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LIFE
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Alla scoperta degli anfibi e dei loro ambienti

Summerschool per docenti ed educatori

Bergamo

3-4 luglio 2026

Principi di ecologia ed etologia degli anfibi e potenziali minacce



3 Luglio 2026

Andrea Melotto, PhD



Cofinanziato
dall'Unione europea

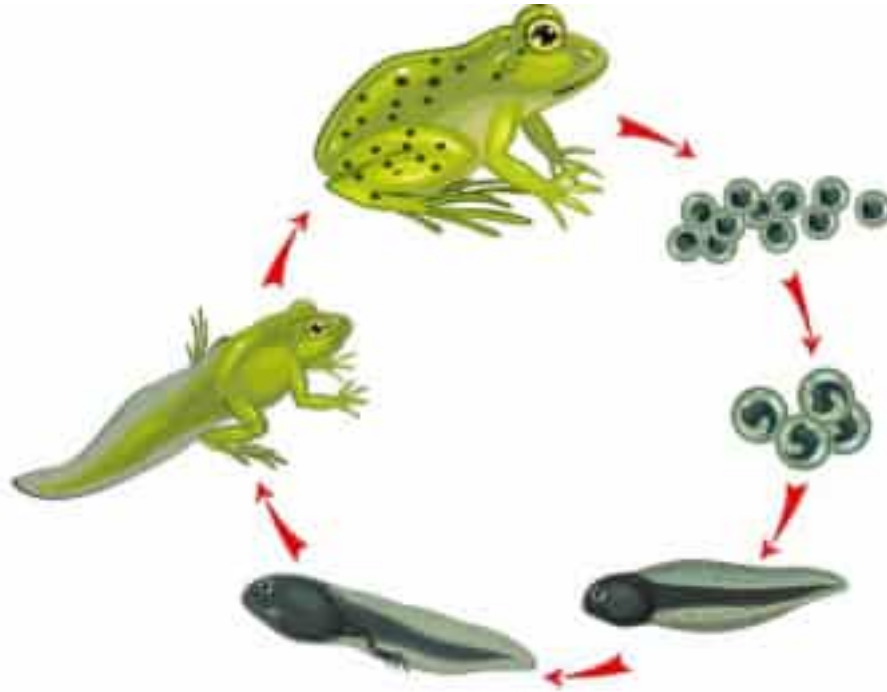


3-4 luglio 2026

Alla scoperta degli anfibi e dei loro ambienti

Most amphibians have
complex life cycles..

Ok, not all of
them...





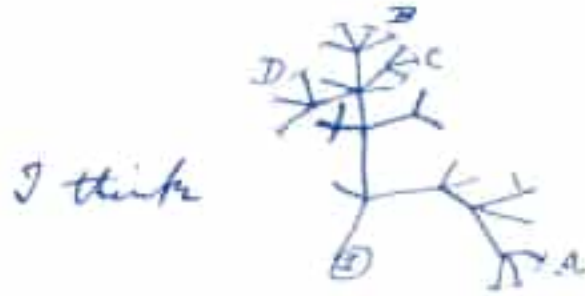
Complex life cycles..

Stricking variety of amazing adaptations

Elevated phenotypic plasticity

Larvae are key components of freshwater ecosystems

Natural selection



Darwin's Intuition

Variation

Selection: variants have differential success

Hereditability

Differential diffusion of the variants

Genetic advent & modern synthesis



Source of variation:

← Mutations



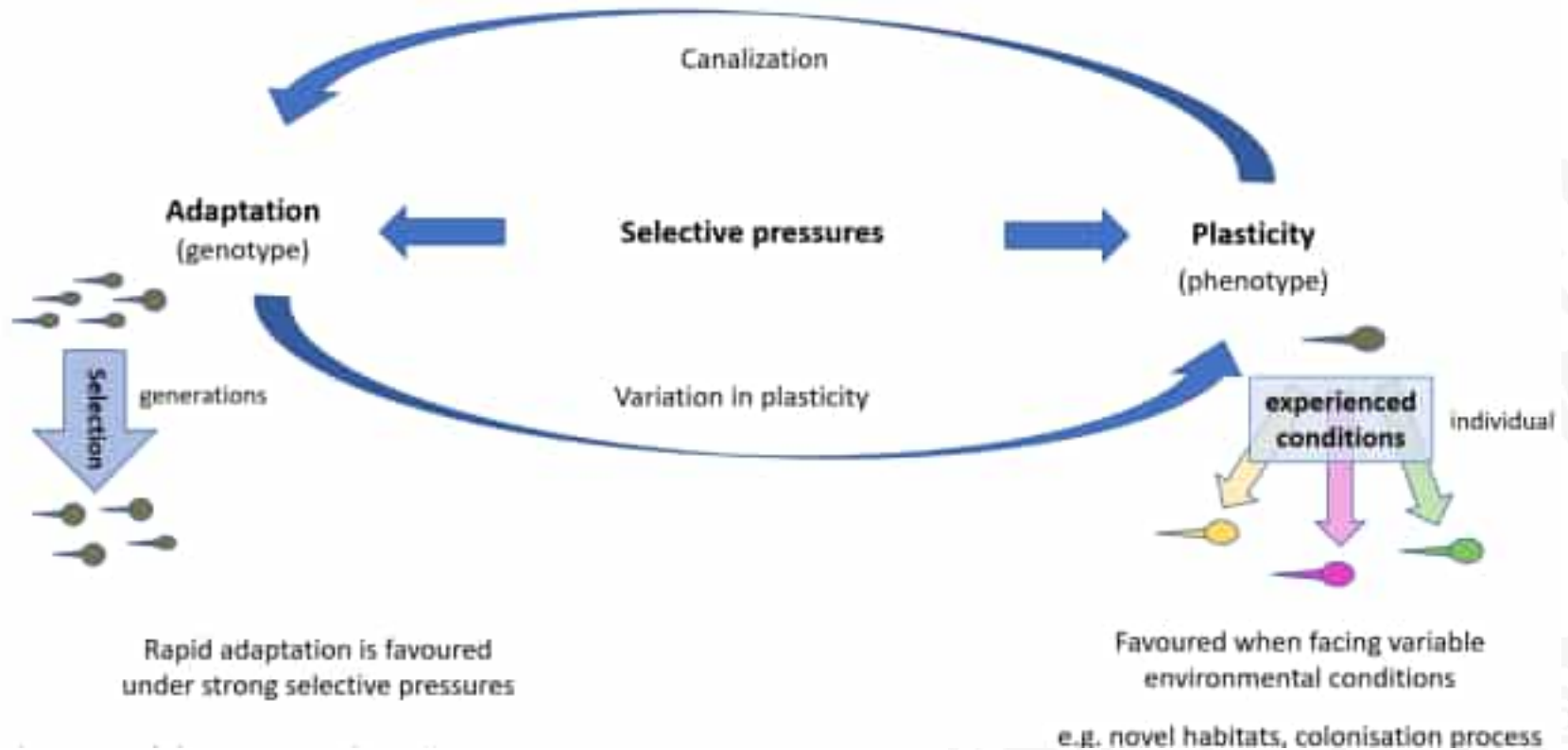
Richard Dawkins
The selfish gene (1976)

Gene machine

FITNESS
Relative parental success



NATURE vs NURTURE



Anuran tadpoles

Key prey in freshwater ecosystems

(on average 90% mortality before adult stage)



Omnivores, mostly vegetation matter... but
carnivore habits or carnivore species also exist



Levis & Pfennig (2018);
Montaña et al. (2019) Freshw. Biol.

Salamander larvae



Important freshwater top or meso-predators



Anti-predator responses in amphibian larvae

High plasticity allows exploiting different environmental contexts

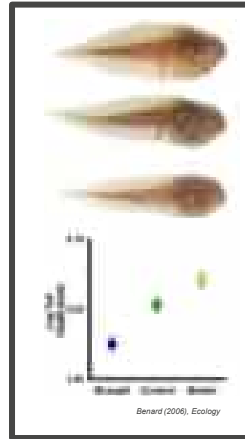
Multiple responses:

