Development of an ecological quality classification system for marine bioinvasions: challenge to marine biological science

Sergej Olenin

Unifob Environmental Research, Bergen, Norway
and
Coastal Research and Planning Institute, Klaipeda University, Lithuania

Lecture outline:

- State-of-the art: what do we know about marine biological invasions in Europe?
- European Marine Strategy Framework Directive and non-indigenous species
- Notion of "*norm* and *pathology*" in environmental research
- Biological pollution: where and when it happens and how it may be assessed?


Bergen
Kazan
Klaipeda
ARCTIC OCEAN
Norwegian Sea
ATLANTIC OCEAN
North Sea
Mediterranean Sea
Black Sea
Sea of Azov
Caspian Sea
CASPIAN DEPRESSION
English Channel
Prime Meridian
Arctic Circle
Reykjavík
ICELAND
NORWAY
SWEDEN
FINLAND
ESTONIA
LATVIA
LITHUANIA
BELARUS
RUSSIA
UKRAINE
POLAND
GERMANY
DENMARK
UNITED KINGDOM
SCOTLAND
ENGLAND
IRELAND
NETH.
BELGIUM
FRANCE
SWITZ.
AUSTRIA
CZECH REPUBLIC
SLOVAKIA
HUNGARY
ROMANIA
CROATIA
BOSNIA & HERZ.
YUGOSLAVIA
BULGARIA
ITALY
SPAIN
PORTUGAL
MOROCCO
ALGERIA
GREECE
TURKEY
GEORGIA
AZERBAIJAN
SYRIA
IRAQ
KAZAKHSTAN
EUROPE
ASIA
Oslo
Helsinki
Stockholm
Tallinn
St. Petersburg
Nizhniy Novgorod
Moscow
Kazan
Perm'
Yekaterinburg
Chelyabinsk
Ufa
Samara
Saratov
Voronezh
Volgograd
Kiev
Kharkiv
Dnipropetrovs'k
Donets'k
Zaporizhzhya
Odessa
Chişinău
Copenhagen
Dublin
Hamburg
Berlin
Warsaw
The Hague
Amsterdam
London
Brussels
Paris
Luxembourg
Prague
Munich
Vienna
Bratislava
Budapest
Milan
Ljubljana
Belgrade
Bucharest
Sofia
Skopje
Tirana
Athens
Istanbul
Ankara
İzmir
Yerevan
Tabrīz
Baku
Baghdād
Halab
Madrid
Barcelona
Lisbon
Rome
Naples
Algiers
Andorra la Vella
Monaco
San Marino
Mont Blanc 4807 m (15,771 ft)
Etna 3323 m (10,902 ft)
El'brus 5642 m (18,510 ft)
Volga
Don
Dnieper
Danube
Rhine
Loire
Po
Tigris
Sukhona
Kama
Wisła
Elbe
65°
60°
5°
10°
15°
20°
25°
30°
35°
40°
45°

Key definitions

- **<u>Non-indigenous species</u>**
  (synonyms: alien, exotic, non-native, adventive) are species introduced outside of their natural range and outside of their natural dispersal potential. Their presence in the given region is due to intentional or unintentional introduction by humans.

- **<u>Invasive alien species</u>**
  are a subset of established non-native species which have spread, are spreading or have demonstrated their potential to spread elsewhere, causing significant harm to biological diversity, ecosystem functioning, socio-economic values and/or human health in invaded regions.

Economic losses (examples)

- Reductions in fisheries production
  (including collapse of the fishery) due to competition, predation and/or displacement of the fishery species by the invading species
- Impacts on aquaculture
  (including closure of fish-farms), especially from introduced harmful algae
- Physical impacts on coastal infrastructure
- Reduction in the economy and efficiency of shipping;
- Impacts on recreation facilities
- The costs of responding to the problem incl. research monitoring, education, communication, regulation, compliance, management mitigation and control costs

Documented information is very limited
for **fisheries and aquaculture**
(estimate of **€162 million/year** in damage costs: no information is available on control costs)

EC 2008 IAS Impact assessment

Impacts on human health

EXAMPLE

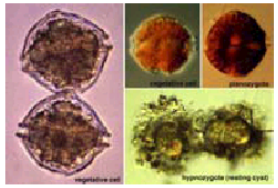
❖ **Cholera (*Vibrio cholerae*)**

Various strains of cholera have been introduced to South America, Gulf of Mexico and other areas. In 1991, for example, a freighter from South Asia emptied its bilges off the coast of Peru. Along with the wastewater came a strain of cholera that reproduced well in the unusually warm and polluted coastal waters. The epidemic began simultaneously at three separate seaports. The bacterium made its way into shellfish and through this, to humans, and spread in an epidemic killing a reported 5,000 people. The unchlorinated water supply in Peru's cities then carried the cholera strain and delivered it into people's houses (Dimijian, 1999). The epidemic extended along South America affecting more than a million people and reportedly killing more than ten thousand by 1994.

Photo: G. Casale

EXAMPLE

❖ **Toxic algae (red/brown/green tides)**



Several species of toxic algae have been transferred to new areas in ship's ballast water and sediments and have established in the new environment. They may form harmful algal blooms (HABs). Depending on the species, they can cause massive kills of marine life through oxygen depletion, release of toxins and/or mucus. They can foul beaches and impact heavily on tourism and recreation. Some species may contaminate filter-feeding shellfish and cause fisheries to be closed. Human health can be affected because HABs can cause fish poisoning (ciguatera) and/or shellfish poisoning.

