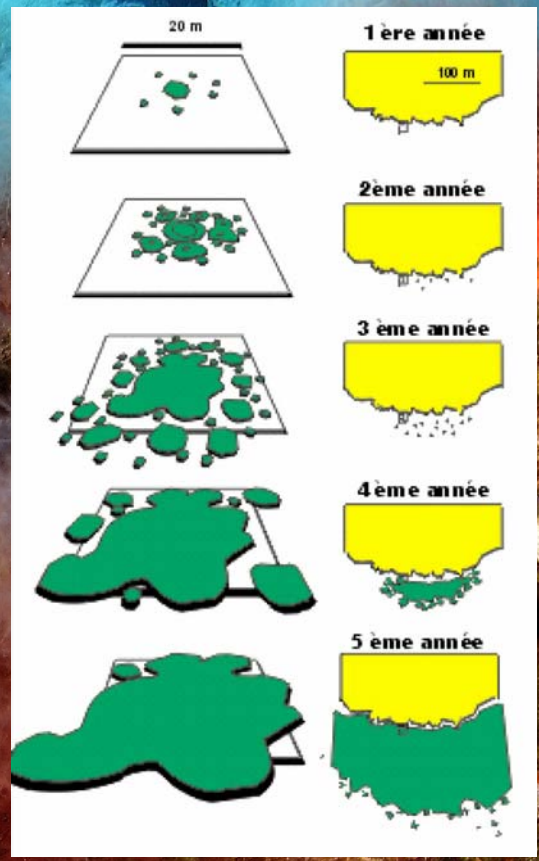
Differences in invasibility

Island	Menorca	Mallorca	Cabrera	Eivissa	Formentera	
Species						
Caulerpa taxifolia						
Acrothamnion preissii						
Asparagopsis taxiformis						
Womersleyella setacea						
Lophocladia lallemandii						
Caulerpa racemosa						
	Extremely invasive					
	Very invasive					
	Invasive					
	Non invasive					

Differences in invasibility

Caulerpa taxifolia

- Non-invasive in Balearic Islands
- Strongly invasive in Southern France and Northern Italy



Why *Caulerpa taxifolia* is not invasive in the Balearic Islands?

There are several evidences that pathogens can act as natural enemies [1,2]

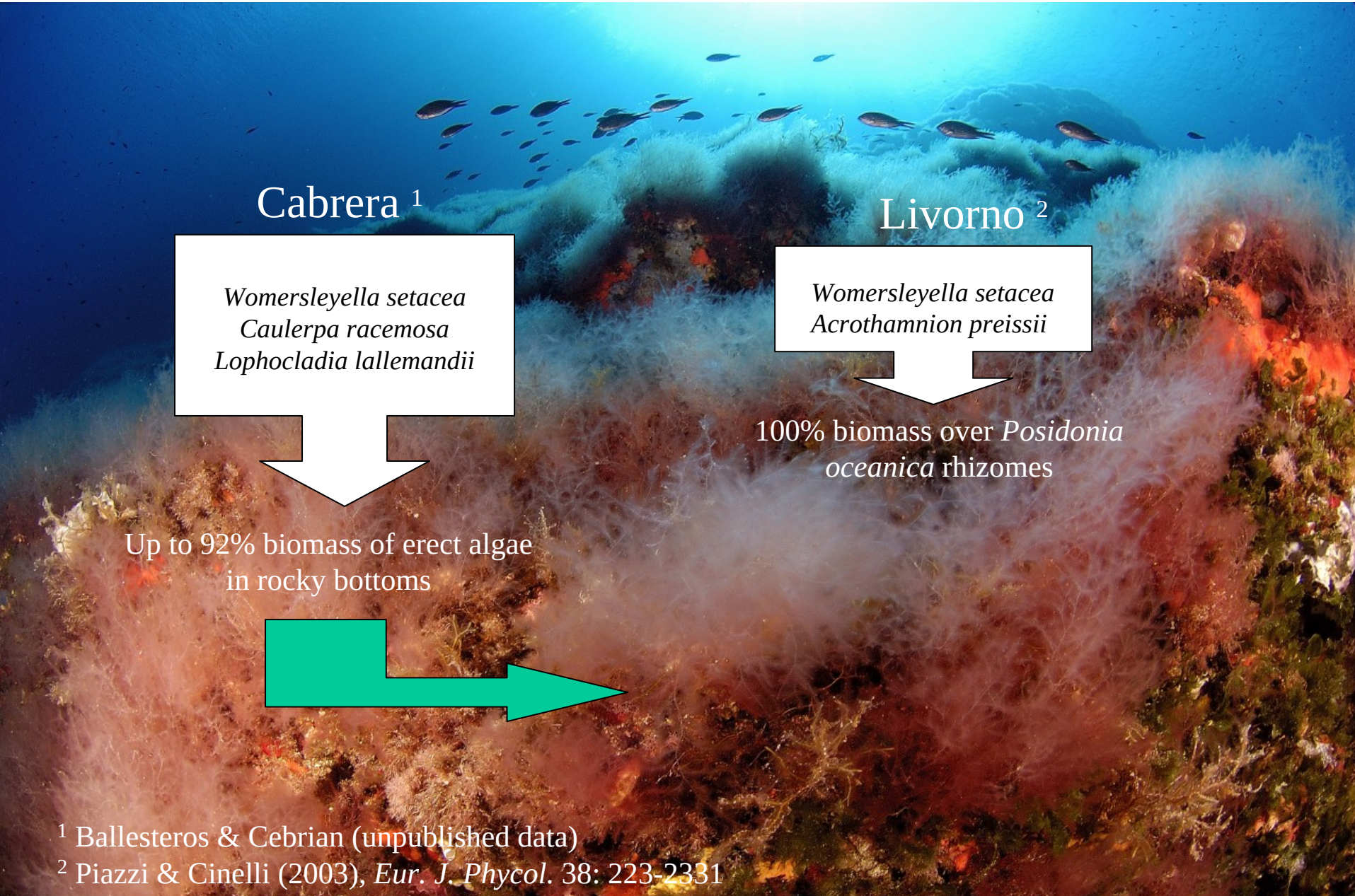
Possible explanation to the low impact and invasibility of *Caulerpa taxifolia* in the Balearic Islands