Behavioural



activity
reduction,
shelter use,
aggregation

Morphological



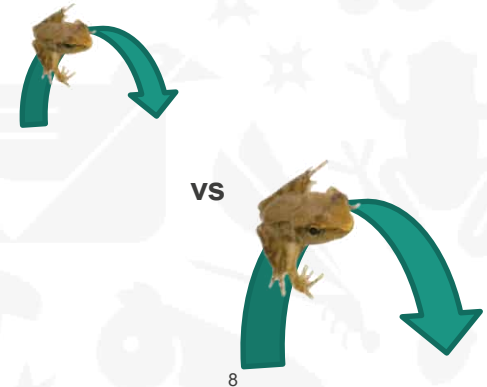
defensive
structures,
muscle increase

Life-history



rapid
development

Trade-offs between
escaping predators and
subsequent performance



Carry-over effects

Providing key ecosystem services

Key component of trophic chain in freshwater ecosystem



Biomass flux between terrestrial and aquatic environments



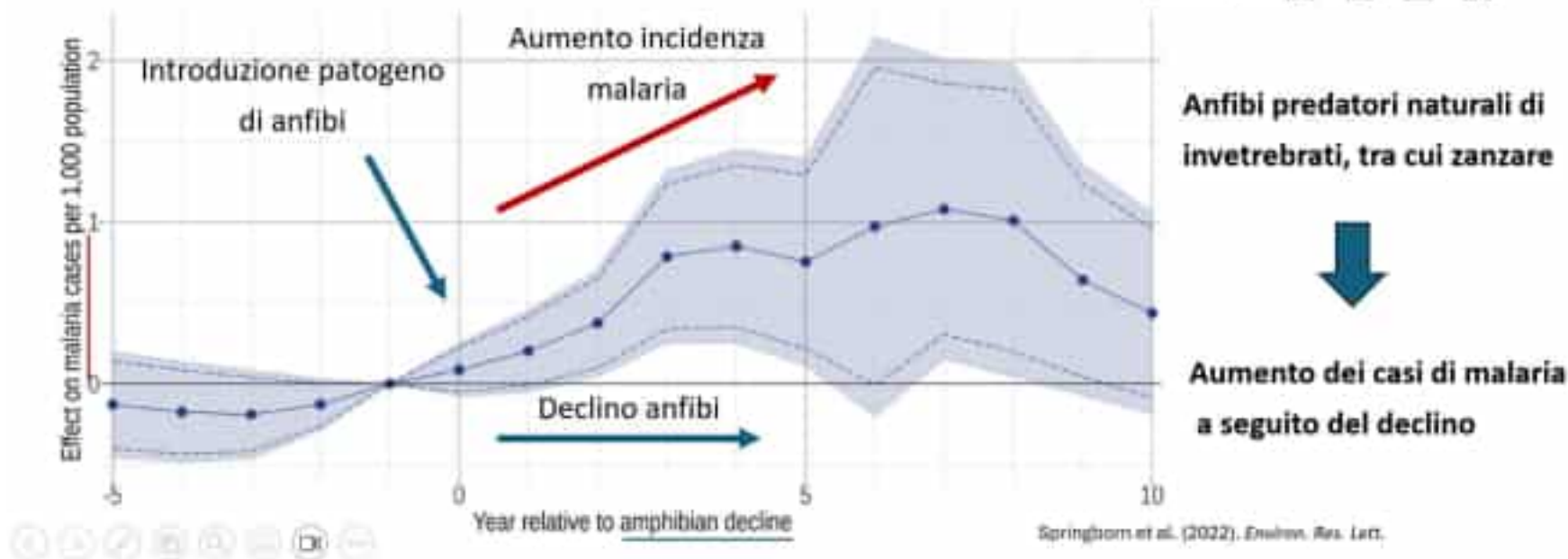
Biological control



In centro America, collasso degli anfibî causato dalla chitridiomicosi

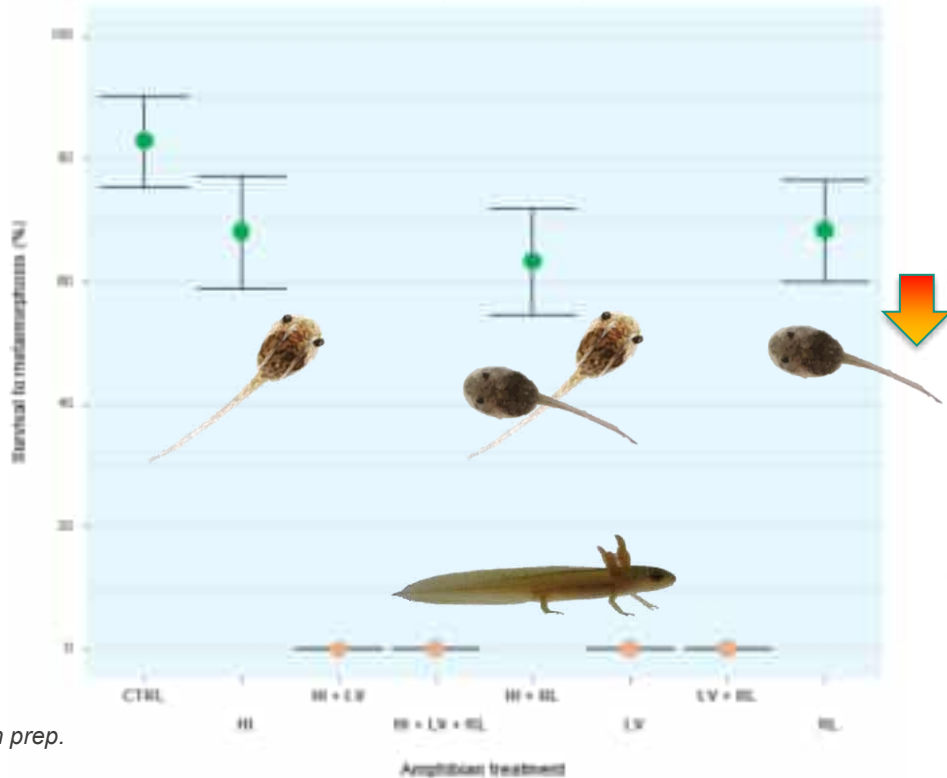
Batrachochytrium dendrobatidis: patogeno fungino letale

introdotto in Centro America negli anni '80 con le attività umane

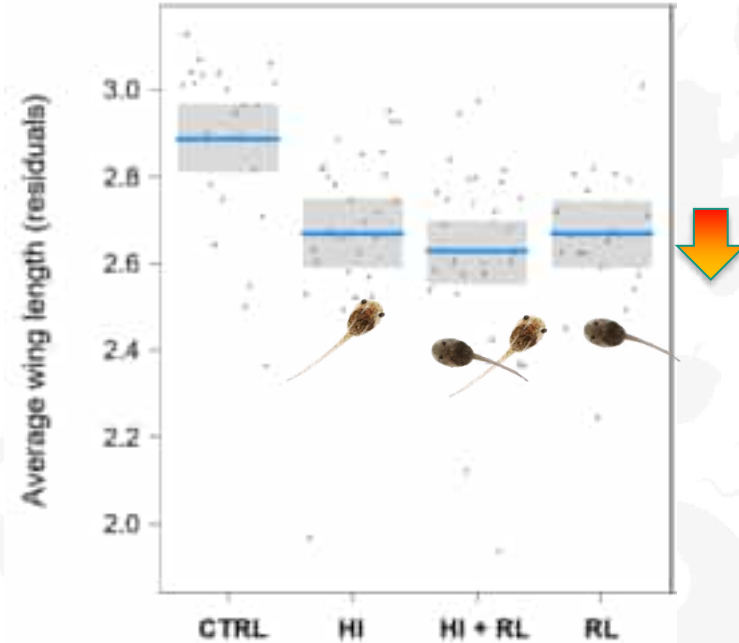


In our lab... predation and competition vs mosquitoes

Tiger mosquito larva survival



Adult size



Melotto in prep.

Come se la passano gli anfibi?



State of the World's Amphibians: The Second Global Amphibian Assessment

This report, led by Rewild, Synchronicity Earth, and the IUCN SSC Amphibian Specialist Group, summarizes how amphibians are faring, the pressures upon them, and the solutions needed for massively scaling up their conservation. Through the second Global Amphibian Assessment, more than a decade of research on amphibians by over 1,000 experts has been compiled to assess the extinction risk of 8,011 species worldwide.

The data delivers an incredibly alarming message – **2 in every 5 amphibian species are threatened with extinction**, making them the most threatened vertebrate group. The amphibian crisis continues to worsen, as pressures largely driven by human activities take hold. While habitat loss and degradation remain the most common threat to amphibians, an increasing number of species are being pushed to the brink of extinction by disease and climate change effects. The urgency to act is becoming increasingly critical.

Key results of the GAA2

8,011 species assessed
Completed in June 2022

41%

Threatened Populations
2,878 amphibians listed as Critically Endangered, Endangered or Vulnerable.

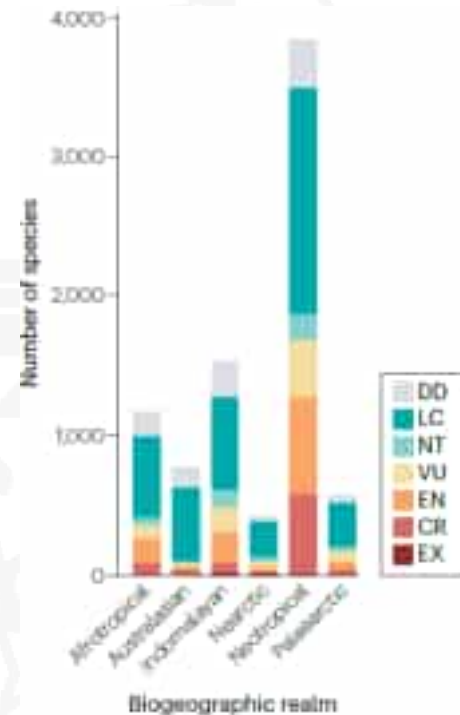
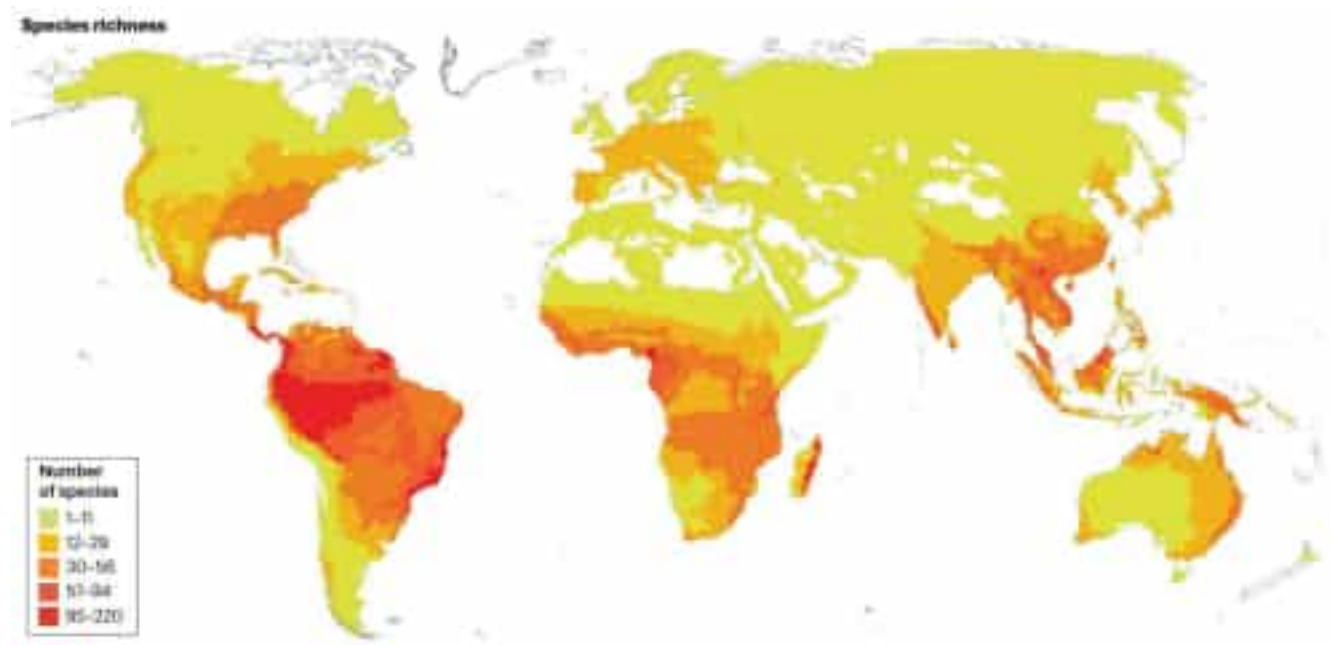
2 in 3

Subspecies are Threatened
Compared to frogs and caecilians, salamanders are at greatest risk of extinction with 84% of species threatened.

222

Possible Amphibian Extinctions
There are currently 37 amphibians listed as Extinct, with a further 186 species that are Possibly Extinct.

Amphibian richness and threats at global scale



Borzée et al. (2025) Nat. Rev. Biodivers.

Minacce antropiche per gli anfibii

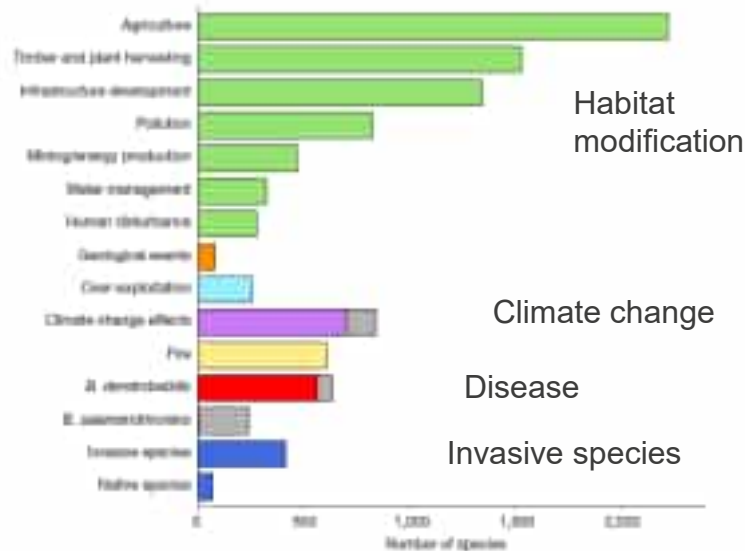
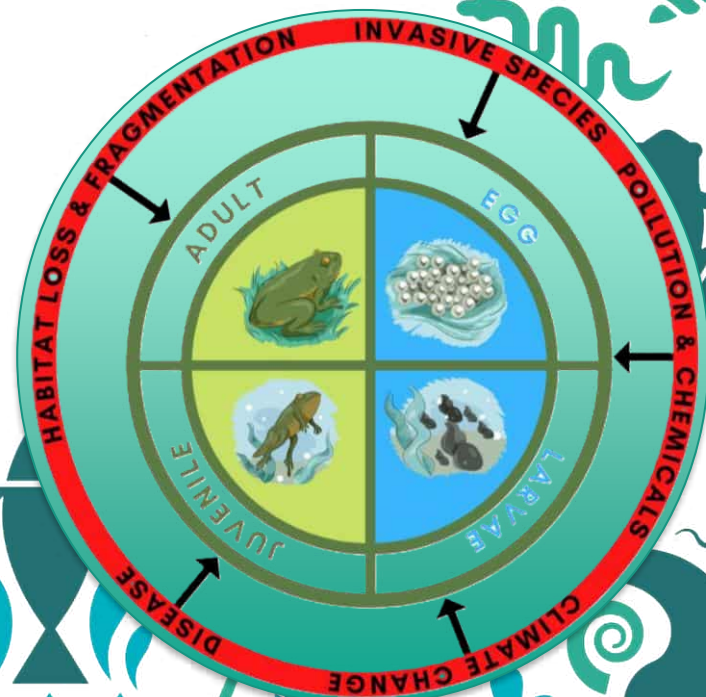


Fig. 2 The types of threats affecting amphibian species in this unpaired categories. The threats to a species were coded using the threat classification scheme and grouped for each of comparison into the "Classification scheme" and "Threats to amphibian species" see Table of the Methods. All threats

shaded in green are causing habitat loss and degradation. The green sections denote the number of species for which the threat timing is in the future rather than ongoing. Note that most species are experiencing multiple threats.

