

Are we facing a more
gelatinous future for
coastal waters – the
Adriatic Sea case



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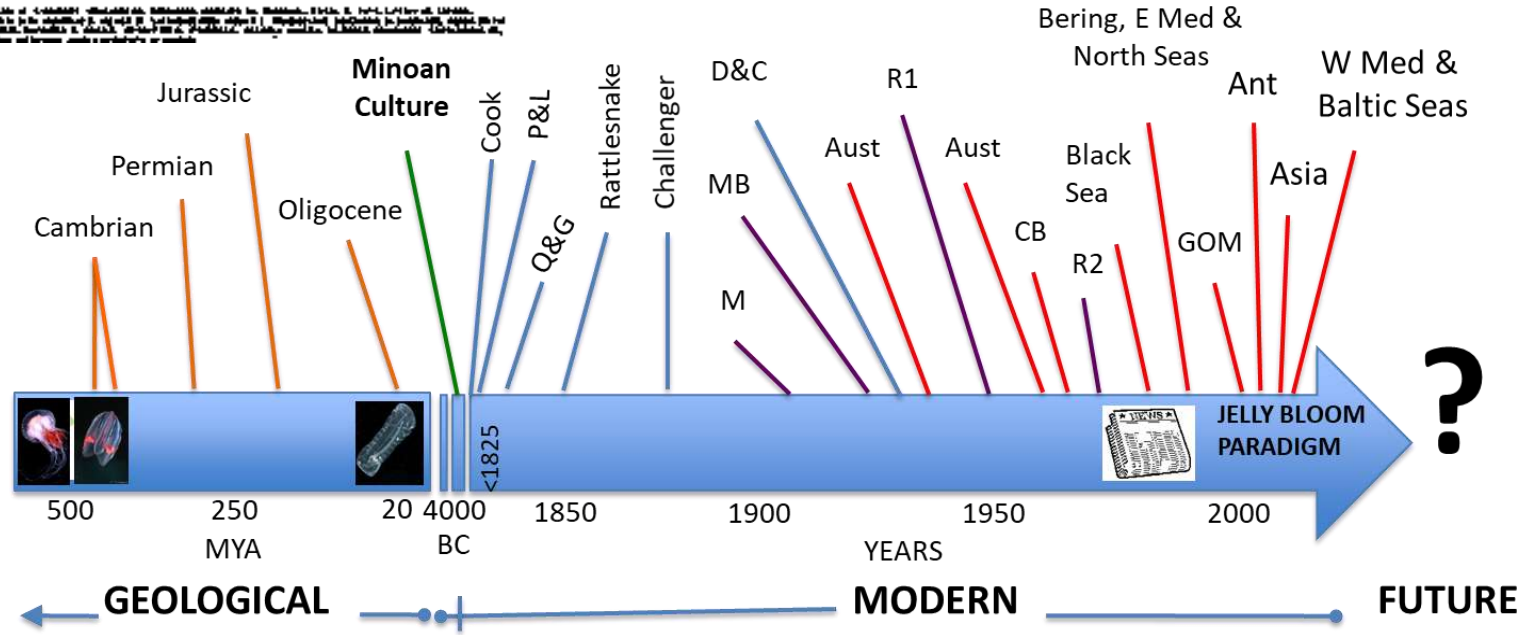
foto: Robert Radolovič

Questioning the Rise of Gelatinous Zooplankton in the World's Oceans
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ARTICLE IN ADVANCE
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Are jellyfish blooms recent phenomena?

Jellyfish blooms on the geological time scale



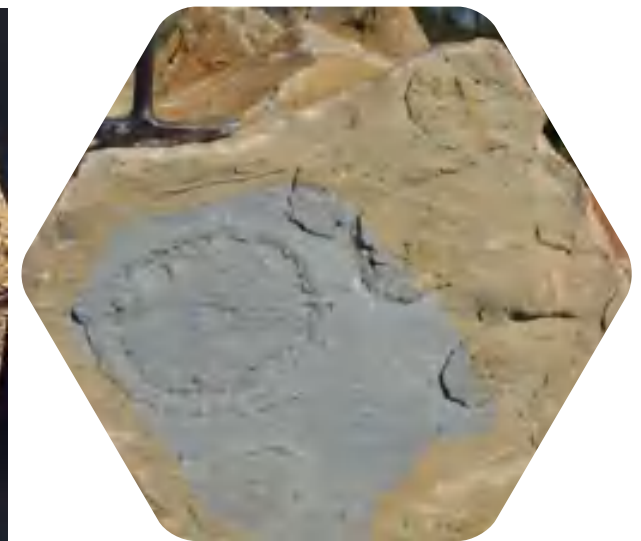
Trieste, 17 May 2017



Solnhofen, Germany, upper Jurassic
Rhizostomites admirandus Haeckel 1866



Elerji, Slovenia
 middle Eocene



Jellyfish research: history

- Aristotle – ‘the founder of zoology’: Acalephae, cnide (name Cnidaria)
- second half of 19th century first golden “gelata” era: Graeffe, Haeckel, Hadži, Leuckart, Agassiz, Mayer... described many gelatinous organisms
- the last decades of the 20th century - a revival of the jellyfish research - mainly due to problems with blooms



JULES VERNE
VINOT MILLE LIEUES
ou
LES MERS

1870

Jellyfish perception – global problem?

Linking human well-being and jellyfish ecosystem services, impacts, and societal responses

William M. Legler^{1,2}, Stefan Collares³, Sally J. Hellmann⁴, Carlos M. Ferrer⁵, James Baird⁶, Jennifer E. Powell⁷, Lawrence P. Meyer⁸, Homer Malmgren⁹, Kelly B. Swartz¹⁰, Giovanni S. Cecchi G. Ricci¹¹, Kelly H. Cook¹², Anthony D. Brooker¹³, and Robert H. Lamb¹⁴

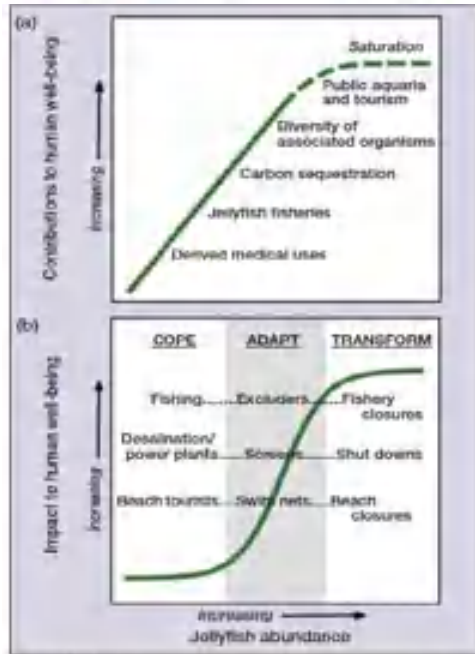
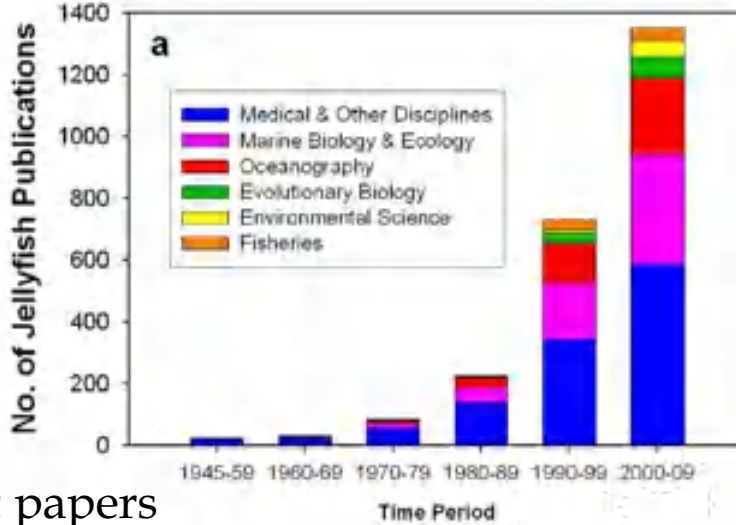


Figure 1. (a) Linear scaling relationship between ecosystem services illustrated in the text and jellyfish abundance. A theoretical saturation (dashed portion) is assumed to occur. (b) Societal responses to increasing jellyfish abundance illustrate thresholds where adaptation capacity will be needed to avoid a societal transformation.