if

pathogens from *Caulerpa prolifera* could also affect to *Caulerpa taxifolia* (but... what about *Caulerpa racemosa*?)

[1] Torchin *et al*. (2003), *Nature* 421: 628-630
[2] Mitchell & Power (2003), *Nature* 421: 625-627

Question 5: Are there synergistic effects between alien species?



[1] Ballesteros & Cebrian (unpublished data)
[2] Piazzi & Cinelli (2003), *Eur. J. Phycol.* 38: 223-2331

Question 6: Can we know where an invasive species comes from?

Caulerpa taxifolia

- Invasive clone comes from Eastern Australia [1,2]
- 2 different Mediterranean clones [3] ⇒ 2 colonisation events

[1] Jousson *et al.* (1998), *MEPS* 172: 275-280
[2] Jousson *et al.* (2000), *Nature* 408: 157-158
[3] Meussnier *et al.* (2004), *Eur. J. Phycol.* 39: 83-92

Question 7: Are MPAs good sites for aliens' invasion?

Observations: Diverse ecosystems are richer in aliens

[1] Londsdale (1999), *Ecology* 80: 1522-1536
[2] Levine & D'Antonio (1999), *Oikos* 87: 15-26
[3] Stohlgren *et al.* (1999), *Ecol. Monogr.* 69: 25-46

Experimental evidences: Diverse communities are more resistant to invasions

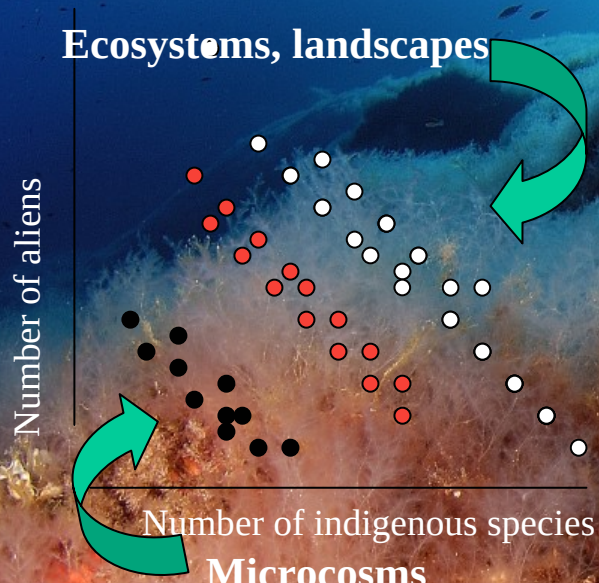
[4] Stachowicz *et al.* (1999), *Science* 286: 1577-1579
[5] Knopps *et al.* (1999), *Ecol. Lett.* 2: 286-293
[6] Naeem *et al.* (2000), *Oikos* 91: 97-108

?

Problem of scales

Biodiversity is important at small scales:

High biodiversity → Low invasivability



Other factors are more important at greater scales:
recruit arrival, resources, physical environment,
habitat heterogeneity

High biodiversity → High invasivability

This could explain the high number and impact of aliens in Cabrera or Freus d'Eivissa and Formentera, and, probably, other Mediterranean MPAs

Levine (2000), *Science* 288: 852-854
Shea & Chesson (2002), *TREE* 17(4): 170-176

Question 8: Which kind of management actions can be implemented?