Luedtke et al. (2009) Nature

Complex life-cycle, many threats!



Changes in abiotic factors



Changes in habitat availability



Changes in biotic interactions

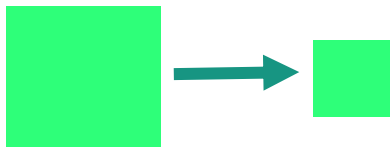
Habitat modification



Increase in human-modified landscapes



Suitable habitat loss



Reduction of breeding sites and natural areas



Fragmentation among suitable patches



Qualche esempio...

Examples of habitat changes that may affect amphibian communities (modified from Dodd and Smith 2003 and based on data from Hedges 1983, Baskett 1995, Mac et al. 1988 and Dahl 2000, reproduced with permission.)

Wetland habitats:

- 135,400ha of wetlands lost per year between mid-1950s and mid-1970s
- 117,400 ha of wetlands lost per year between mid-1970s and mid-1980s
- 155,200 ha of wetlands lost to urbanization and rural development between 1986 and 1997
- 70-90% loss of wetlands in Connecticut, Maryland and Ohio between 1780 and 1980
- 88% of pocosins of Atlantic Coastal Plain destroyed by 1980
- 50% loss of everglades ecosystem by the early 1990s; the remainder greatly altered.
- 50 to 80% loss of wetlands in Alabama between 1780 and 1980
- 54% loss of wetlands in Michigan, Minnesota and Wisconsin
- 30 to 36% loss of wetlands in Arizona, New Mexico and Utah between 1780 and 1980
- 91% loss of vernal pools and wetlands from California
- 70% loss of ponds in Britain between 1880 and 1980s
- 82% of marshlands destroyed in Essex County, England, between 1938 and 1981
- Xanthopus gill has lost 90% of its wetland breeding sites in South Africa due to habitat loss.

Stream and River Habitats

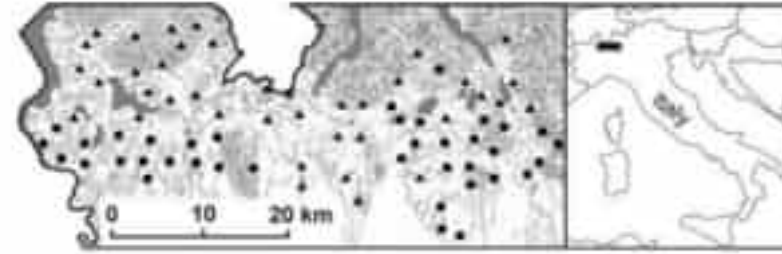
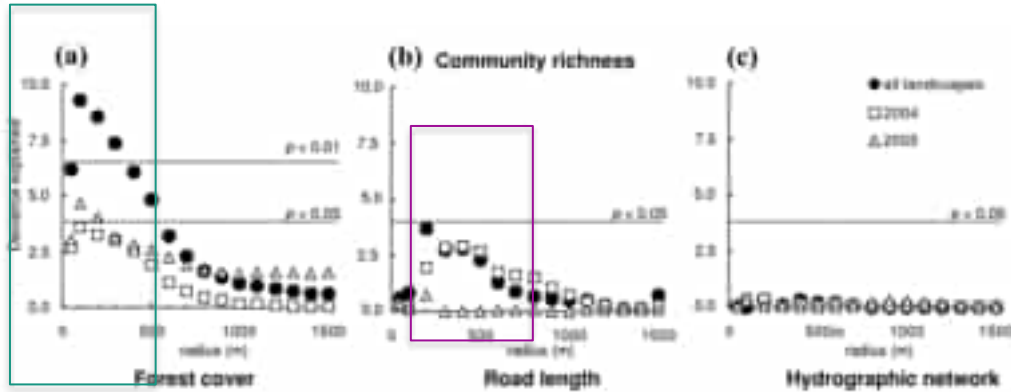
- 98% of the original 5.2 million kilometers of streams in the continental United States have been seriously affected
- 91% of river lengths in lower 48 US states developed by 1986
- 33% of hydrological basins in northeastern United States affected by toxics; 63% by excess nutrients
- 68% of the riparian forest in the United States has been destroyed.
- 85 to 98% of riparian forest in Arizona and New Mexico have been destroyed or severely degraded.

Terrestrial Habitats

- 0.01% of native grasslands remain in pre-European contact condition
- 85 to 95% loss of oldgrowth forest in Blue Ridge and Cumberland Plateau provinces of Tennessee
- 88% of Illinois forests present in 1820 are gone today
- 68% of old-growth forest on Olympic Peninsula, Washington, is in patches of 40 h or less
- 85% of coastal redwood forest reduced in California
- 0.2% of original forest remains in Puerto Rico
- Forest cover is only 13% of Cuba, 10% of the Dominican Republic, 5% of Jamaica and less than 1% of Haiti because of deforestation.



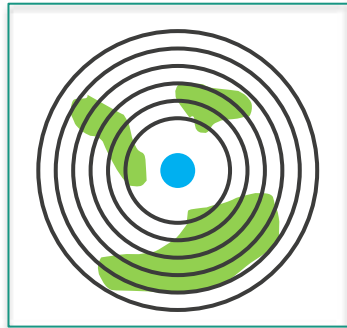
Diversi elementi influenzano la struttura spaziale dell'habitat



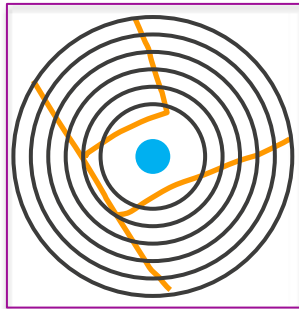
Componenti differenti possono influenzare l'abbondanza degli anfibi a scale spaziali diverse

Disponibilità di ambiente idoneo importante a scala spaziale ridotta

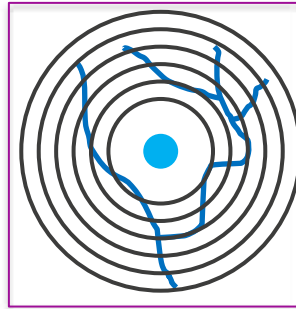
Barriere e connettività importanti per struttura metapopolazioni



Copertura forestale



Densità reticolo stradale



Bacino idrografico

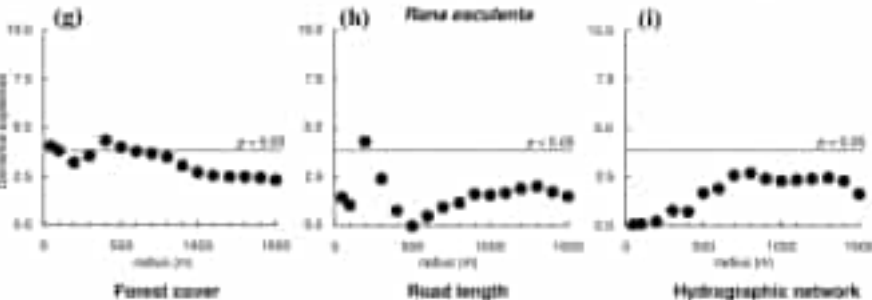
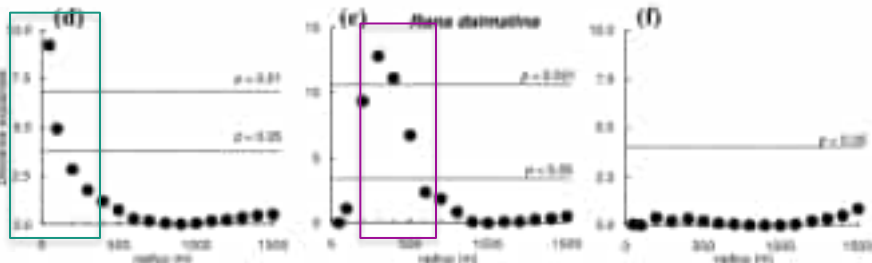
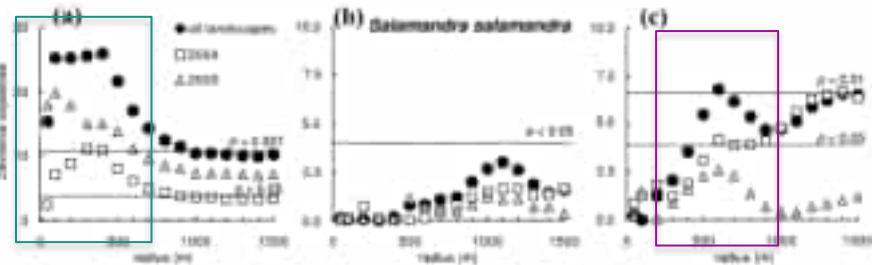
Ficetola et al. (2009) Conservation Biology

E questi elementi possono variare notevolmente a secondo dell'ecologia delle diverse specie...

importanza di garantire la disponibilità ed l'integrità di porzioni di habitat un adeguata alle necessità ecologiche di esse ed in grado di mantenere la connettività tra popolazioni



Ficetola et al. (2009) Conservation Biology



La rana di Lataste in Lombardia

Progressivo declino negli ultimi 20 anni



presenta
potenzialmente
estinta
localmente
estinta

Spesso a causa di cattiva gestione o variazione d'uso suolo

Decline and Extinction of the Italian Agile Frog *Rana latastei* from Core Areas of Its Range

Giuseppe Faccenda ^{1,2,3,4}, Rocco Mammì ^{1,2,3,4}, Elia Le Pichon ^{1,2,3,4}, Martina Mammì ^{1,2,3,4}, Benedetta Bazzagli ^{1,2,3,4}, Valeria Mariani ^{1,2,3,4}, Simone Casarini ^{1,2,3,4}, Andrea Molteni ^{1,2,3,4} and Matteo Falcucci ^{1,2,3,4}

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Summary: The Italian Agile Frog (*Rana latastei*) is a species that has experienced a significant decline in its range in recent years. This decline is primarily due to the loss of its natural habitats, which are being converted into agricultural and urban areas. The loss of habitats is leading to a decrease in the frog's population, and in some areas, the frog has become locally extinct. This study aims to investigate the causes of this decline and to develop conservation strategies to protect the remaining populations of the Italian Agile Frog.