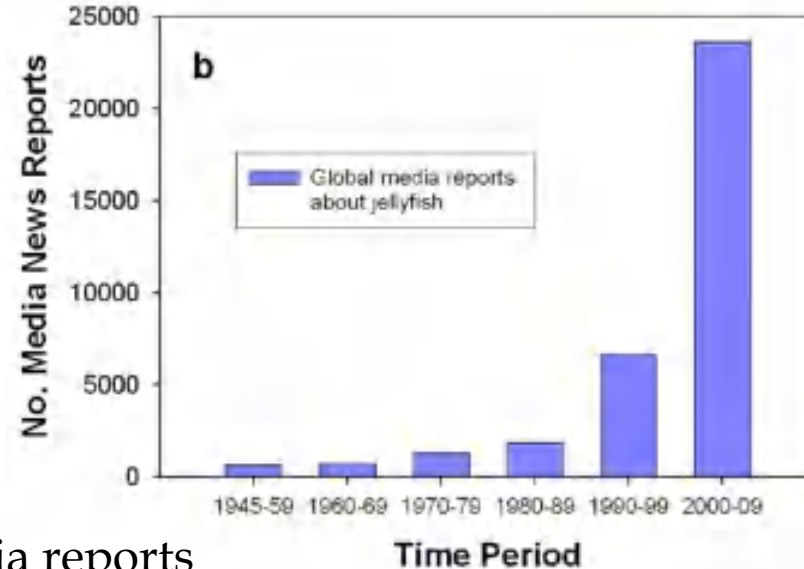


Questioning the Rise of Gelatinous Zooplankton in the World's Oceans

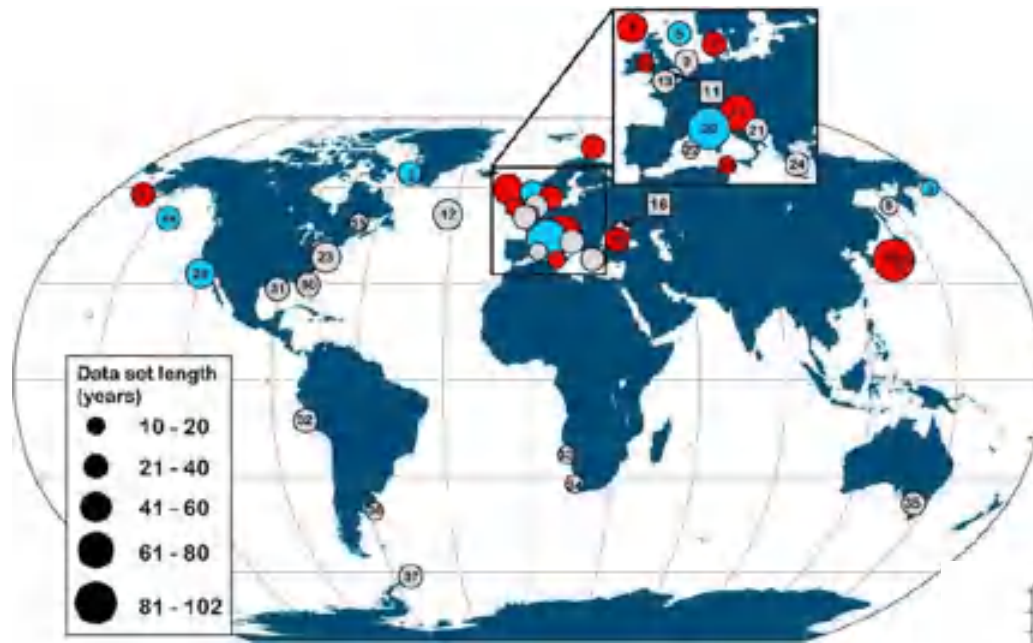
Maine ecology: Attack of the blobs



Scientific papers



Media reports



www.pnas.org/cgi/doi/10.1073/pnas.1210920110

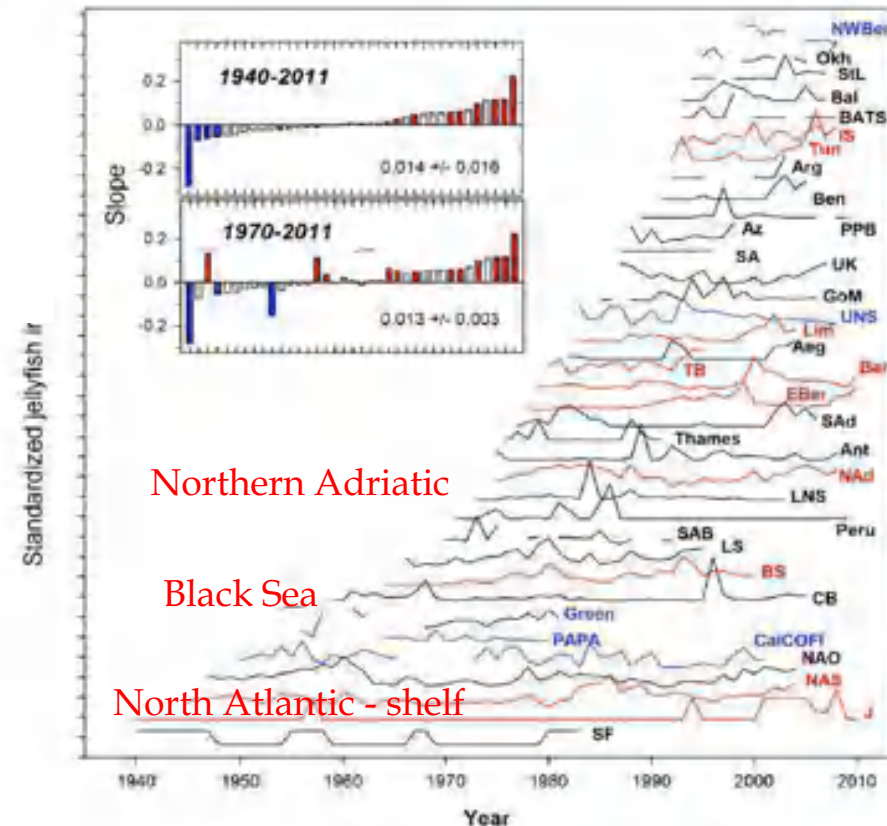
Recurrent jellyfish blooms are a consequence of global oscillations

Robert H. Gendron^{1,2}, Carlos M. Duarte^{3,4}, Kylie A. Pitt⁵, Kelly A. Robinson^{6,7}, Cathy M. Lucas⁸, Kelly R. Swadlow⁹, Thomas W. Blanton¹⁰, Kelly Sogard¹¹, Jennifer S. Posada¹², Mary Beth Dwyer¹³, Shin-ichi Uye¹⁴, Lawrence P. Maden¹⁵, Richard D. Brodeur¹⁶, Steven H. D. Haddock¹⁷, Alois Miliute¹⁸, Gregory D. Pury¹⁹, Bruno Briscoe²⁰, Javier Quiñones²¹, Marcelo Adre²², Rachel Harvey²³, James M. Arthur²⁴, and William H. Graham²⁵

Colours indicate trends in jellyfish abundance over time (linear regressions, $P < 0.05$):

significant increase (red),
 significant decrease (blue),
 no trend (gray)

Analysis included available published and unpublished long-term datasets till 2011 (datasets > 10 years)



Adriatic Sea

- an elongated semi-enclosed sea basin with a southeast-northwest orientation
- major freshwater inputs on north-western shore (Po) – most productive part
- generally cyclonic circulation pattern
- Three distinct basins:
 - NEA – with depths < 50 m (TB < 30 m)
 - CEA – transition area between shallow northern part and deep southern and characterized by many island on east
 - SEA – deep (> 1000 m), communicating through Otranto Straits with Ionian Sea
 - BK – Boka Kotorska is large bay often called fjord due to steep mountain coast



Scyphozoa (no. of species)

Adriatic: 9 native + 4 NIS

Mediterranean: 10 native + 13 NIS

Ctenophora (no. of species)

Adriatic: 14 native + 2 NIS

Mediterranean: 30 native + 2 NIS

Examples of jellyfish blooms in the Adriatic:

A) *Rhizostoma pulmo*

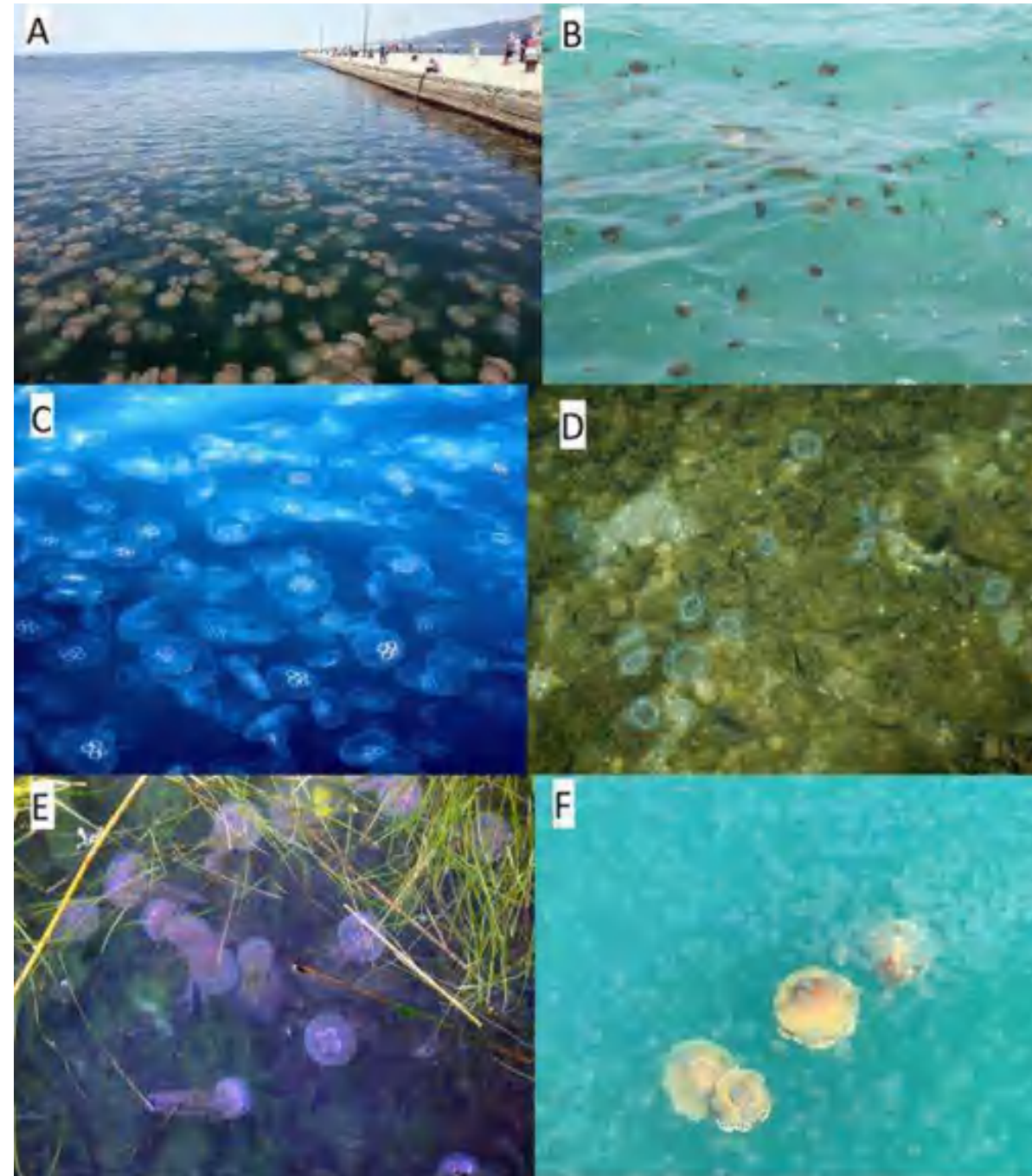
B) *Chrysaora hysoscella*

C) *Aurelia solida*

D) *Discomedusa lobata*

E) *Pelagia noctiluca*

F) *Mnemiopsis leidyi* & *Cotylorhiza tuberculata*



Scyphomedusae and Ctenophora of the Eastern Adriatic:
Historical Overview and New Data