- Eradication not possible, at least in wide areas
- Manual methods, physical and chemical methods
- Biological methods: introduction of predators

Beroe ovata [1]

⬇

Mnemiopsis leidyi

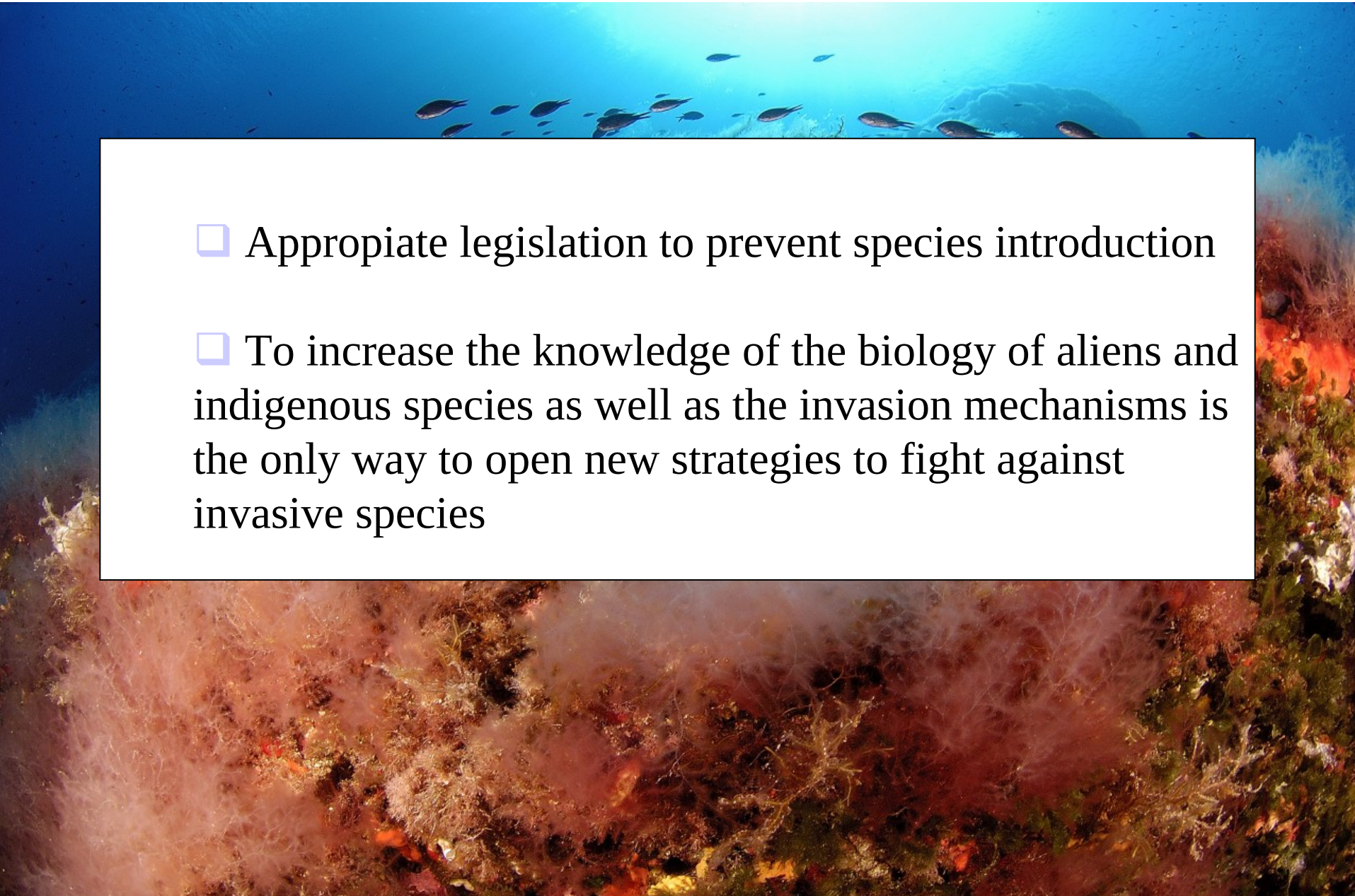
Elysia subornata [2]

⬇

Caulerpa taxifolia

[1] Shiganova *et al*. (2001), *Mar. Biol.* 139: 431-445.
[2] Thibaut *et al*. (2001), *J. Mar. Biol. Ass. U.K.* 81: 497-504.

Management actions



- Appropiate legislation to prevent species introduction

- To increase the knowledge of the biology of aliens and indigenous species as well as the invasion mechanisms is the only way to open new strategies to fight against invasive species


Thanks for your attention!