Urban refuge?



Western leopard toad

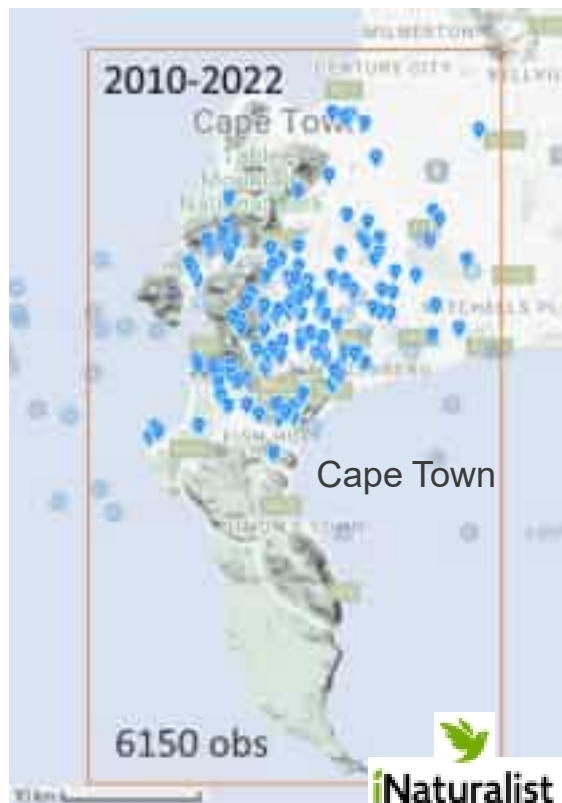
Urban sanctuaries!



Fragmentation,
habitat loss,
small populations



Iconic, and
very popular!



Yellow-bellied toad



Stable and large population



But local declines



Gianfranceschi 2021

Once common in Trieste

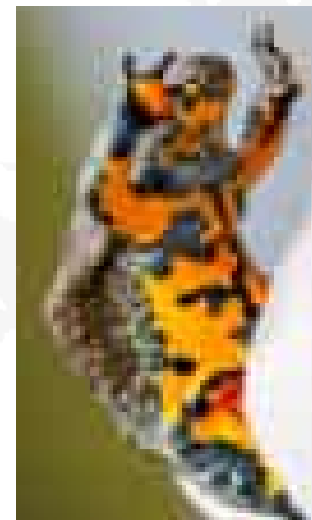


Sunny gardens, orchards, pools



Habitat loss
Traditional practice decline

Pretty guy, but less considered!



Management of urban populations makes the difference

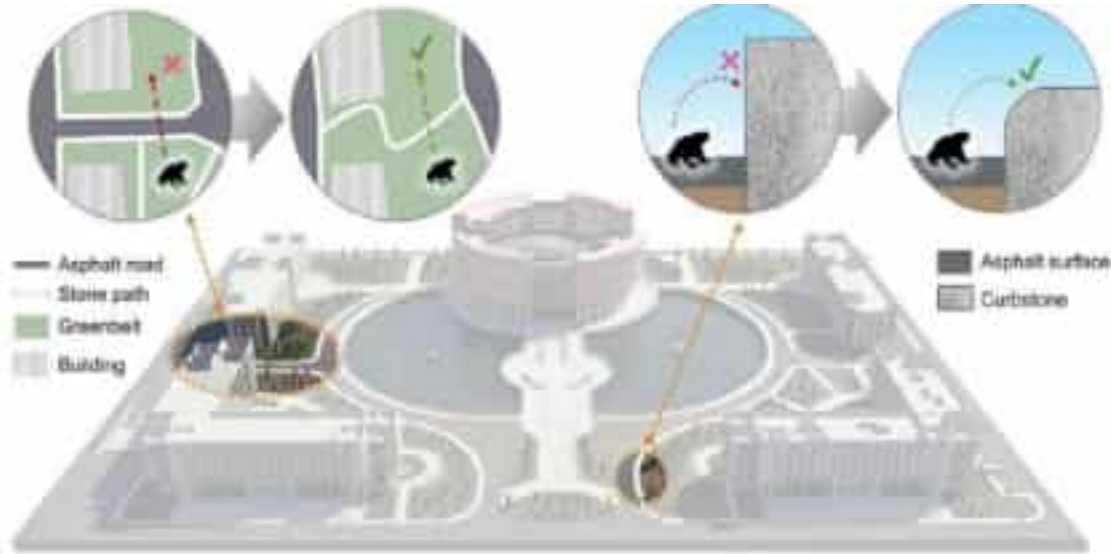


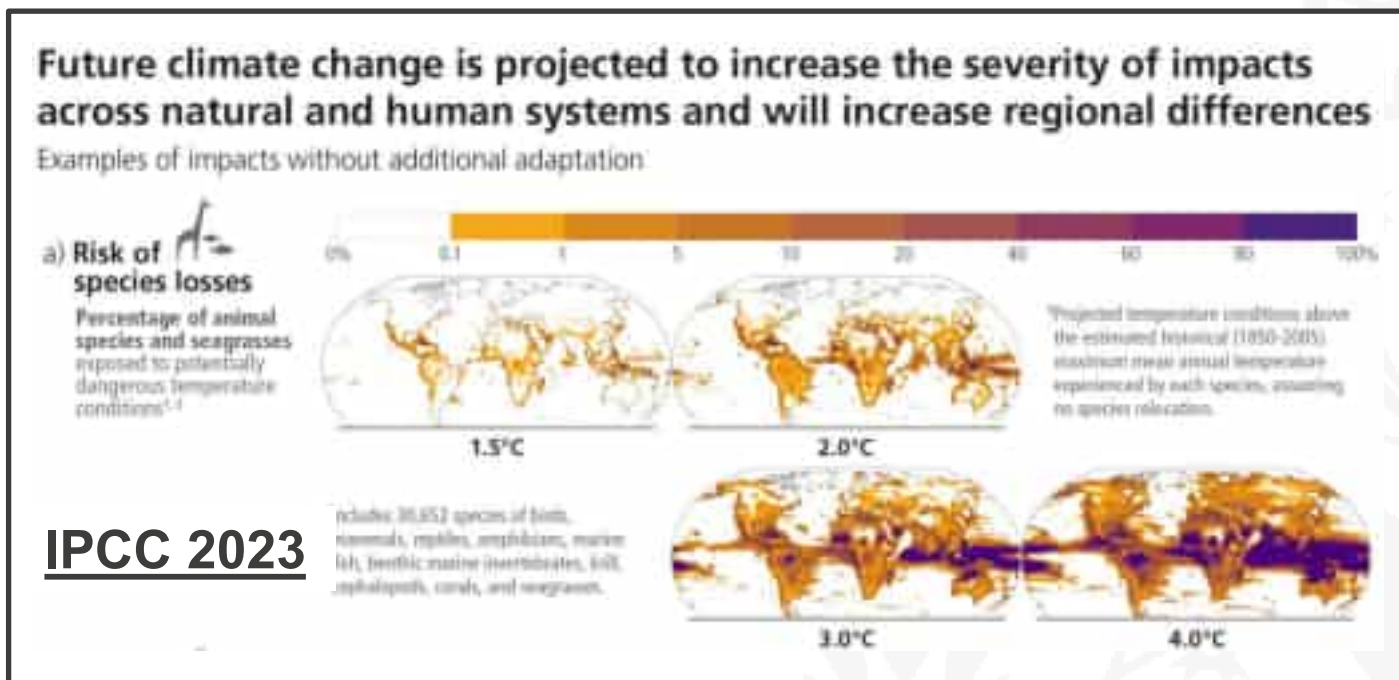
Figure 10. Conceptual design for amphibian corridors integrating micro-conservation. Two micro-level interventions to mitigate artificial barriers: (a) planning continuous greenbelts to guide amphibians away from crossing asphalt roads; (b) replacing tall, 90-degree curbstones with low-profile curbs with gentle slopes, enabling amphibians that stray onto the pavement to easily climb and escape. Illustration: Peng Yusi

Peng et al. (2026) FrogLog

Preserving breeding sites integrity and connectivity among them can support suitability of urban refuges

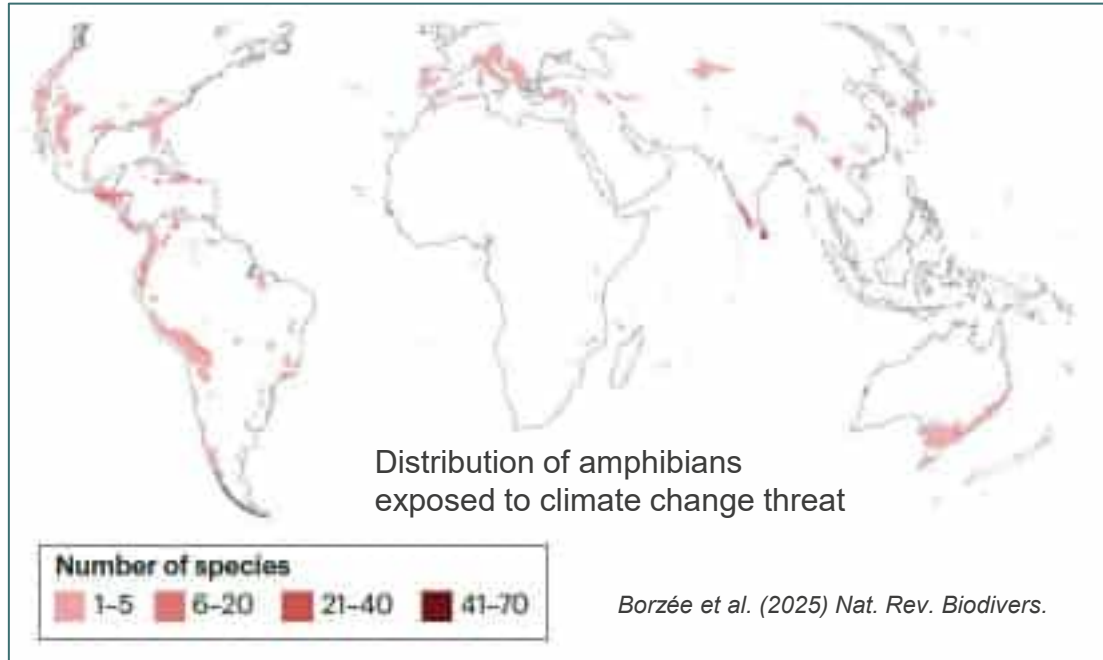


Cambiamenti climatici e biodiversità



<https://www.ipcc.ch/report/ar6/syr/>

...and amphibians?



Sensitiveness to warming and altered rain patterns

Breeding failure

Niche availability shifts

Phenological shifts

Variation in survival and performance

Loss of breeding sites due to altered precipitation regimes and increased aridity

An example from Yellowstone National Park

McMenamin et al. (2008) PNAS

Reduction in wet years

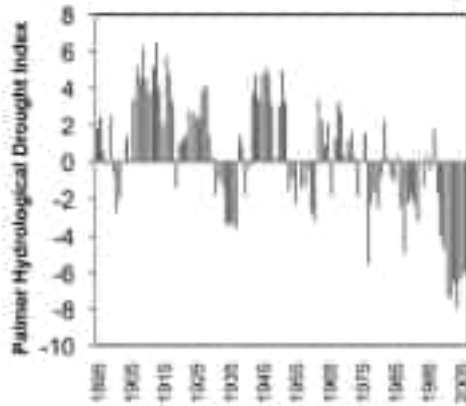


Fig. 2. Annual PHDI of the Yellowstone Drainage region between 1995 and 2007 (25). Values above zero indicate a wet year, and values below zero indicate drought conditions. Best fit linear model of PHDI values post showing has slope = -0.057, adjusted $R^2 = 0.33$, and $P < 0.001$.