Branka Pestorič¹, Davor Lučić^{2,3}, Natalija Bojanić⁴, Martin Vodopivec⁵, Tjaka Kogovšek⁶, Ivana Vrdoljak⁷,
Paolo Pallaga⁸ and Alenka Malej⁹



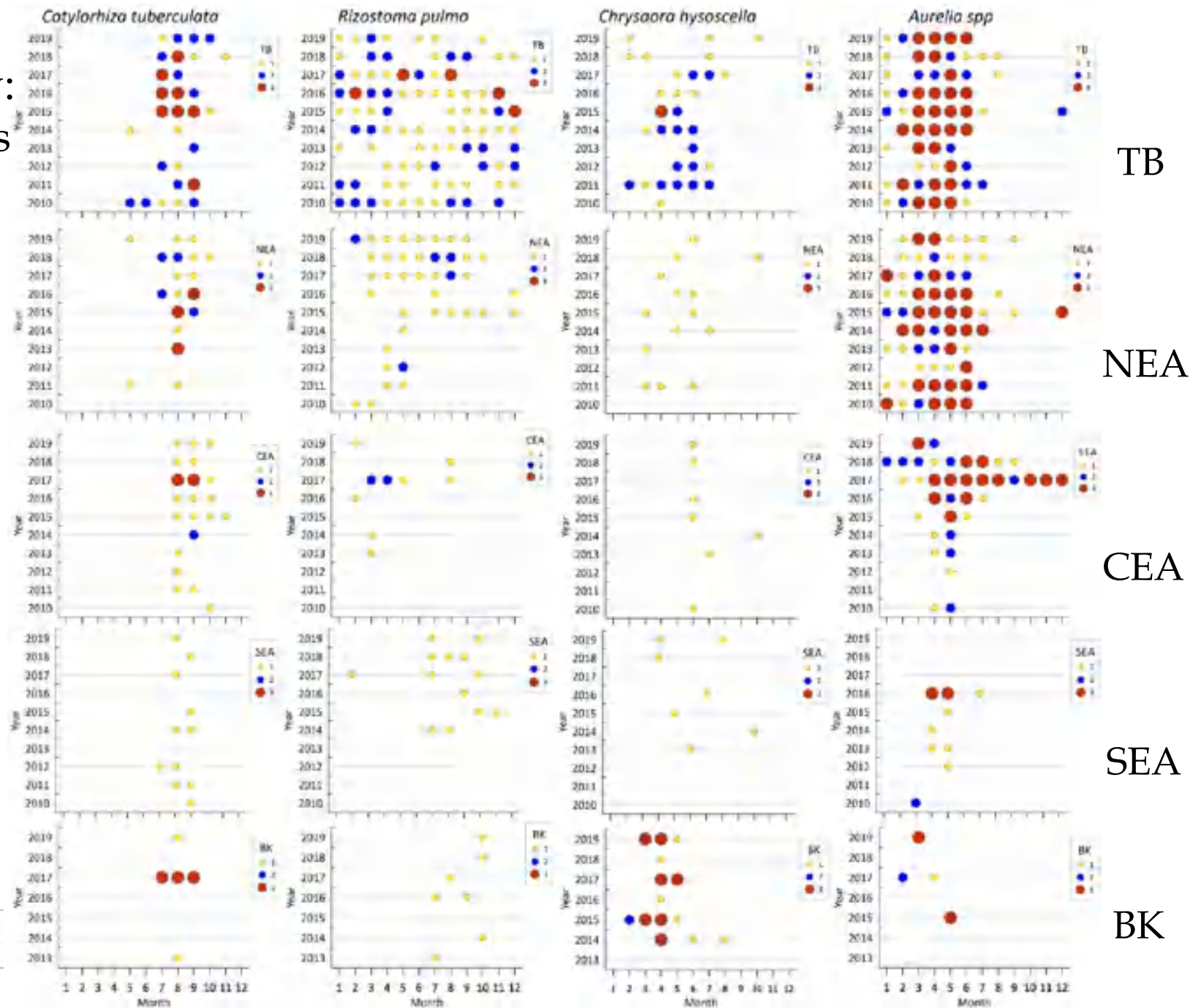
Spatial and temporal variability: four dominant Scyphozoa species (monthly data, 2010 – 2019)

blank – jellyfish not observed

yellow dot – sporadic occurrence of individual organisms

blue dot – frequent occurrence of individual organisms

red dot – frequent occurrence of large aggregations



TB

NEA

CEA

SEA

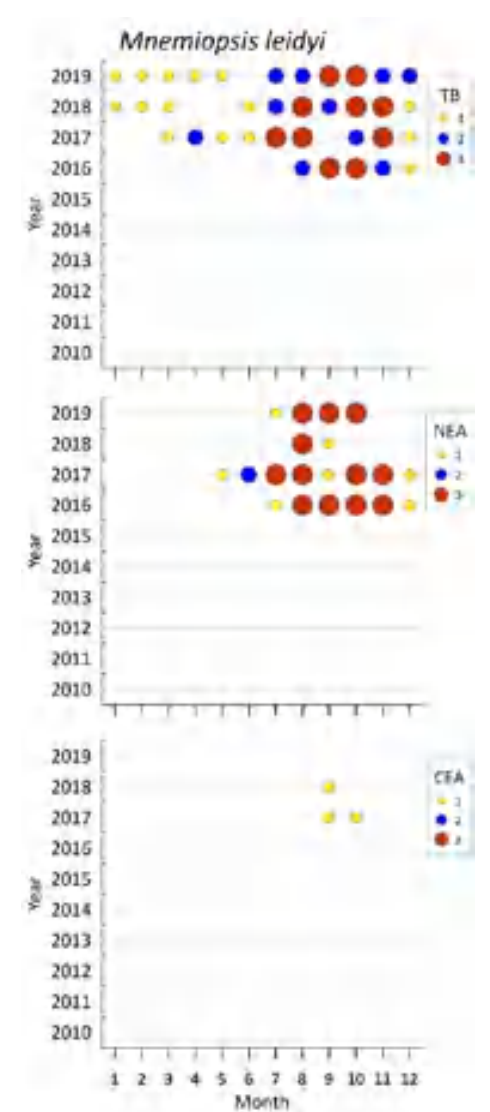
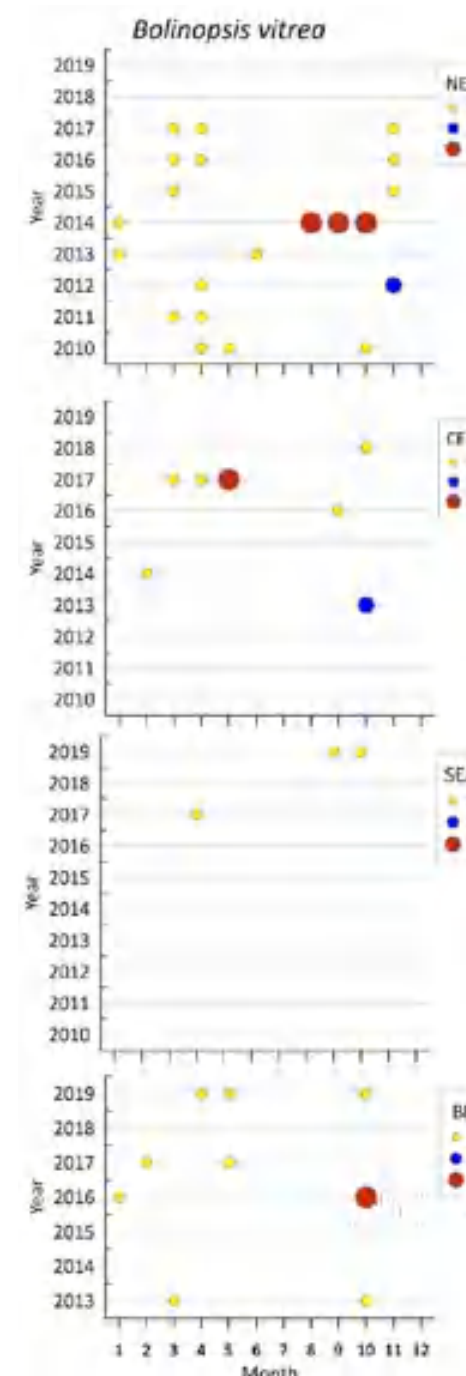
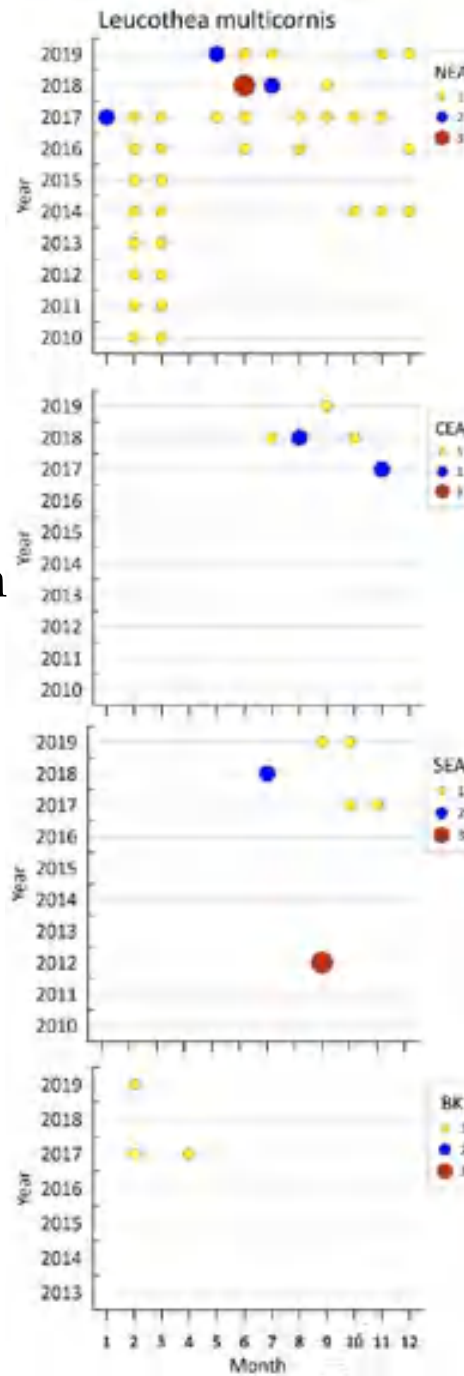
BK