Photo: Y. Fukuyo

Examples of ecological impacts

Caspian Sea:

The invasion of the comb jelly *Mnemiopsis leidyi* causes a 6-fold decrease in abundance of zooplankton, the only food source for the kilka (three species of *Clupeonella*). The white sturgeon (*Huso huso*) feeding on kilka, considered to be highly endangered.

(Shiganova et al. 2001)

Europe, North America:

The zebra mussel *Dreissena polymorpha,* multiple impacts*:* changes in benthic community structure, modification of bottom sediments, increase in water transparency, release of nutrients

(e.g. Karatayev et al., 2002)

Chinese mitten crab *Eriocheir sinensis*

- Most likely introduced by shipping (ballast water and hull fouling of vessels) or imports of living species for aquaria and for human consumption in early 1910. Still spreads in the UK and Spain, in 2006 first found in Ireland.
- The crabs are the second intermediate host for the human lung fluke parasite in Asia (not yet recorded in crabs in Europe).
- Crabs damage nets and prey upon fishes caught in traps and nets. In freshwater ponds they feed on cultured fish and their food as well.
- The burrowing activities of crabs result in increased erosion of dikes, river and lake embankments. They can also clog up industrial water intake filters.

Photo: S. Gollasch

Pacific oyster *Crassostrea gigas*

pro & contra

Three main categories of consequences

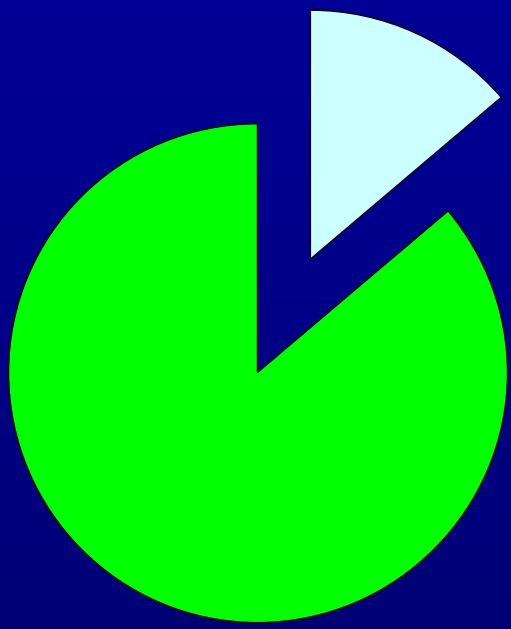
- **Ecological,**
- **Economic,**
- **Human health,**

although they are all inter-linked and influence each other many direct and indirect impacts of invasive aquatic species

State-of-the art:
what do we know about marine biological invasions in Europe?