Reduced species richness

Population declines

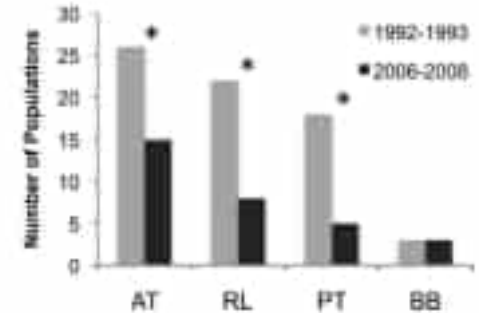
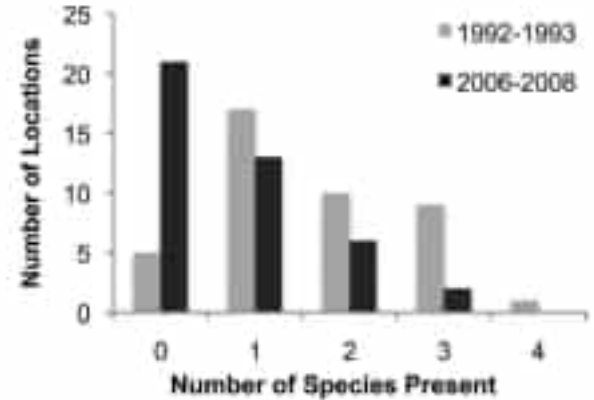


Fig. 4. Number of populations of each species present in 42 Yellowstone parks during at least 1 year during 1992-1993 or 2006-2008. AT, *Ambystoma tigrinum*; BB, *Bufo boreas*; PT, *Pseudacris triseriata*; RL, *Rana lateralis*. Asterisks denote statistical significance, determined by McNemar's Test ($P < 0.01$).

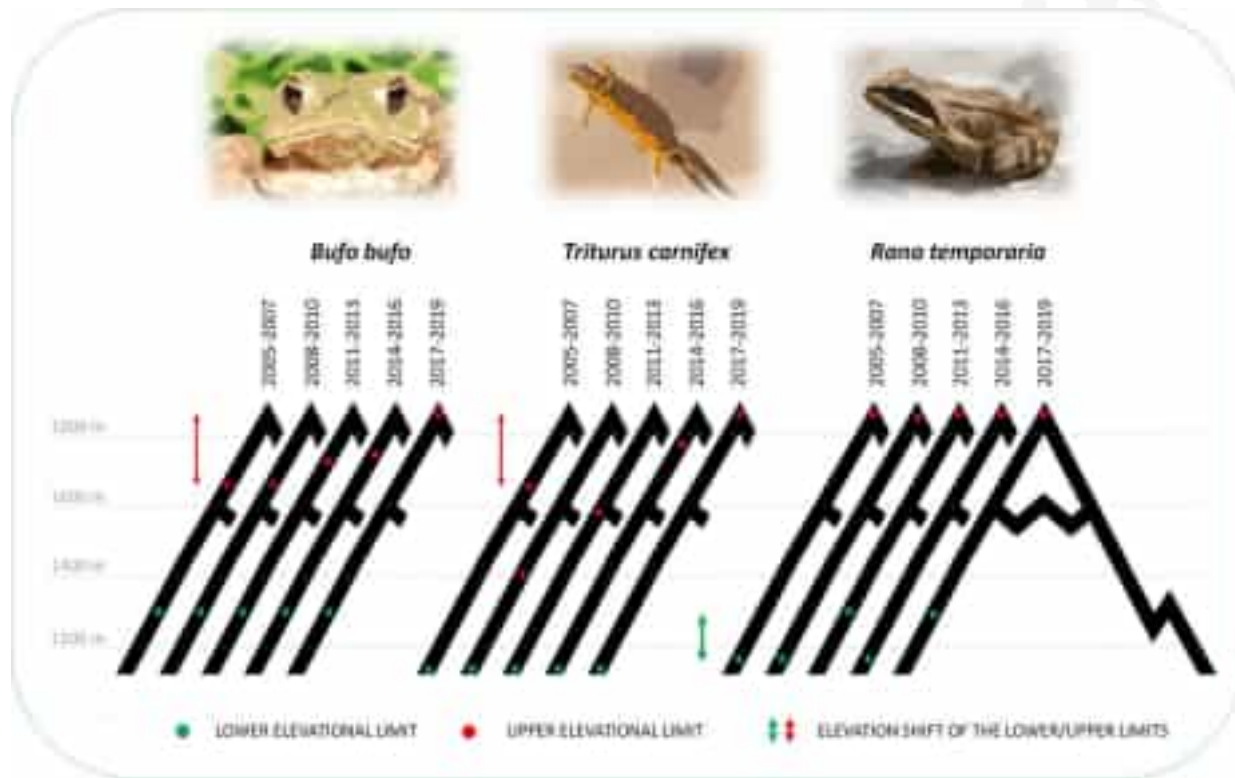
Variazione disponibilità di nicchia lungo un gradiente latitudinale

Altitudinal shifts for typical lowland species

(potential niche expansion)

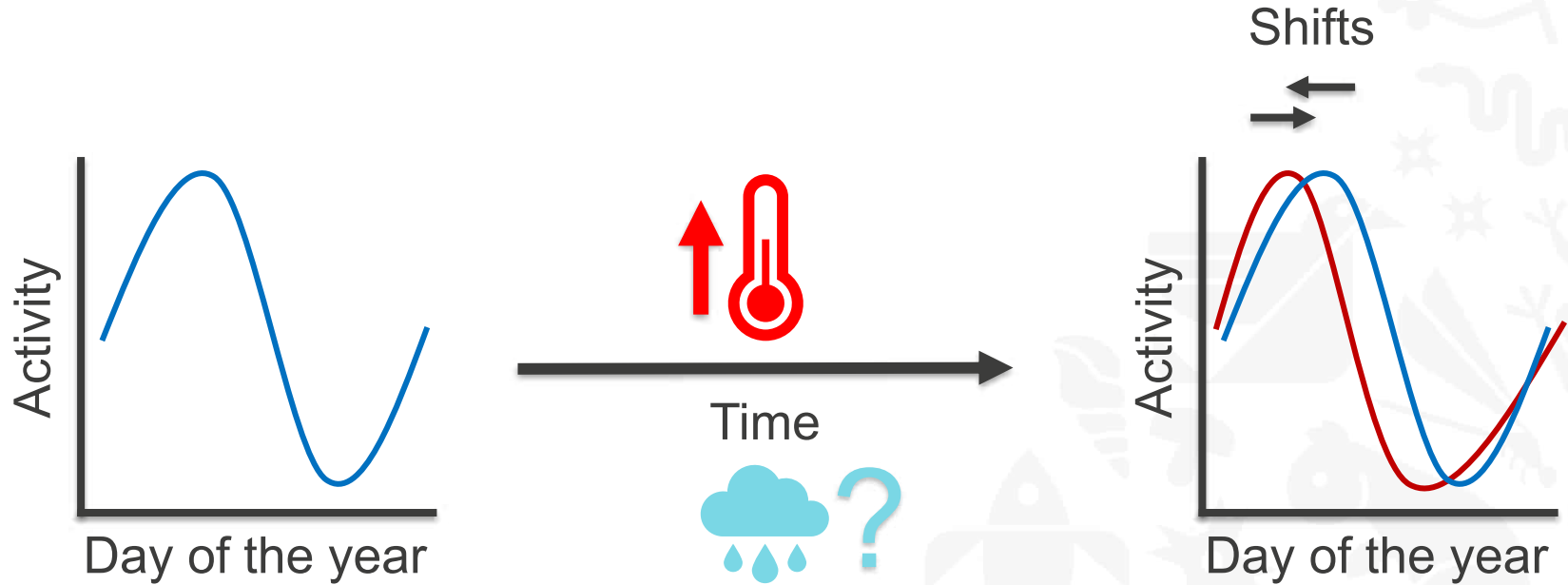
But ecological limits for montane amphibians

(no shifts; niche contraction)



Tiberti et al. (2021) Biol. Conserv.

Shifts in phenology



Some examples

Earlier activity
(common at higher latitudes)



Late breeding



Out-of-season breeding

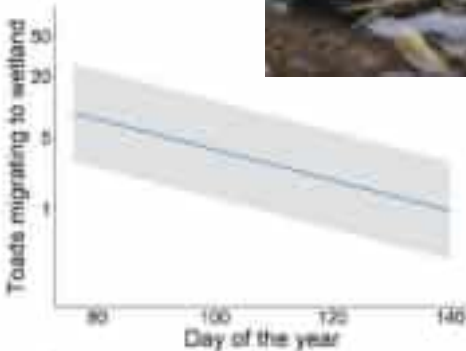


Quo vadis amphibii? Global warming and breeding phenology in frogs, toads and salamanders

Geoffrey M. White and Tobias Uller

G. M. White and T. Uller (2015) *Global warming and breeding phenology in frogs, toads and salamanders*. *Journal of Animal Ecology*, 84, 1111–1121. doi:10.1111/1365-2656.12345

As the world is getting warmer, many animals and plants have shifted the timing of breeding towards earlier dates. However, there is substantial variation between populations in phenological shifts that typically goes unexplained. Identification of the different factors and processes that determine such variation is essential if we are to make predictions for how proposed climate change scenarios will play out in the real world. Global warming is expected to have a range of effects on amphibian breeding phenology, but the extent of variation in amphibian breeding phenology in response to global climate change. We show that there is strong geographic variation in response to global climate change, with species at higher latitudes exhibiting a more pronounced shift in earlier breeding than those at lower latitudes. Our analysis suggests that this latitudinal effect is a result of both the increased temperature and wet precipitation at higher latitudes as well as a response to increased precipitation by southern populations of amphibians in the change in temperature. We suggest that these effects could be explained by direct effects of increasing temperature on higher latitudes in breeding phenology, in contrast, we found very little correlation from other factors between species at lower latitudes. There was no evidence for a latitudinal gradient in breeding phenology in response to precipitation, suggesting that the latitudinal shift has been caused by temperature, not precipitation, suggesting that the latitudinal shift has been caused by temperature, not precipitation.



Dalpasso et al. (2009) *Sci. Rep.*



Melotto et al. (2025) *Acta Herp.*

However this lead to potential risks and phenological mismatches:



Desiccation risk
for aquatic stages



late winter frosts
for aquatic stages



Lethal heat
exposure

Invasive species



Some famous ones...