Spatial and temporal variability:
three dominant Ctenophora species
(monthly data, 2010 – 2019)

Colour code the same as for Scyphozoa

No *Mnemiopsis leidyi* before 2016,
in CEA 2017

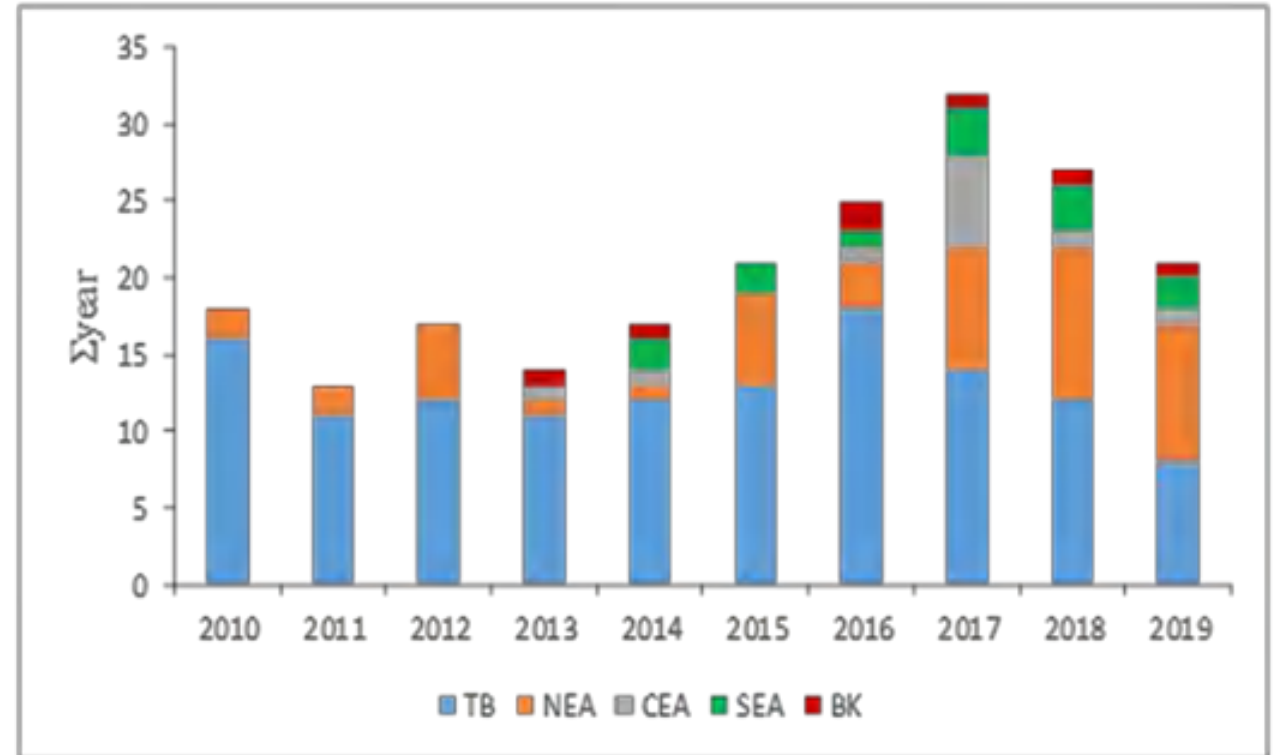
No *Mnemiopsis leidyi* in SEA and BK



Spatial distribution of dominant scyphomedusae in the Adriatic (2010 - 2019)

SIMPER test:

- the greatest similarity between TB and NEA
- the greatest differences among TB, NEA vs. SEA, BK (average dissimilarity ~ 80 %)
- *Rhizostoma pulmo* made the largest contribution to observed differences among areas



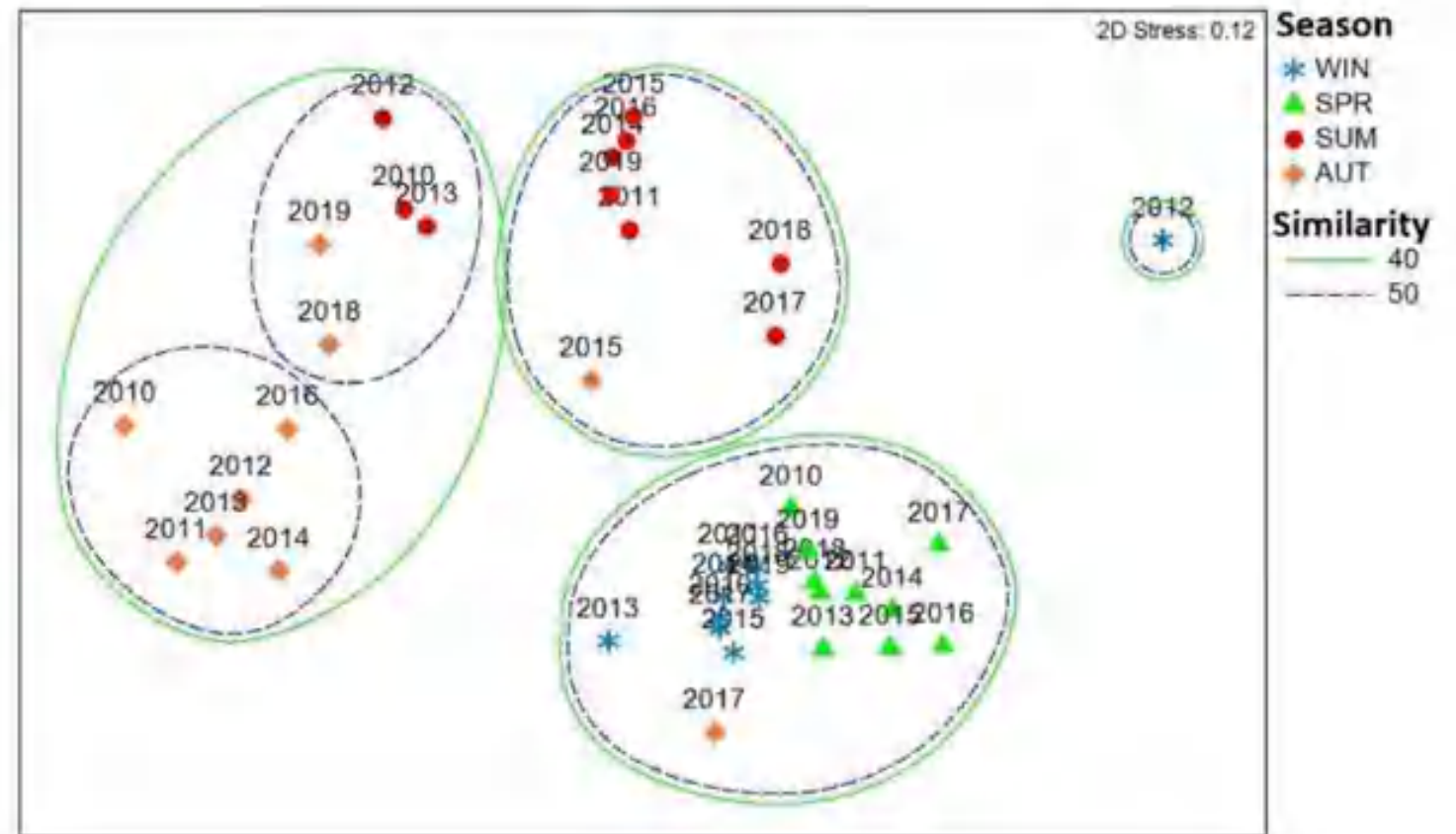
Annual cumulative abundance:

TB - Gulf of Trieste (blue), NEA - northern Adriatic (ochre)
CEA - middle Adriatic (grey), SEA - southern Adriatic (green)
BK - Boka Kotorska Bay (red)