European Alien Species (DAISIE) Database
www.europe-aliens.org

Data coverage:
>50 countries/regions
and coastal seas



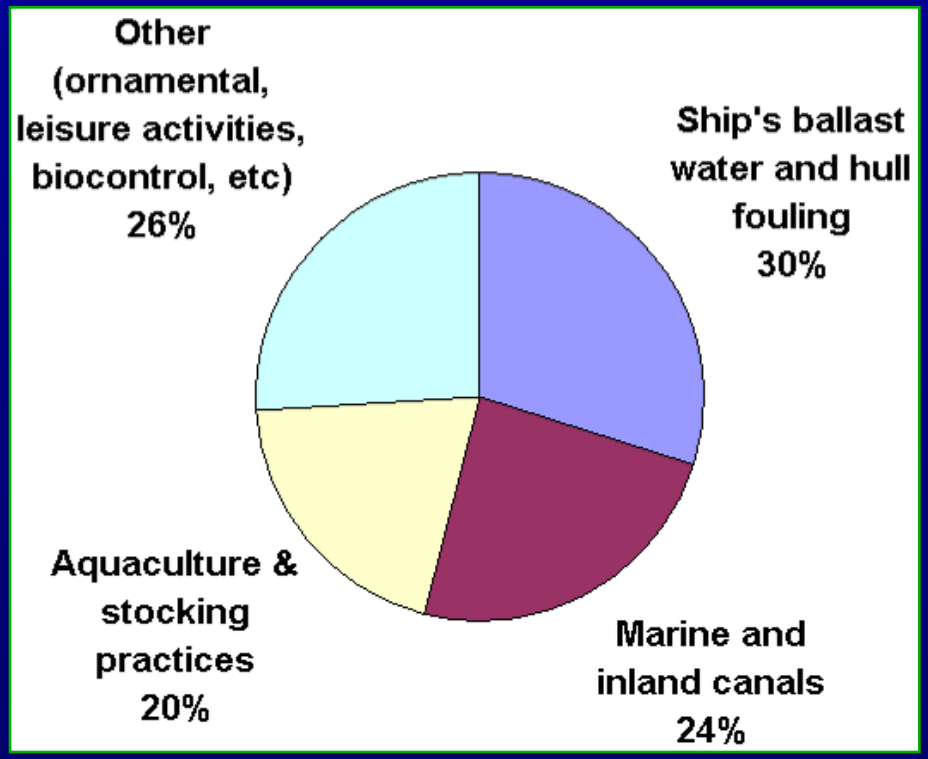
Aquatic species 14%
***n* = 1512**

Terrestrial species
(plants animals etc) 86%

n = 9288

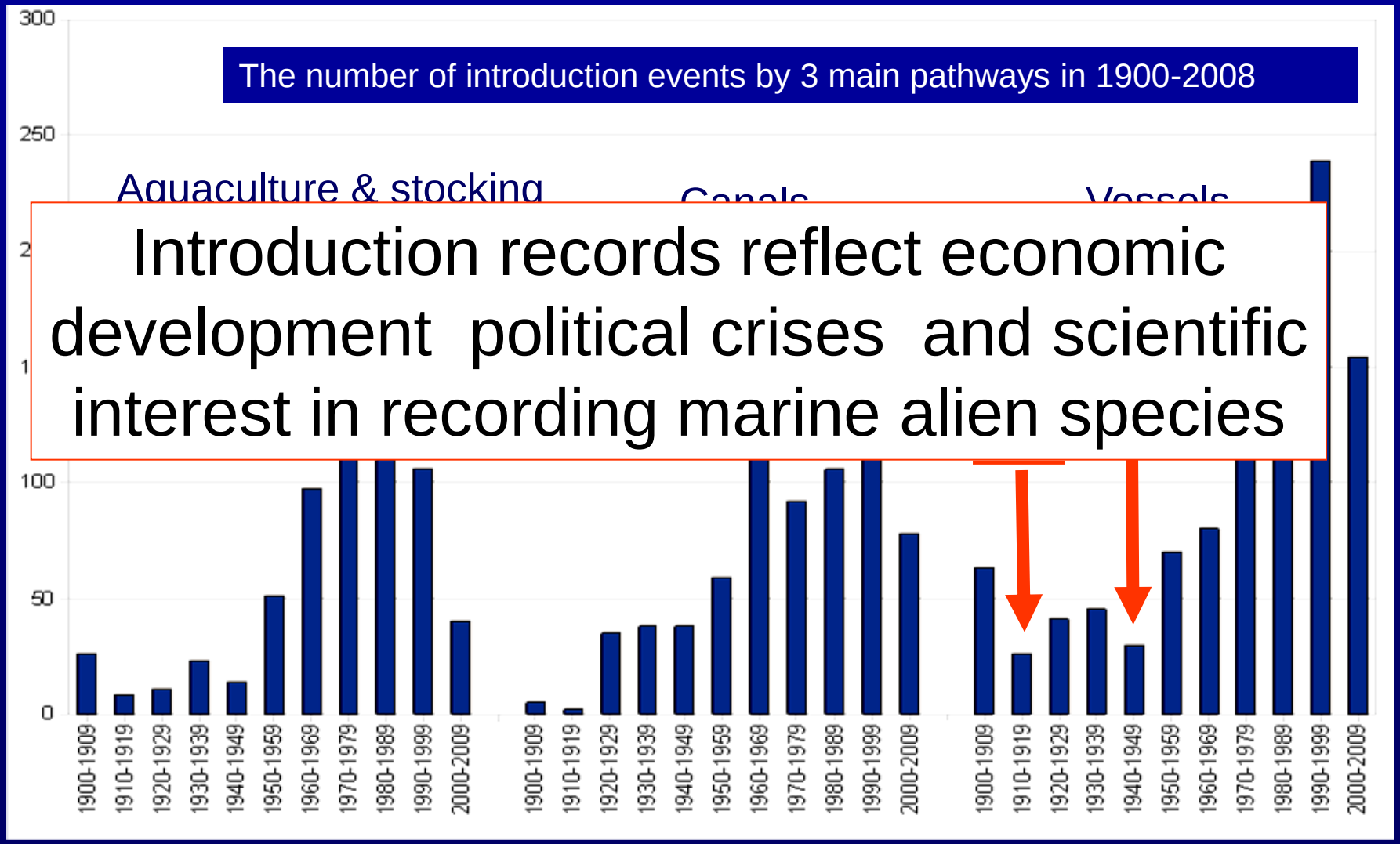
- **Marine species total # 1016 (747 established)**
  - **inland species total # 693 (313 established)**
- **4290** introduction records (events)
  - A record of an alien species in a country/region

Introduction pathways of aquatic alien species in Europe



(DAISIE Database)

The role of the pathways is changing over time



Introduction records reflect economic development political crises and scientific interest in recording marine alien species

(DAISIE Database)

The number of introduced species tells little about the real threat of bioinvasions

- **What matters is the *MAGNITUDE* of the impacts!**

How well do we understand the impacts of alien species on ecosystem services? A pan-European, cross-taxa assessment

Montserrat Vilà[1*], Corina Basnou[2], Petr Pysek[3], Melanie Josefsson[4], Piero Genovesi[5], Stephan Gollasch[6], Wolfgang Nentwig[7], Sergej Olenin[8], Alain Roques[9], David Roy[10], Philip E Hulme[11], and DAISIE partners[12]

Alien species impacts in Europe

Table 2. Total number and percentage of alien species known to have an ecological or economic impact for different taxonomic groups in Europe*