Procambarus clarkii



Callinectes sapidus



Popilia japonica



Aedes albopictus



Xylella fastidiosa



Domestic cat

Invasive alien species:

a major cause of biodiversity loss and extinction

Involved in the 54% of the ~ 800 animal species extinctions
caused by human impact since 1600

Clavero & Garcia-Berthou, 2005 *Trends Ecol. Evol.*
Bellard et al. (2016) *Biol. Lett.*

Invasive species effects on native communities are difficult to predict



Heterogeneity of
responses among species

Nunes et al., 2012 *Oecologia*



Heterogeneity of environmental
pressures among different populations

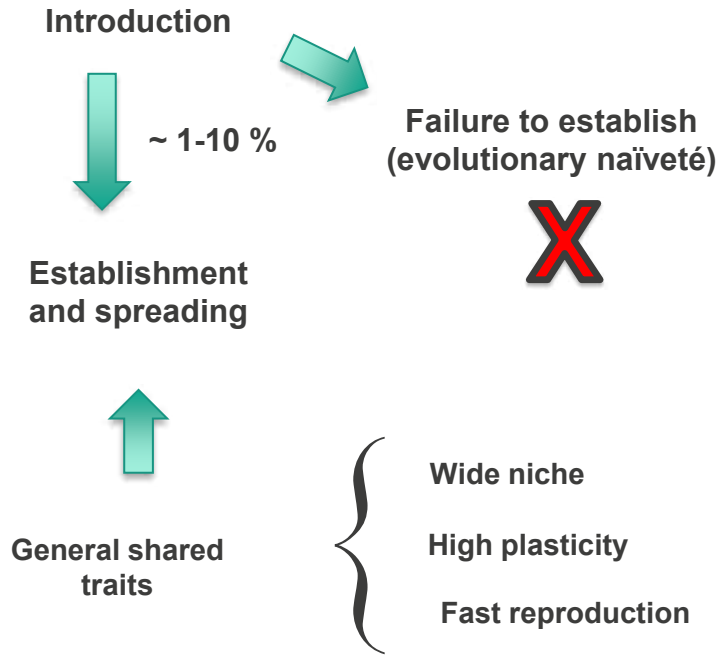
Muths et al., 2017 *Scientific Reports*

Importance to take into this variability in studies on
invasive-native species interactions

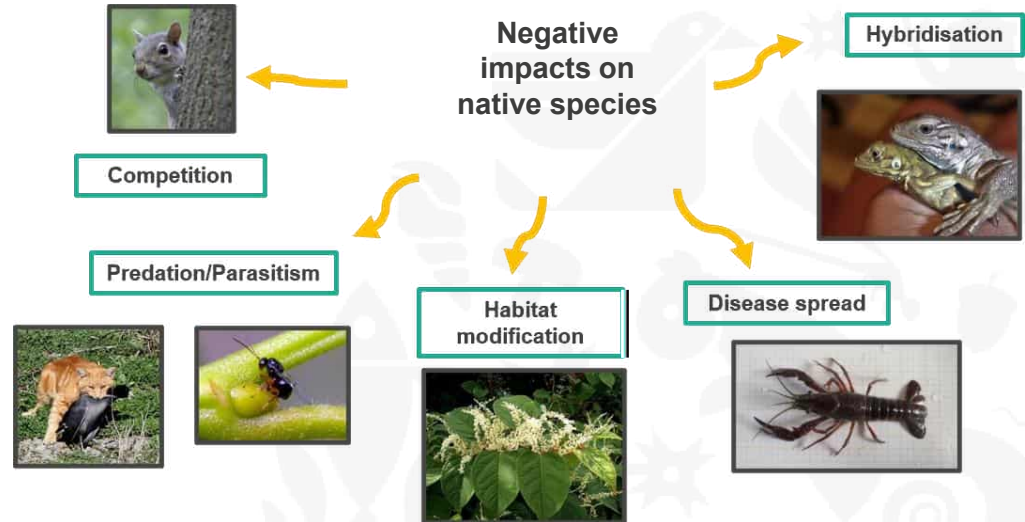
Invasive species

Not all non-native species becomes invasive

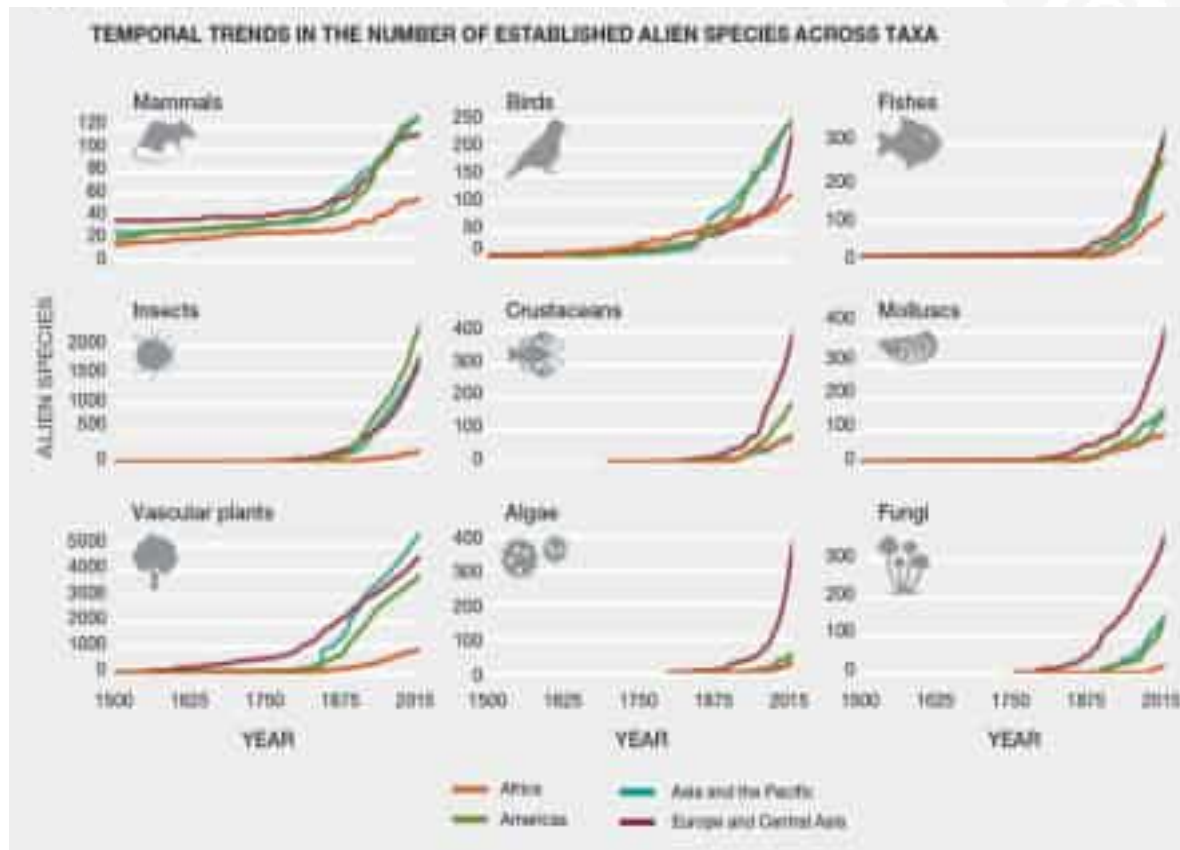
Williamson & Fitter (1996) Ecology



But when they become...



Invasive species are spreading



<https://www.ipbes.net/IASmediarelease>

Ways invasive species impacts on amphibians are multifaceted



Predation and pathogen transmission represent most threatening ones

Let's see some examples

	Predation	Competition	Hybridization	Habitat alteration	Spread of Disease
a) Typical examples	Native bullfrogs (Rana temporaria) are preyed on by introduced American Bullfrogs (Rana catesbeiana). When predators reach the decline of Litoria frogs in Australia?	Introduced frogs compete with native species and reduce diversity of the community?	Introduced (European) Green Frogs (Rana lessonae) and native Italian Red Frogs (Rana italica) are hybridizing, reducing the native genetic diversity?	When introduced American Bullfrogs alter the wetland structure, lowering the availability of invertebrates with negative effects on native amphibians?	When introduced Bullfrogs are carriers of Batrachochytrium dendrobatidis (Bd) to native amphibians?
b) Complexity	Fish predation can cause selective extinction of some amphibians (paedomorphs)? Has impact of predators is stronger in altered habitats?	Cane Toad (Rhinella marina) outcompetes Australian amphibians, but predators exposed to Cane Toads release predation over native amphibians?	Genetic introgression can have ecological impacts on other members of the community?	The invasive Common Reed (Phragmites australis) affects the American Bullfrogs potentially threatening its negative effects on other communities where both these species are thriving?	Asian Horned Lizards (Hemidactylus turkmenicus) can carry pathogens?
c) Most frequent invaders					

Falaschi, Melotto et al. (2020) *Herpetologica*

Amphibians are particularly sensitive to invasive predators

Falaschi, Melotto et al. 2020 *Herpetol.*



Declines and extinctions

Predation is a powerful evolutionary force driving predator-prey interactions

Lack of co-evolution can prevent predator recognition or limit anti-predatory responses



Arm race



Coevolution

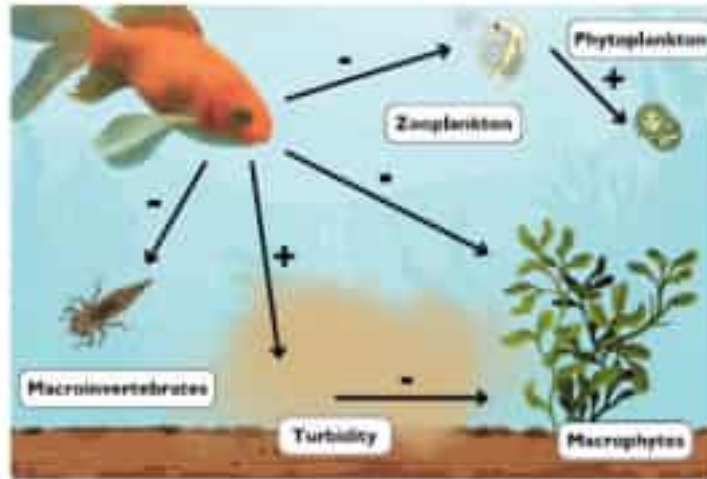


Evolutionary naïveté

Invasive predators...



Massive impacts of invasive fish on native ecosystem community



multifaceted impacts



Local amphibian extinctions

Especially in fragile and/or isolated ecosystems

e.g., alpine lakes

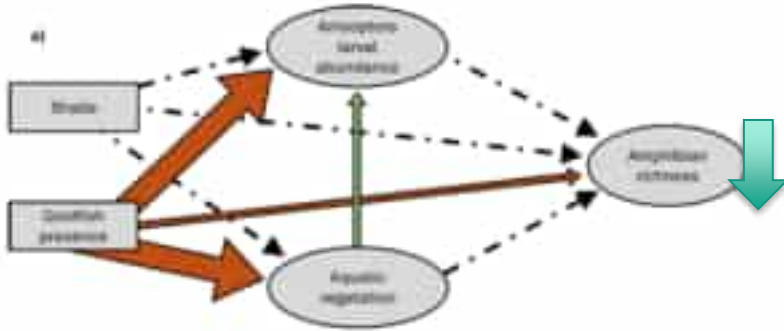


Denoël et al. (2016) Conserv. Biol.