Similarity levels on the temporal scales (year/month 2010-2019) - all areas included

Hierarchical clustering and MDS ordination (Bray-Curtis similarities from semi-quantitative abundance data) :

- no grouping for investigated years
- clearly visible seasonal grouping
- winter 2012 singled out (extremely low winter temperatures; very low jellyfish abundances)



Long-term fluctuations of scyphomedusae in the Gulf of Trieste (reconstructed time series of presence/absence since 1790)

Wavelet analysis - four meroplanktonic species:

Aurelia aurita,

Cotylorhiza tuberculata

Chrysaora hysoscella

Rhizostoma pulmo

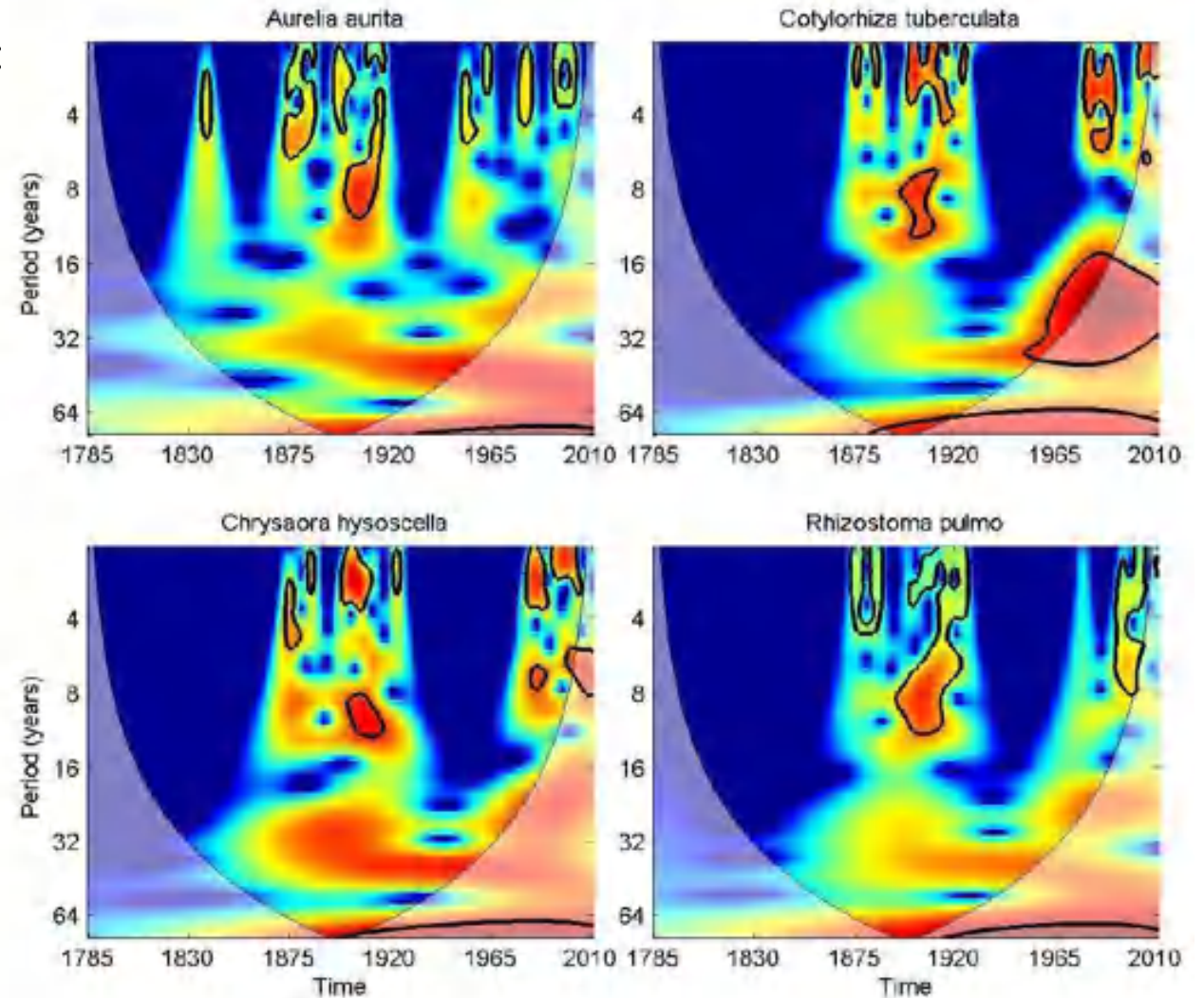
Two main periods of jellyfish outbreaks:

~1875-1920 and since 1970 on

Similar periodicity for all four species:

8 – 12 years during first period

< 8 years from 1970 on



Hydrobiologia (2010) 645:81–96

DOI 10.1007/s10750-010-0217-8

**Recurrence of bloom-forming scyphomedusae:
wavelet analysis of a 200-year time series**

Tijana Kogovčič • Daria Begonović •
Alerka Mahaj

Gulf of Trieste: long-term plankton and jellyfish semi-quantitative data

	J	F	M	A	M													
Stichololche	0	0	0	0	0													
Acanthometra																		
Tintinnen																		
Ceratium	+	+	c	c	+	+	+	+	+	+	+							
Actinularien		~	~															
Ephyra																		
Aurelia		+	+						e									
Rhizostoma		+	c		~				+	+	+	c	+	+	cc	c	+	
Chrysaora	+	c	c	+					+	+	+							
Sarsia	+	+													c	c	cc	c
Discomedusa		+	c	c														
Stenostroma				+					~	+	+	+	+	+	+	+	+	+
Tiara	c	cc	c						c	+	+	+	+	+	c	+	c	
Obelia	+	+	+	+	~	~			+	+	+	+	+	+	+	+	+	+
Physidium	+	+													+	+	+	
Laodice																		+
Tima-Irene	c	+		+	+							~				+		
Ocyropsis	+	+																
Aequorea	+	c		c														
Solmundella		+													+			
Praya	+	+		+								~						
Diphyes	c		+	+	+	+						+	+	+	+	+	+	+
Manophyes	c		+															
Halitemma		+	~	+														
Cydippe	+	c	+	+	c	c						+	+					
Beroe		+		c								+						
Eucharis		c		+														
Ophio-Pluteus	+	c	~	+											+	+	+	
Echino-Pluteus		+													+	+	+	
Auricularia		+		+	~	+	c	+	+	+	+	+	+	c	+	c	+	+

Stiasny, 1910, data for 1909

Our observations (semi-quantitative data)

Each month of the year is assigned a value between 0 and 3:

- 0 - jellyfish are not seen at all;
- 1 - sporadic occurrence of individuals;
- 2 - occurrences of individuals and/or small aggregations;
- 3 - occurrences of large aggregations

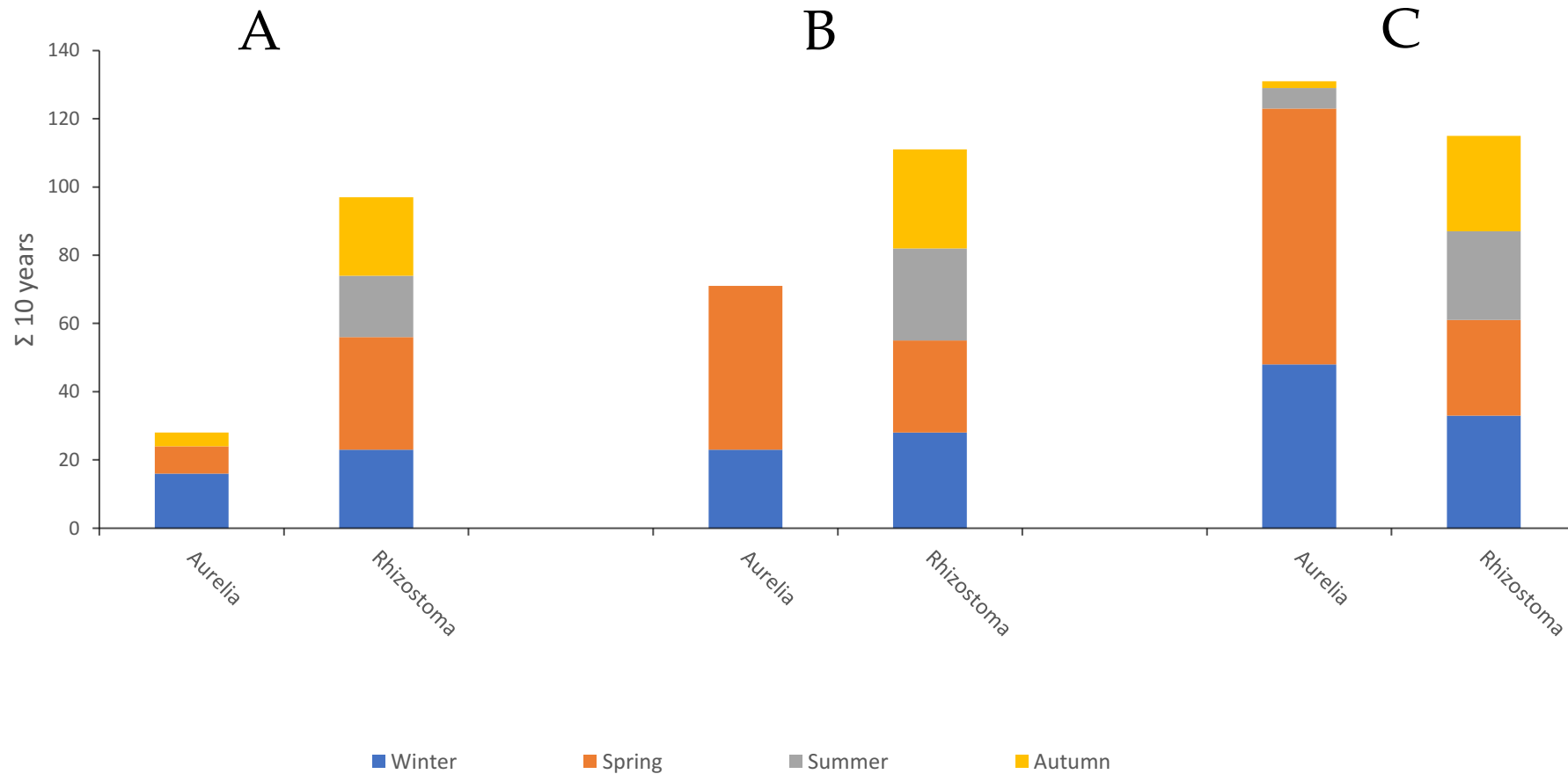


Gulf of Trieste - comparison of three 10-year periods (*Aurelia*, *Rhizostoma*):