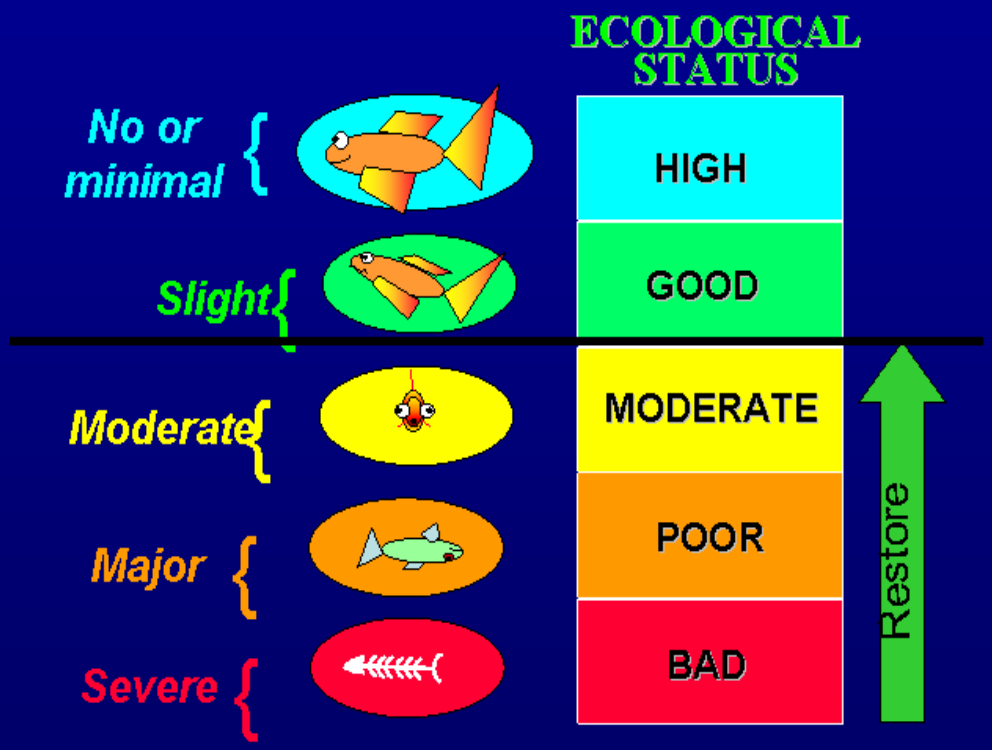
Taxonomic group	*Total*	*Ecological impact (%)*	*Economic impact (%)*
Terrestrial plants	5789	326 (5.6)	315 (5.4)
Terrestrial invertebrates	2481	342 (13.8)	601 (24.2)
Terrestrial vertebrates	358	109 (30.4)	138 (38.5)
Freshwater flora and fauna	481	145 (30.1)	117 (24.3)
Marine flora and fauna	1071	172 (16.1)	176 (16.4)

*DAISIE database search at 12 Feb 2008

Biological pollution: where and when it happens and how it may be assessed?

European Marine Strategy Framework Directive

- Aimed at achieving or maintaining Good Environmental Status (GES) in the EC marine environment.
- Parties to this agreement will be required to report on the environmental status of the seas under their jurisdiction by defined deadline.
- GES is defined by 11 qualitative descriptors



Descriptors of Good Environmental Status

1. Biological diversity

2. Non-indigenous species ***introduced by human activities are at levels that do not adversely alter the ecosystems"***

8. Contaminants
9. Contaminants in fish and other seafood for human consumption
10. Marine litter
11. Introduction of energy including underwater noise

What is “pollution”?

- everything what is
  not in right place
  not in right time and
  not in right quantities
  as it should be

Encyclopedia Britannica about "pollution"

- *"the addition of any substance or form of energy … to the environment at a rate faster than the environment can accommodate it by dispersion breakdown recycling or storage in some harmless form"*

The central question in applied environmental research: definition of "*norm and anomaly*"

Perception of "what is good and what is bad" (essentially "norm and anomaly") is relativistic and changing over time

Early Soviet poster before the modern awareness:

"The smoke of chimneys is the breath of Soviet Russia"

Perception of “what is good and what is bad” (essentially, “norm and pathology”) is relativistic and changing over time

Biological pollution

- The impacts of alien invasive species sufficient to disturb ecological quality by effects on:
  - an individual (internal biological pollution by parasites or pathogens)
  - a population (by genetic change i.e. hybridization)
  - a community (by structural shift)
  - a habitat (by modification of physical-chemical conditions)
  - an ecosystem (by alteration of energy and organic material flow).
- The biological and ecological effects of biopollution may also cause adverse economic consequences.

Based on:
Elliott M. (2003). Biological pollutants and biological pollution – an increasing cause for concern. Mar Pol Bull 46: 275-280.
Olenin S Minchin D Daunys D (2007). Assessment of biopollution in aquatic ecosystems. Mar Pol Bull 55 (7-9) 379-394

The central question in applied environmental research: definition of "*norm and pathology*"

- Assessment of ecological quality is based on the definition of pollution
  - what quantity of *"a substance or form of energy"* makes harm (causes pollution)?
- Assessment of quality is often considered as a function of the aim ("*good*" or "*bad*" in relation to the particular goal):
  - e.g., a water body is good for commercial fishing, but is not suitable for bathing (anthropocentric point of view)
- In many cases, some parameters indicate "good quality", while others – "bad condition"
  - examples are many both in medical science and in applied ecology
- Even less (much less!) is known about alien (non-indigenous, non-native, exotic) species…

How to measure the level of biological pollution?