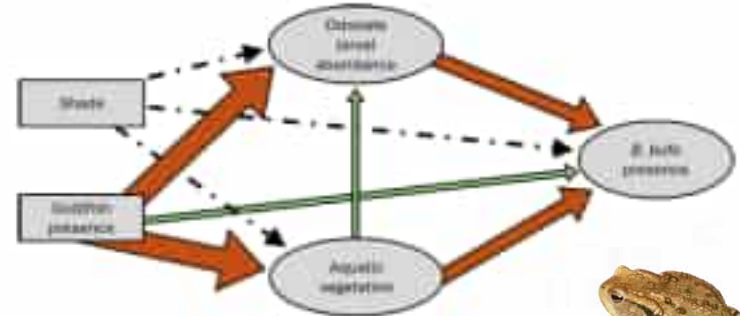
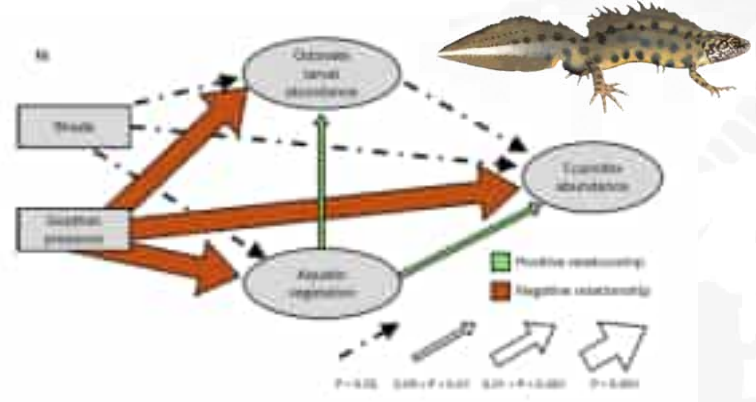
Ongoing study in Slovenian ponds

Fish presence has cascading effects reducing amphibian richness



But species-specific effects can vary

Palatable prey



Toxic prey



Procambarus clarkii

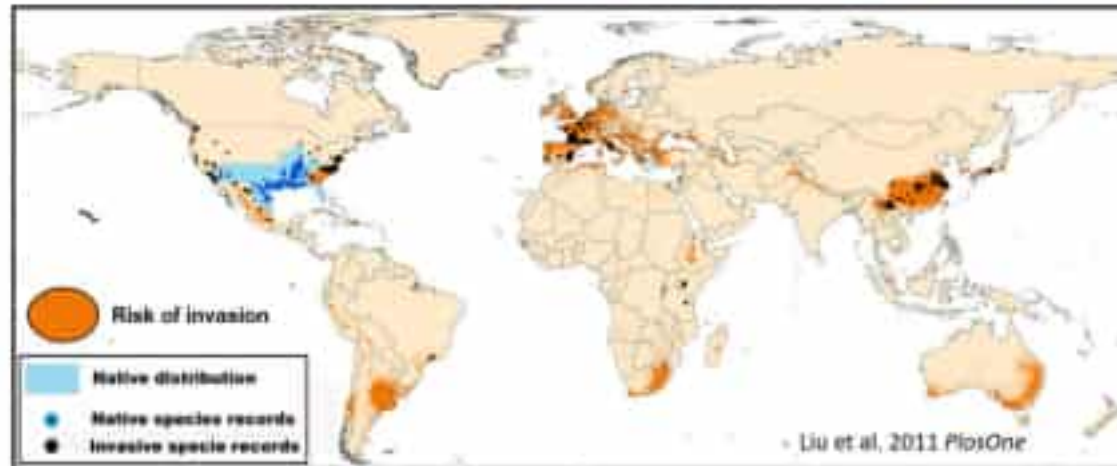


The red swamp crayfish

Fast spread

Voracious predator

Disease vector



Collapse of the amphibian community of the Paul do Boquilobo Natural Reserve (central Portugal) after the arrival of the exotic American crayfish *Procambarus clarkii*

M.J. Cruz¹, P. Segurado², M. Sousa² & R. Rebelo¹

¹Centro de Biologia Ambiental, Lisbon, Portugal

²Centro de Estudos Florestais, Instituto Superior de Agronomia, Lisbon, Portugal

³Instituto da Conservação da Natureza e da Biodiversidade, Lisbon, Portugal



Table 1. Status of each amphibian species in the two sampling sessions. Methods used: a) drift fence; b) acoustic surveys; c) aquatic traps; d) visual encounter surveys.

Species	1993/98	Based on	2001	Based on
<i>Pleurodeles waltl</i>	Very abundant	a, c, d	Rare; absent from the main wetland	d
<i>Salimandria atra</i>	Rare	d	X Not found	
<i>Triturus cristatus</i>	Rare	d	X Not found	
<i>Triturus marmoratus</i>	Very abundant	a, c, d	Rare	a
<i>Alytes cisternasi</i>	Rare	b, d	X Not found	
<i>Dicoglossus galganoi</i>	Rare	d	Rare	a, d
<i>Pelobates cultripes</i>	Common	b, d	Rare; absent from the main wetland	d
<i>Pelodytes punctatus</i>	Abundant	a, b, d	X Not found	
<i>Bufo bufo</i>	Rare	d	X Not found	
<i>Bufo calamita</i>	Rare	b, d	Rare	a, d
<i>Hyla arborea</i>	Very abundant	b, c, d	X Not found	
<i>Rana perezi</i>	Very abundant	a, b, c, d	Rare	b, d
<i>Rana lessonae</i>	Rare	d	X Not found	



Distribuzione di *P. clarkii* in Italia

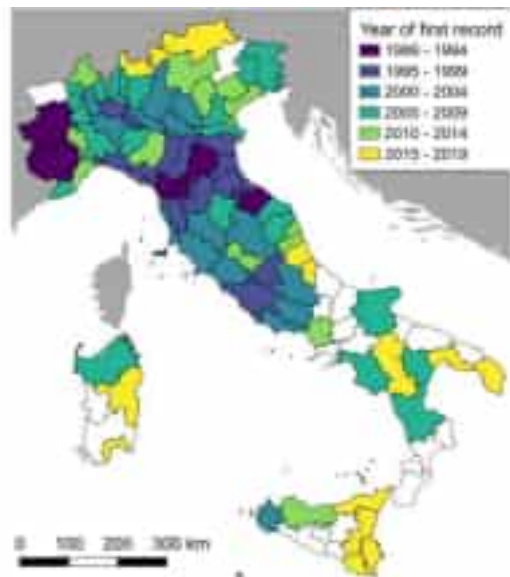


Figure 1. Distribution map of *Proscamburnus clarkii* at the provincial level. The colors represent the different periods of first observation of the species. Grey represent territories outside the Italian boundaries.

Lo Parrino et al. (2020) *Biogeographia*

2020

Presente in > 80 %
delle province italiane

Elevata suscettibilità alla predazione



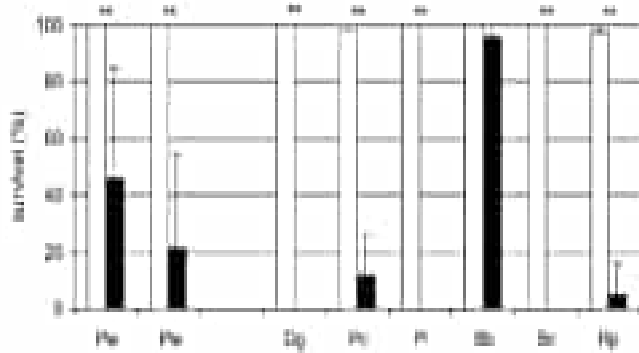
uova ed embrioni



urodeli



anuri



gambero



controllo

Stadio larvale

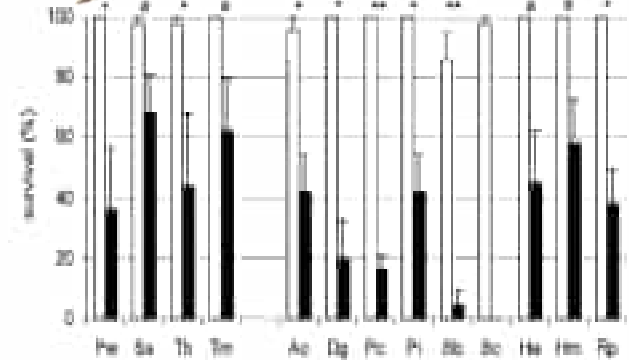


Evidenze da test di efficienza predatoria in lab

urodeli



anuri



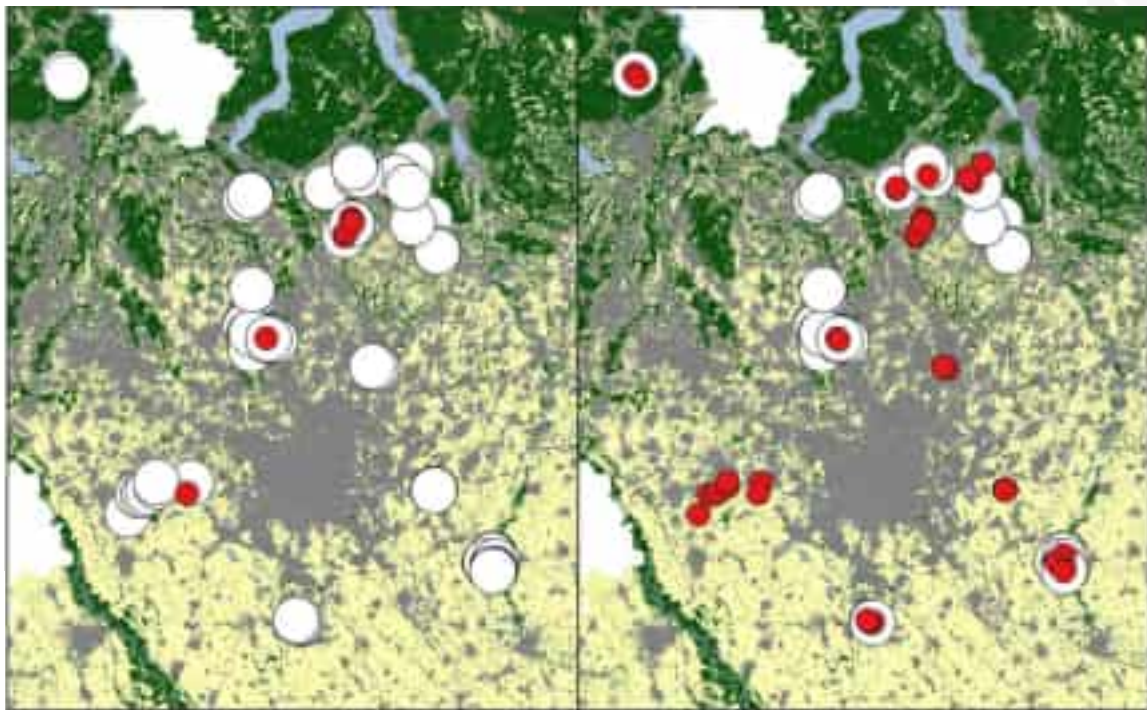
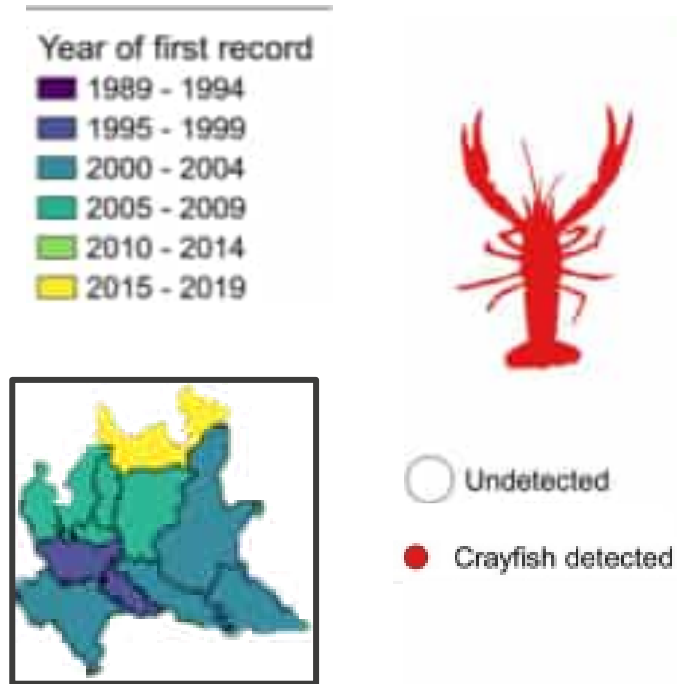
Cruz & Rebelo (2005) Amphibia-Reptilia