A) 1900-1909; B) 2000-2009; C) 2010-2019

$$\Sigma \text{year}_{10} = [(t.o. \times \text{rel. ab. } 1) + (t.o. \times \text{rel.ab. } 2) + (t.o. \times \text{rel.ab. } 3)]$$

t.o. = times observed; rel. ab. 0, 1, 2, 3 = relative abundance / 10 years



Mass occurrences/increases of jellyfish – contributing factors

- metagenic life history (exchange of attached polyp and free-swimming medusa)
- different asexual modes of polyp reproduction
- high fecundity of medusae
- high feeding capacity and high growth rate
- live in habitats that create favourable conditions for aggregation (shallow water, enclosed or semi-enclosed systems, specific local hydrodynamics...)
- anthropogenic factors (artificial substrates and enhanced connectivity, removal of predators/competitors, eutrophication, introduction of NIS, warming)

Polyps



Lateral budding



Stolons



Moon jellyfish life cycle



Bloom

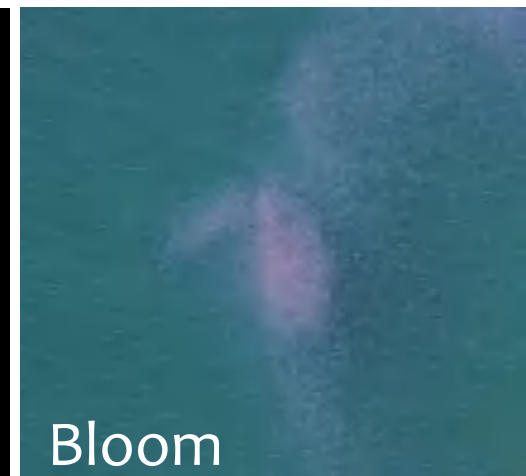
Strobilation



Ephyra



Bloom



Unmasking *Aurelia* species in the Mediterranean Sea: an integrative morphometric and molecular approach

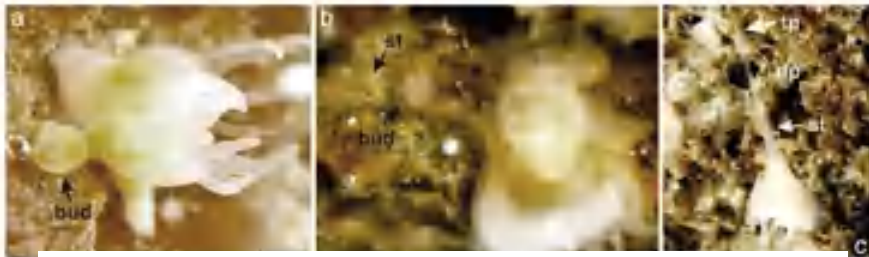
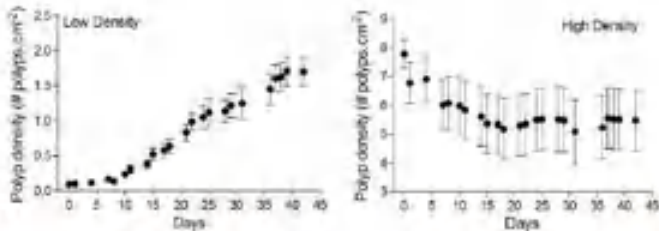
SIMONETTA SCORRANO^{1,2a}, GIORGIO AGLIERI^{1,2}, FERDINANDO BOERO^{1,2,3},
MICHAEL N. DAWSON¹ and STEFANO PIRAINO^{1,2a†}



Figure 5. Interspecific morphological differences in the anastomosis and bell indentations. A, *Aurelia coarctata* (= *Aurelia* sp. 1), female, bell diameter (BD) = 125 mm; B, *Aurelia relictata* sp. nov. (= *Aurelia* sp. 5), immature specimen, BD = 65 mm; C, *Aurelia solida* (= *Aurelia* sp. 8), male, BD = 160 mm.

Aurelia solida – non-native species

Fig. 1. Effects of polyp density on the population growth of *Aurelia aurita* s.l. polyps (mean ± SD).



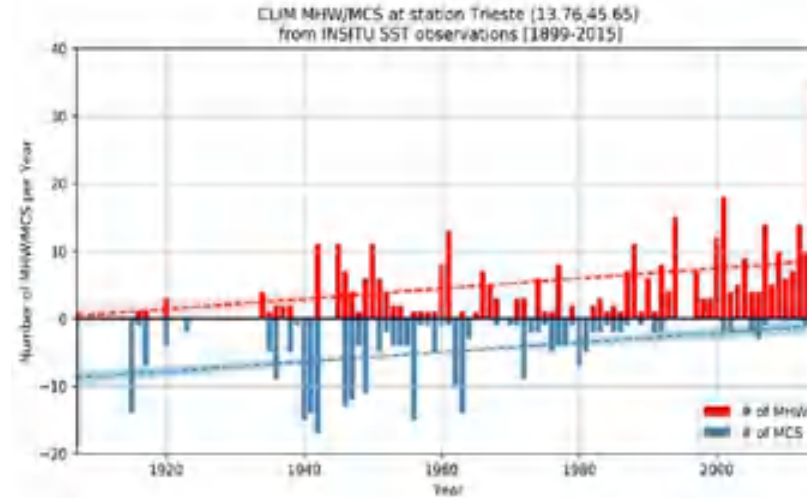
Density-dependent effects control the reproductive strategy and population growth of *Aurelia aurita* s.l. scyphistomae

Agnesa Echarri^{1,2}, Valentin Malček³, Tjasa Kogovšek^{4,5}, Aleksa Malej¹

Zooplankton in Warming and more Oligotrophic Coastal Sea: the Northern Adriatic Case

Malej A.¹, D. Ladic², M. Lizer¹, T. Kogovšek¹, P. Lucić³

¹Marine Institute of Biology, Marine Biology System, Pula, Croatia
²University of Zadar, Institute of Marine and Coastal Research, Zadar, Croatia
³Institute of Oceanography and Fisheries, Split, Croatia



- a mean temperature rise of 1.1 ± 0.3 °C per century was estimated from the time series (1899 – 2015) of sea surface temperature (SST) measured in Trieste harbour (Raicich & Colucci, 2019)

- superimposed onto long-term warming trend are increasing number of marine heatwaves (MHW) and a reduced number of marine cold spells (MCS)