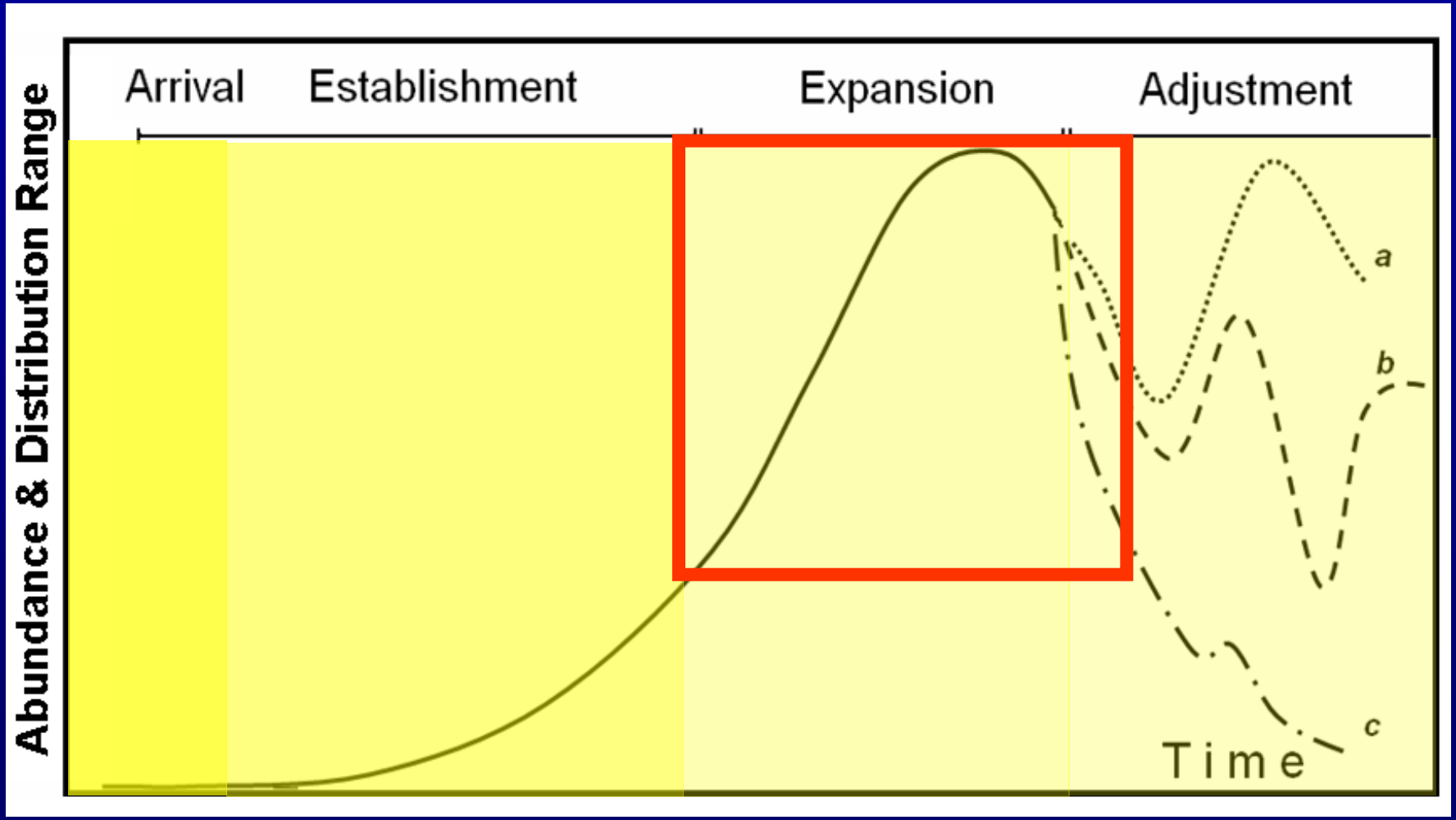
Beaufort Scale

Beaufort number	Wind Speed (mph)	Seaman's term		Effects on Land
0	Under 1	Calm		Calm; smoke rises vertically.
1	1-3	Light Air		Smoke drift indicates wind direction; vanes do not move.
2	4-7	Light Breeze		Wind felt on face; leaves rustle; vanes begin to move.
3	8-12	Gentle Breeze		Leaves, small twigs in constant motion; light flags extended.
4	13-18	Moderate Breeze		Dust, leaves and loose paper raised up; small branches move.
5	19-24	Fresh Breeze		Small trees begin to sway.
6	25-31	Strong Breeze		Large branches of trees in motion; whistling heard in wires.
7	32-38	Moderate Gale		Whole trees in motion; resistance felt in walking against the wind.
8	39-46	Fresh Gale		Twigs and small branches broken off trees.
9	47-54	Strong Gale		Slight structural damage occurs; slate blown from roofs.
10	55-63	Whole Gale		Seldom experienced on land; trees broken; structural damage occurs.
11	64-72	Storm		Very rarely experienced on land; usually with widespread damage.
12	73 or higher	Hurricane Force		Violence and destruction.

Source: www.mountwashington.org/education/

Is it possible to develop something similar to measure the bioinvasion consequences?

Impacts at different phases of invasion



Modified from: Reise, Olenin, Thieltges (2006). Helgoland Marine Research, 60 (2): 106–112

Biopollution assessment rationale

1) Define the assessment unit

2) Define the assessment period

Abundance and distribution range of alien species.

A	Species occurs in low numbers in one or several localities
B	Species occurs in low numbers in many localities, or in moderate numbers in one or several localities, or in high numbers in one locality
C	Species occurs in low numbers in all localities, or in moderate numbers in many localities, or in high numbers in several localities
D	Species occurs in moderate numbers in all localities, or in high numbers in many localities
E	Species occurs in high numbers in all localities

(Olenin, Minchin, Daunys, 2007. Assessment of biopollution in aquatic ecosystems. *Marine Pollution Bulletin*)

Biopollution assessment

Impact on community – the changes caused in native species composition and abundance, including shifts in type-specific communities

C0	No displacement of native species, ranking of native species unchanged, type specific community present
C1	Local displacement of native species, dominant species remain the same, type-specific communities are present
C2	Large scale displacement of native species, changes in type-specific communities, shifts in community dominant species
C3	Population extinctions, alien species are dominant, loss of type-specific community
C4	Extinction of native keystone species, extinction of type-specific communities

Impact on habitat – the character of habitat modification

H0	No habitat alteration
H1	Alteration of a habitat, but no reduction of spatial extent of a habitat
H2	Alteration and reduction of spatial extent of a habitat
H3	Alteration of a key habitat, severe reduction of spatial extent of habitat
H4	Loss of habitats in most or the entire assessment unit, loss of a key habitat

Impact on ecosystem – the impact on ecosystem processes and functioning

E0	No measurable impact
E1	Weak changes with no loss or addition of new ecosystem function
E2	Moderate modification of ecosystem performance, changes in functional group(s)
E3	Severe shifts in ecosystem functioning, reorganization of the food web
E4	Extreme, ecosystem-wide shift in the food web and/or loss of the role of a functional group(s)

(Olenin, Minchin, Daunys, 2007. Assessment of biopollution in aquatic ecosystems. *Marine Pollution Bulletin*)

Confidence level
applied for assessing the impacts

High	The impacts were documented by field and/or experimental studies for the given assessment unit
Medium	The impacts were documented by field and/or experimental studies for a part of the assessment unit and extrapolated to the entire system by expert judgment
Low	The impacts were not documented neither by field nor by experimental studies, expert knowledge of the species impact based on data from studies made elsewhere was applied

Combined abundance and distribution range class and evaluation of impact of aliens on: native species and communities (C), invaded habitat (H) and ecosystem functioning (E).

ADR	species and communities					habitat					ecosystem function				
	C0	C1	C2	C3	C4	H0	H1	H2	H3	H4	E0	E1	E2	E3	E4
A	0	1	–	–	–	0	1	–	–	–	0	1	–	–	–
B	1	1	2	–	–	1	1	2	3	–	1	1	2	–	–
C	1	1	2	–	–	1	2	2	3	4	1	2	2	–	–
D	–	2	2	3	4	–	2	3	3	4	–	2	2	3	4
E	–	–	3	3	4	–	2	3	3	4	–	2	3	3	4

The decision support scheme for assessment of Biopollution Level (BPL)