Warming, artificial structures

Offshore marine constructions as propagators of moon jellyfish dispersal

Marija Vodopivec^{1,2}, Albano J. Bellu² and Aleksa Malej^{1,3}

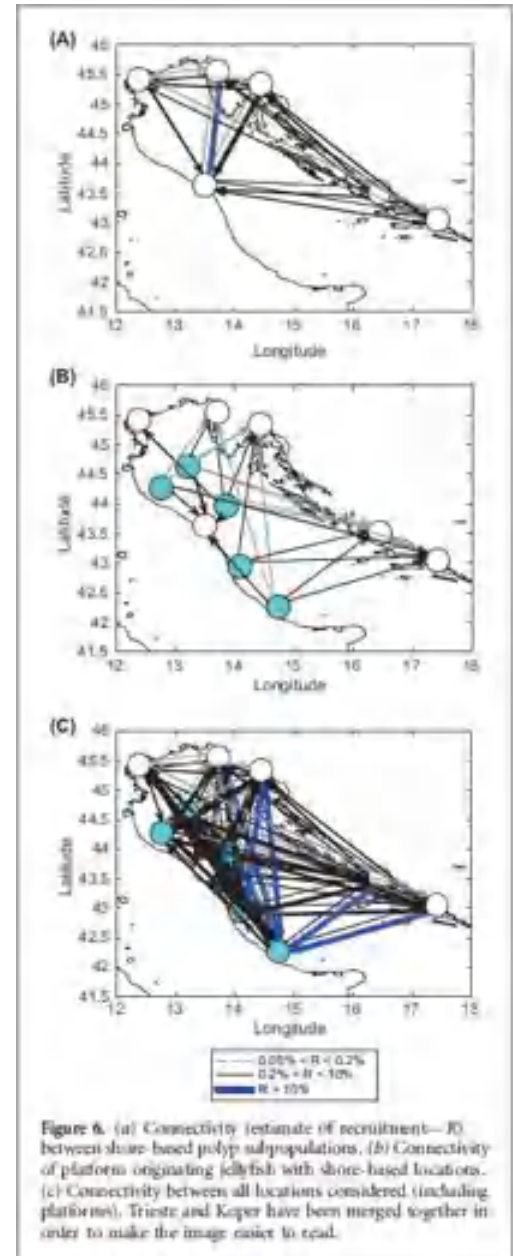
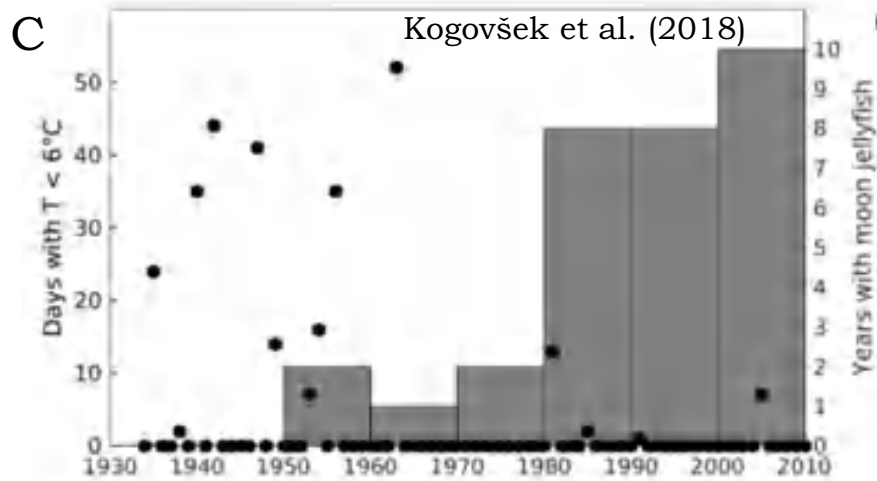
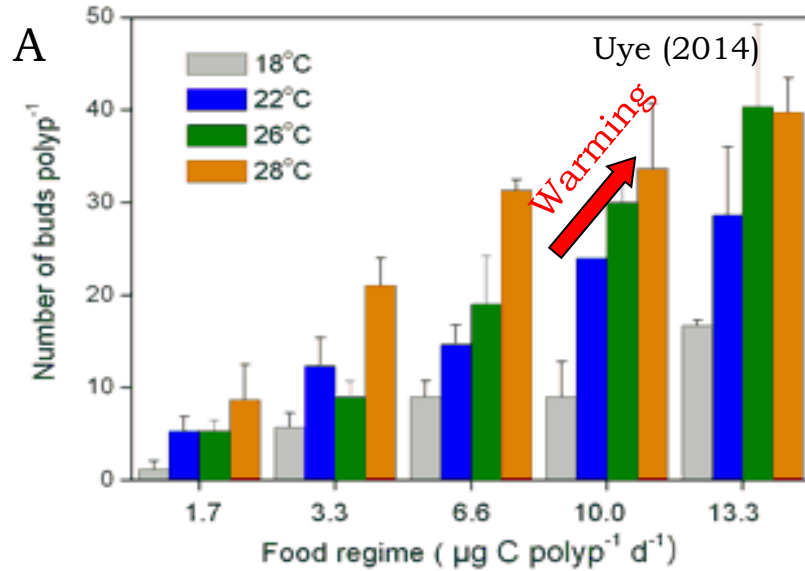


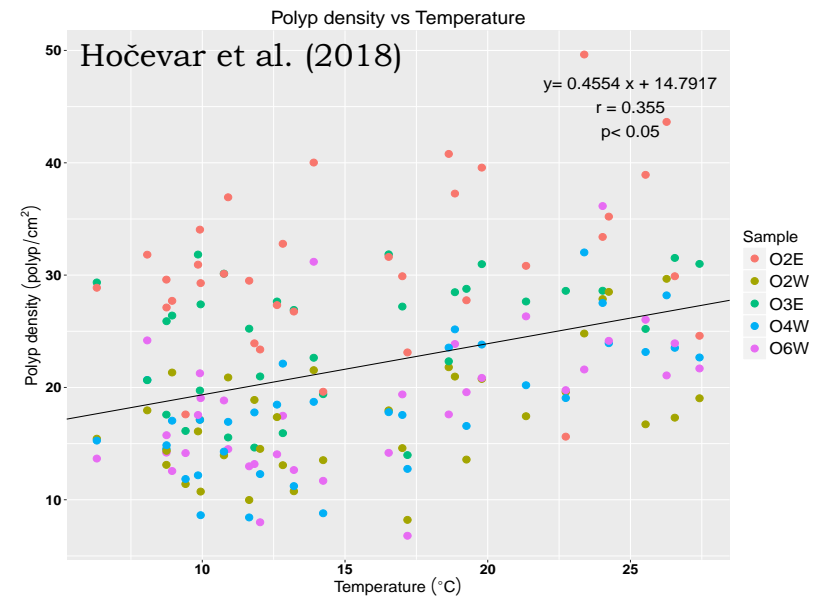
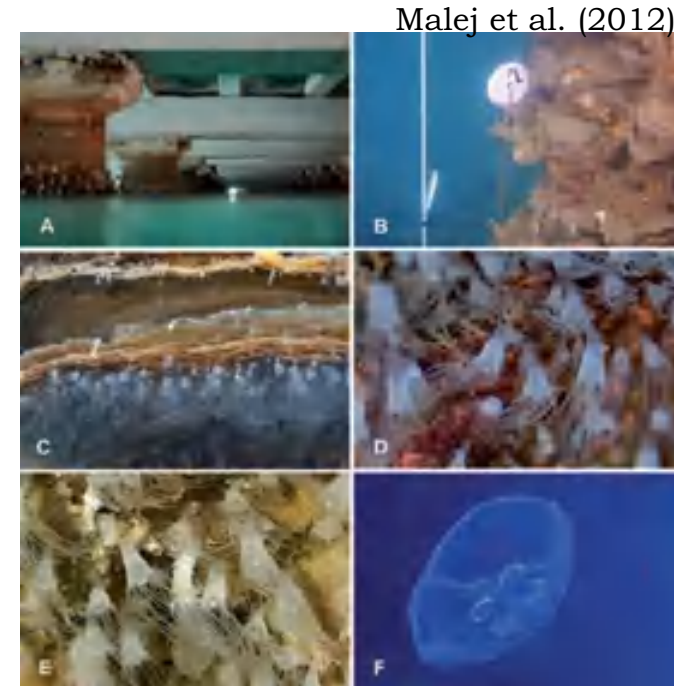
Figure 6. (a) Connectivity estimate of recruitment—R₁—between shore-based polyp subpopulations. (b) Connectivity of platform originating jellyfish with shore-based locations. (c) Connectivity between all locations considered (including platforms). Trieste and Koper have been merged together in order to make the image easier to read.

Temperature effects on asexual reproduction and mortality

- A) laboratory experiments
- B) Field evidence
- C) Impact of cold spells



B



Redescription of *Pelagia benovici* into a new jellyfish genus, *Mawia*, gen. nov., and its phylogenetic position within Pelagiidae (Cnidaria : Scyphozoa : Semaestomeae)

M. Avian^{A,F,*}, A. Ramžak^{B,*}, V. Tirelli^C, I. D'Ambrò^{C,D} and A. Malej^{B,E}

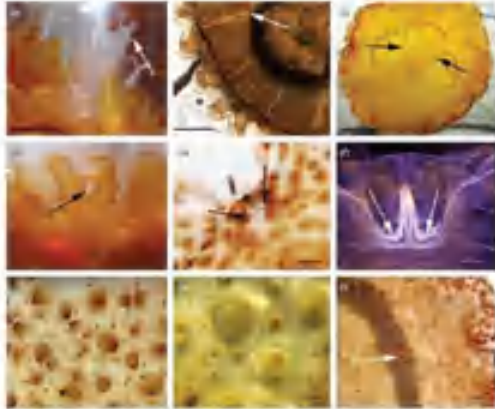


Fig. 4. New genus of jellyfish genus *Mawia* (Cnidaria: Scyphozoa: Semaestomeae) and its redescription. (A) Oral arms of the male *M. benovici* with oral arms and oral arms. (B) Oral arms of the female *M. benovici* with oral arms. (C) Oral arms of the female *M. benovici* with oral arms. (D) Oral arms of the female *M. benovici* with oral arms. (E) Oral arms of the female *M. benovici* with oral arms. (F) Oral arms of the female *M. benovici* with oral arms. (G) Oral arms of the female *M. benovici* with oral arms. (H) Oral arms of the female *M. benovici* with oral arms. (I) Oral arms of the female *M. benovici* with oral arms.



Fig. 5. Phylogenetic relationship between *Mawia benovici* (Cnidaria: Scyphozoa: Semaestomeae) and other pelagiid jellyfish. The tree is based on the analysis of the 12S rDNA (12S rDNA) and 18S rDNA (18S rDNA) sequences. The scale bar represents 0.1 substitutions per site. The tree is rooted with *Physalia physalis* as the outgroup. The bootstrap values are shown at the nodes.

Comparative phylogeography of macroplanktonic species, *Aurelia* spp. and *Rhizostoma pulmo* (Cnidaria: Scyphozoa) in European Seas

Andreja Ramžak · Katja Stopar · Alenka Malej

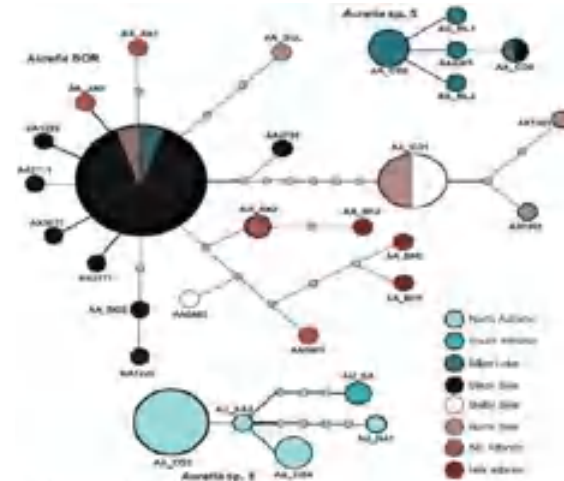


Fig. 6. Comparative phylogeography network of *Aurelia* spp. and *Rhizostoma pulmo* in European seas. The size of each node represents the number of genetic lineages. The color of each node represents the genetic lineage. The legend indicates the genetic lineage: North Adriatic (light blue), South Adriatic (dark blue), Mediterranean (black), Black Sea (red), Baltic Sea (green), North Sea (purple), and Atlantic (orange).