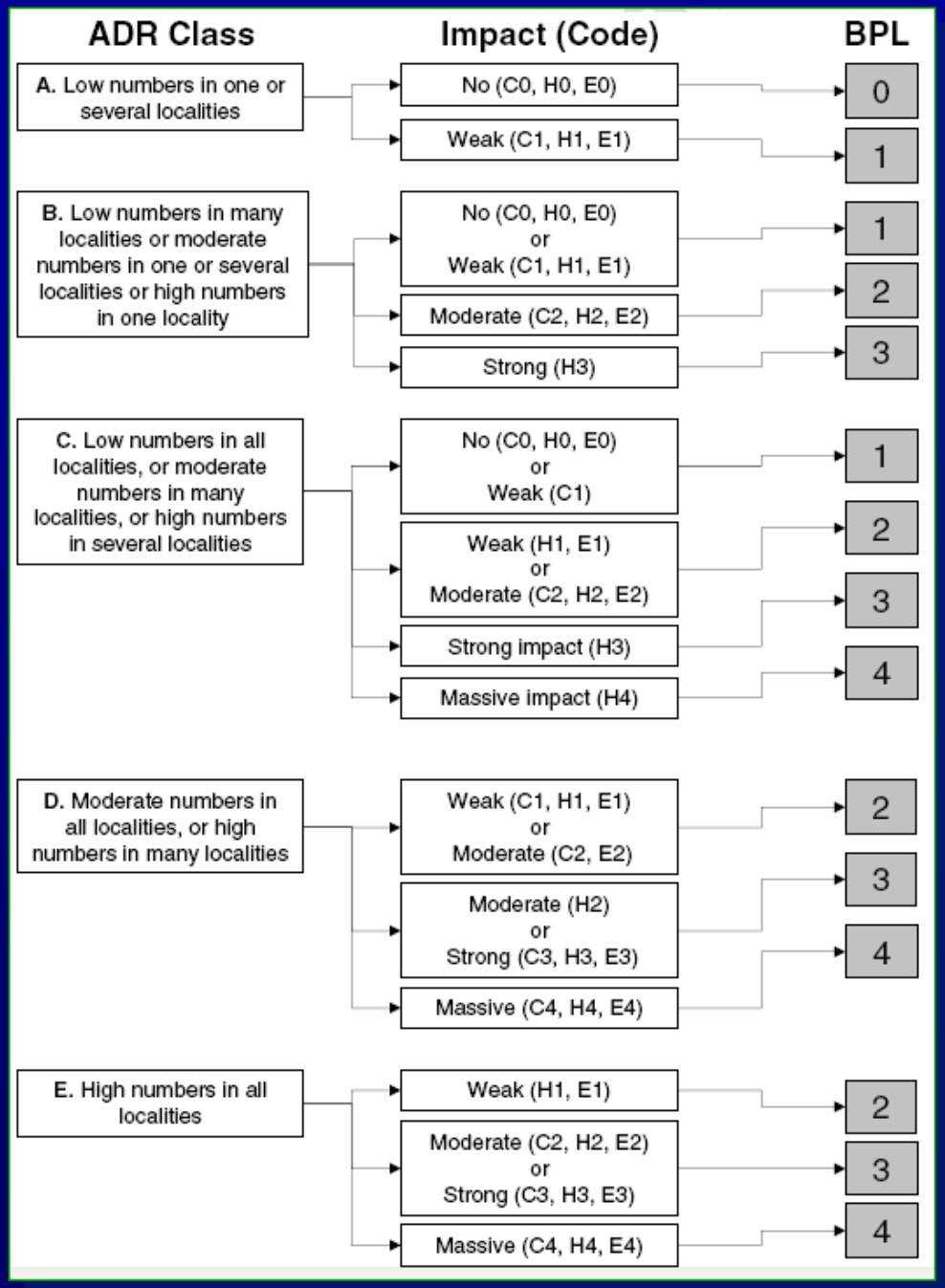
Used to develop the

Computerized

Biopollution

Assessment

Tool



Biopollution assessment tool

http://corpi.ku.lt/~biopollution/

- **Provides a uniform approach for assessment of alien species impacts, enabling comparison between different alien species and different areas.**
- **May be used for:**
  - **acquiring baseline information on alien species,**
  - **monitoring of biopollution impacts,**
  - **prioritizing impacting species (target species lists),**
  - **evaluation of effectiveness of bioinvasion management.**

Challenges

- When does an alien species stop being “an alien” species?
  - » After it stops acting as a biological pollutant, causing harm to a system?
- How reference conditions can be defined in relation to biological pollution?
  - » Is it possible in principle?
  - » What is the acceptable level of biological pollution?
- How to show the importance of bioinvasion research without succumbing to “publicity rising hysteria” about “killing algae”, “fish-eating comb jellies” and other mass media clichés ?

Acknowledgements

EU FP6 Projects:

- **DAISIE** - Delivering Alien Invasive Species Inventories for Europe
- **ALARM** - Assessing Large-scale environmental risks with tested methods
- **IMPASSE** - Environmental impacts of invasive alien species in aquaculture
- **MARBEF** - Marine Biodiversity and Ecosystem Functioning

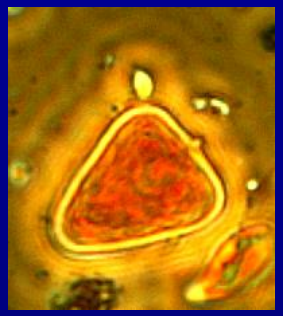
EU FP7 Project:

- **MEECE** - Marine Ecosystem Evolution in a Changing Environment

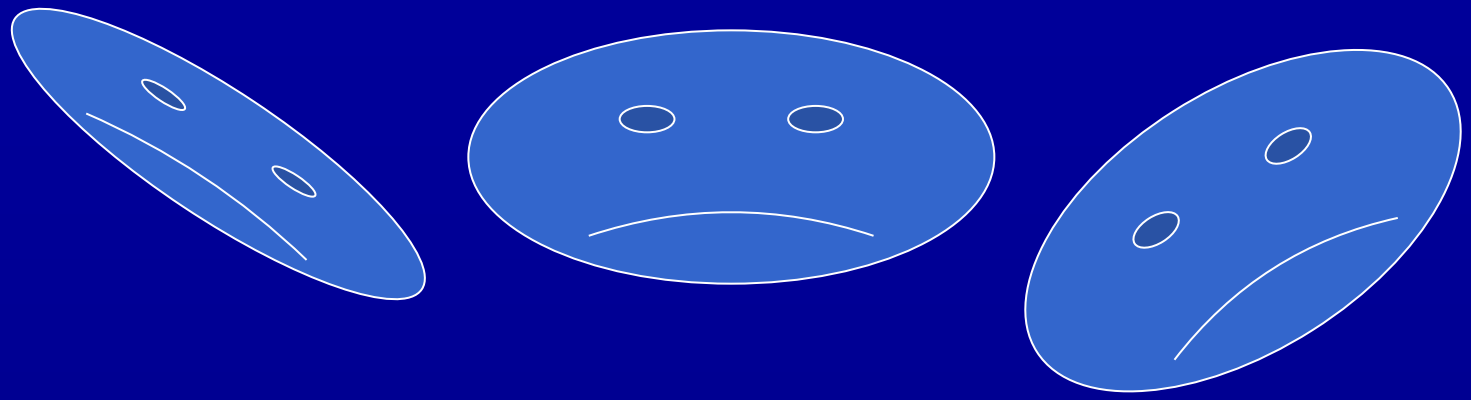
A Lithuanian State Science and Studies Foundation project:

- **BINLIT** - Biological invasions in Lithuanian ecosystems under the climate change: causes, impacts and projections