Why Do Only Males of *Mawia benovici* (Pelagiidae: Semaestomeae: Scyphozoa) Seem to Inhabit the Northern Adriatic Sea?

Valentina Tirelli^{1,*}, Tjaša Kogovšek², Manja Rogelja³, Paolo Paliaga³, Massimo Avian³ and Alenka Malej^{4,5}

M. benovici – a non-native species introduced from the shore near Dakar (Senegal, Bayha et al. 2017); by ballast waters or hull fouling. Our suggestion: polyps rather than medusae introduced

Lack of genetic structure in the jellyfish *Pelagia noctiluca* (Cnidaria: Scyphozoa: Semaestomeae) across European seas

Katja Stopar^{1,*}, Andreja Ramžak^{2,*}, Peter Trnabelj³, Alenka Malej⁴

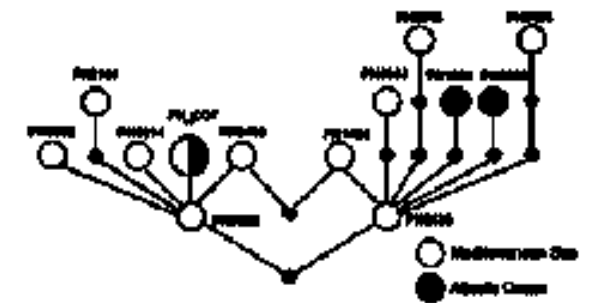


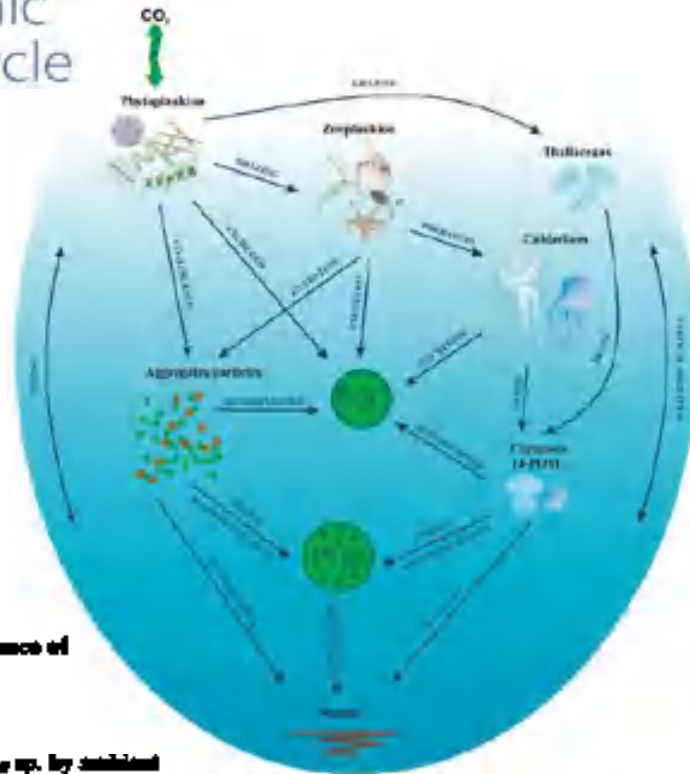
Fig. 7. Medusa genetic network in the Adriatic for *Pelagia noctiluca* (Cnidaria: Scyphozoa: Semaestomeae). The size of each node represents the number of genetic lineages. The color of each node represents the genetic lineage: Mediterranean Sea (white), Adriatic (black).



Mario Lebrato (Leibniz Institute of Marine Sciences, Germany) and Daniel O.B. Jones (National Oceanography Centre, UK)

Bloom/end of bloom

- ❖ feeding
- ❖ jelly-falls
- ❖ biomass stoichiometry



Jellyfish biochemical composition: importance of standardised sample processing

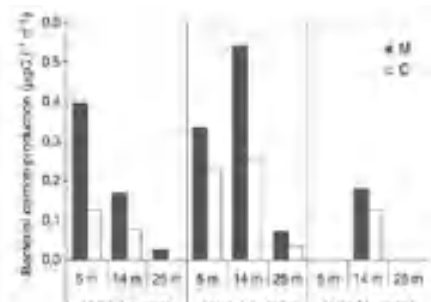
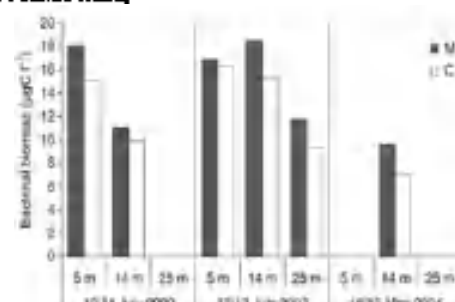
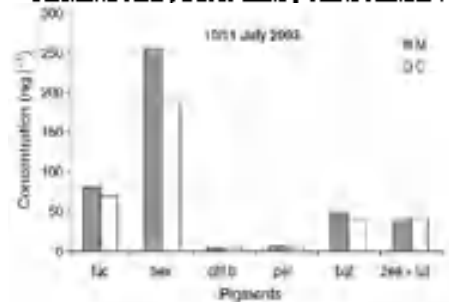
T. Kopylov^{1,2}, T. Uchida³, E. Rhee⁴, A. Mincer¹

Degradation of the Adriatic medusa *Aurelia* sp. by bacterial bacteria

Valentin Turk¹, Alena Malej², Maja Buc³, Valentina Turk⁴

Feeding of *Aurelia* sp. (Scyphozoa) and links to the microbial food web

Valentina Turk¹, Doron Kuzik², Vesna Flander-Petric³ & Alena Malej¹



***Aurelia aurita* Ephyrae Reshape a Coastal Microbial Community**

Lisa Baccantini¹, Maja Buc², Alena Malej³ and Doron Kuzik⁴

Jellyfish Modulate Bacterial Dynamic and Community Structure

Where: Valentin Turk¹, Alena Malej², Valentina Turk³

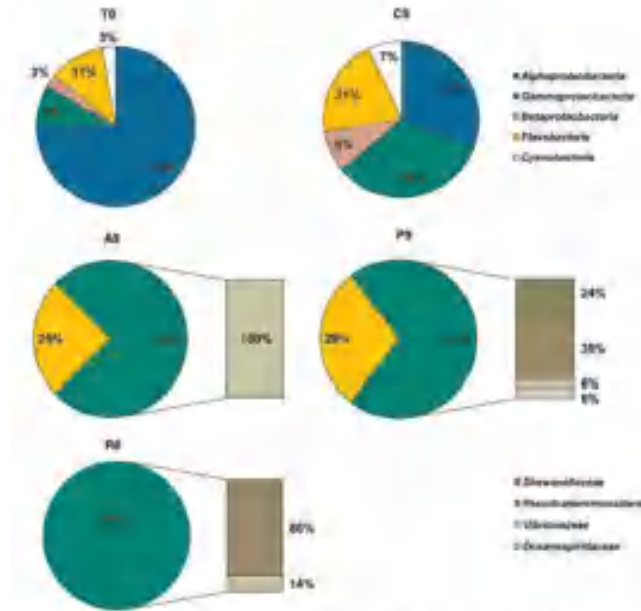


Figure 4. The distribution of phyla in each 125 mL 5-day P0 of samples from different treatments. Data collected from the sample at the beginning of the experiment (T0 on day 0) from the control (C0) on day 0 from the treatment with Aurelia (A0) and treated with Aurelia (P0). doi:10.1371/journal.pone.0021424.g004

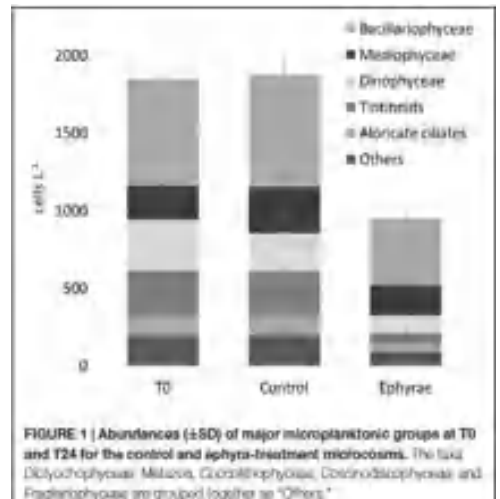



FIGURE 1 | Abundances (±SD) of major microplanktonic groups at T0 and T24 for the control and aphyra-treatment microcosms. The taxa Bacillariophyceae, Mollusca, Ciliophora, Dinophyta, and Bacillariophyceae and Flagellata are grouped together as "Others."

Summary

- jellyfish blooms are not a new phenomenon and finds of fossilized scyphomedusae show that dense accumulations already occurred in the Cambrian (> 500 myo years)
- *Aurelia* and *Rhizostoma* blooms were monitored in the northern Adriatic more than 120 years ago
- the frequency of blooms has increased in the last decades, their duration is longer
- anthropogenic disturbances (habitat changes, especially new artificial substrates, warming, introduction of new species, overfishing) have contributed to this development

A circular inset showing a microscopic view of several cells, likely yeast or similar microorganisms, stained in a light blue color against a dark blue background. The cells are of various sizes and shapes, some showing internal structures like nuclei or vacuoles. The circular inset is set against a white background.

Thank you for
your attention