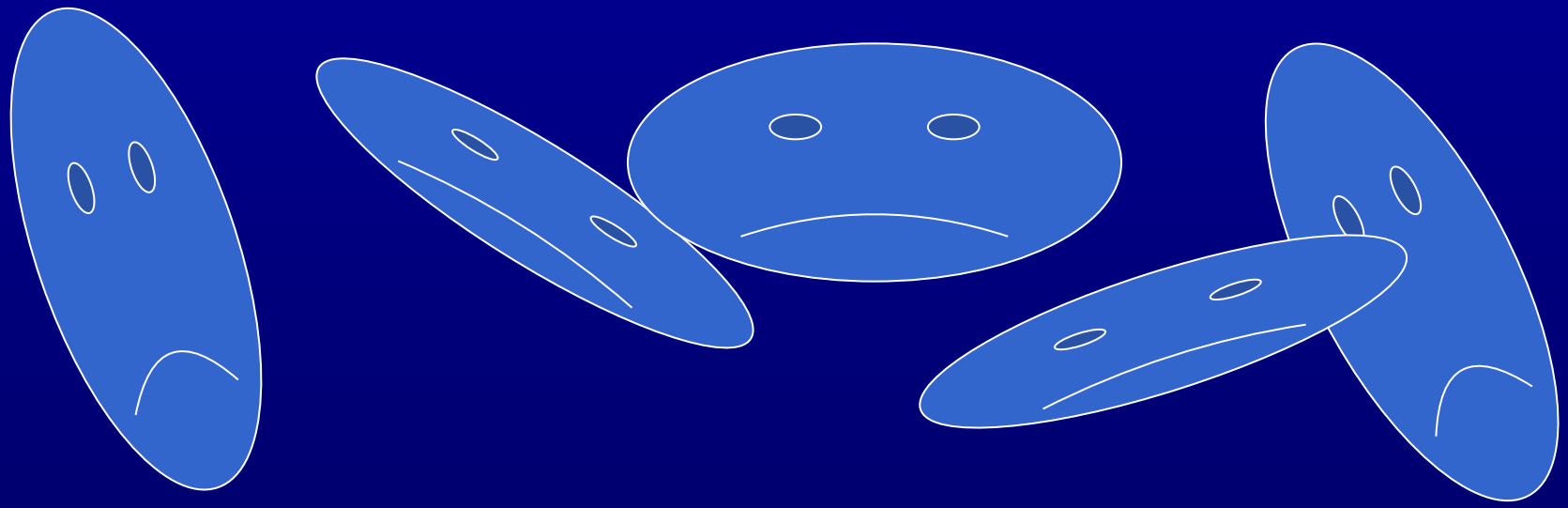
Colleagues:
Anna Occhipinti Ambrogi, Dario Savini, Francesca Gherardi, Elena Tricarico, Bella Galil, Stephan Gollasch, Laurence Miossec, Ian Cowx, Andy D. Nunn, Dan Minchin, Darius Daunys, Viktoras Didžiulis



Thank you for your attention!



Equal rights to parasites?



There are opinions that the terms and notions widely used in invasion biology (e.g., *“aliens”, “non-native”, “exotics”, “non-indigenous”, “xeno-diversity”)* remind the phraseology of the notorious racist theories and provoke xenophobic feelings.

Does this ethical concern have anything to do with the scientific problem of bioinvasions?

Are such parallels between the human world and natural life permissible?

EU Water Framework Directive: Ecological Quality Indicators

BIOLOGICAL

- Phytoplankton
- Phytobenthos
- Macrofauna
- Fish

- Species composition, abundance and biomass of natural communities;
- Presence of indicator (sensitive) species and values of relevant indices

PHYSICO-CHEMICAL

- Nutrients
- Salinity
- Transparency
- Oxygen
- Synthetic pollutants
- pH
- Temperature

HYDRO-MORPHOLOGICAL

- Changes in sediment transport
- Water flow
- Channel patterns
- Conditions of the shore zones
- Substrate conditions

- Concentrations of chemicals must meet environmental quality standards;
- Both physico-chemical and hydro-morphological parameters should be in the ranges which ensure proper functioning of the water type specific ecosystem and the achievement of the values specified for the relevant biological quality elements.

WFD Ecological Quality Indicators

BIOLOGICAL
- Phytoplankton
- Phytobenthos
- Macrofauna
- Fish

PHYSICO-CHEMICAL
- Nutrients
- Salinity
- Transparency
- Oxygen
- Synthetic pollutants
- pH
- Temperature

HYDRO-MORPHOLOGICAL
- Changes in sediment transport
- Water flow
- Channel patterns
- Conditions of the shore zones
- Substrate conditions

All parameters may be changed by invasive alien species!

WFD Ecological Quality Indicators

BIOLOGICAL
- Phytoplankton
- Phytobenthos
- Macrofauna
- Fish

- Hybridization with native species,
- Change in species composition
- Change of community structure,
- Elimination of native species (incl. sensitive/indicator species)

PHYSICO-CHEMICAL
- Nutrients
- Salinity
- Transparency
- Oxygen
- Synthetic pollutants
- pH
- Temperature

- Changes in nutrient regime (e.g. due to algal blooms, modification of benthic-pelagic coupling, alteration of food web)
- Bioaccumulation of synthethic pollutants
- Habitat engineering (encrusting of solid objects, changes of bottom sediments)
- Alteration of coastal biotopes

HYDRO-MORPHOLOGICAL
- Changes in sediment transport
- Water flow
- Channel patterns
- Conditions of the shore zones
- Substrate conditions