In Lombardia

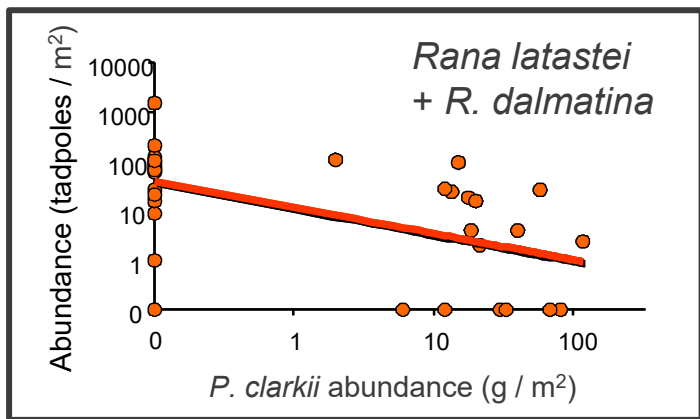
Diffusione del gambero nelle aree monitorate

~ 2004

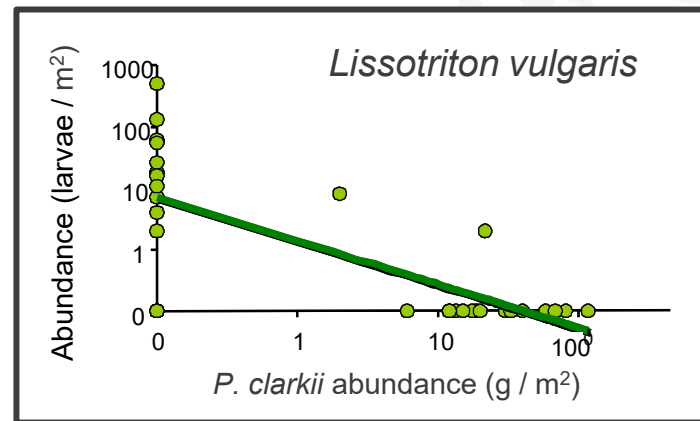
2020



...anche in Italia forti impatti sulla comunità anfibia



Predazione
sugli stadi
larvali in natura



**Riduzione
abbondanza**



**Estinzioni
locali**

Ficetola et al., 2011 Diversity & Distributions

Rearing experiment



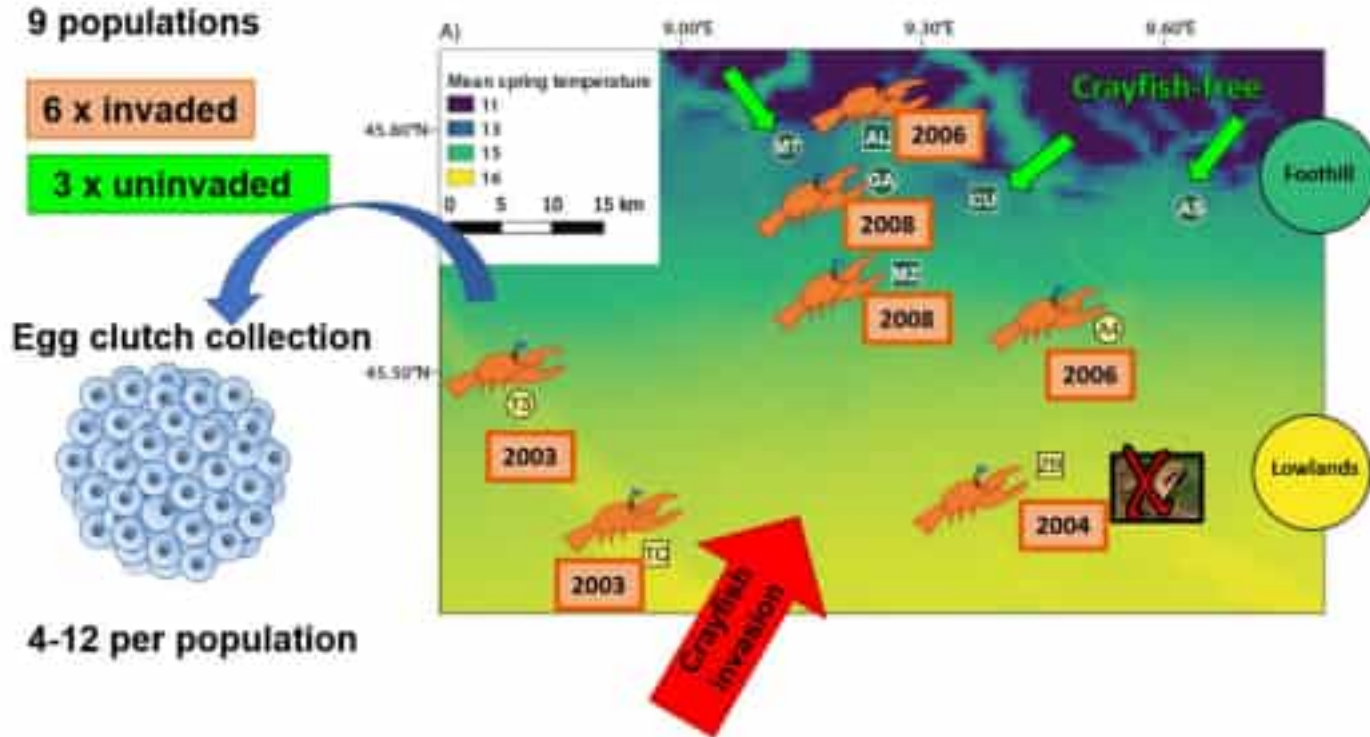
R. latastei

VS



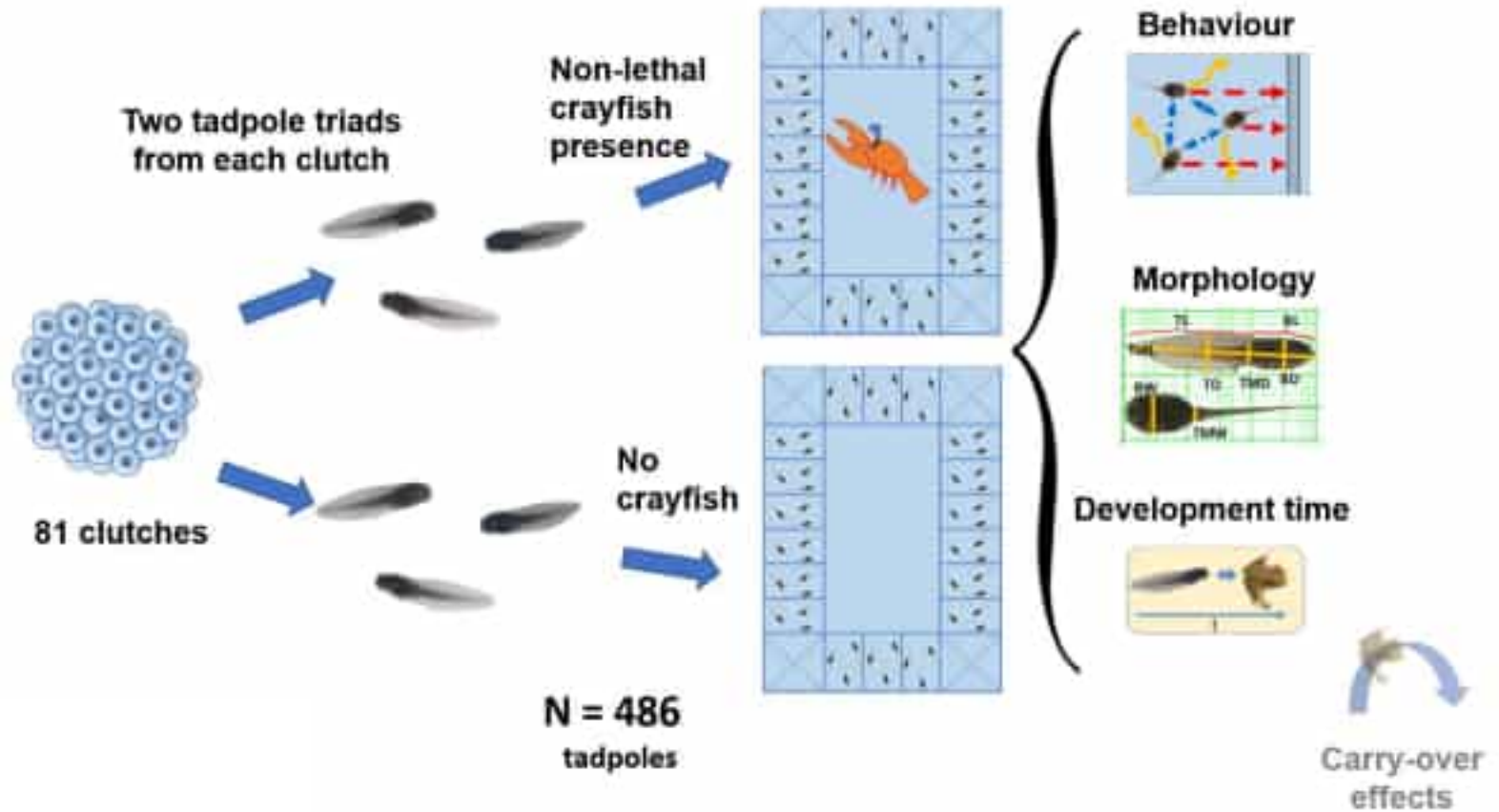
P. clarkii

Experimental setting



Melotto et al. 2020, Nat. Comm.

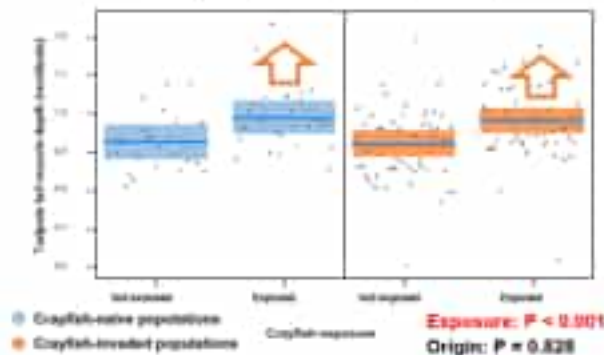
Experimental plan



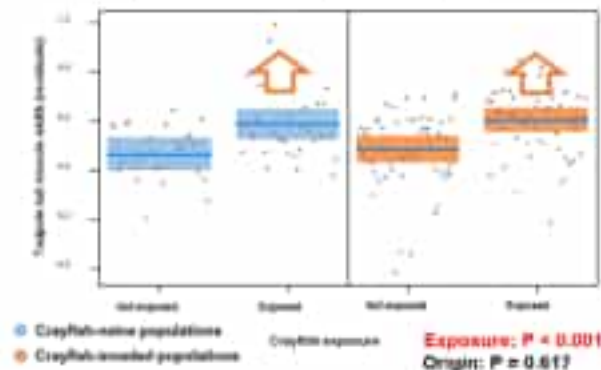
How do tadpoles respond?



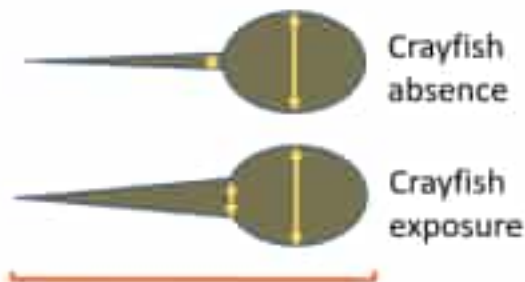
Relative tail muscle depth



Relative tail muscle width



Relative muscle size increases with *P. clarkii* exposure



Significant morphological plasticity!

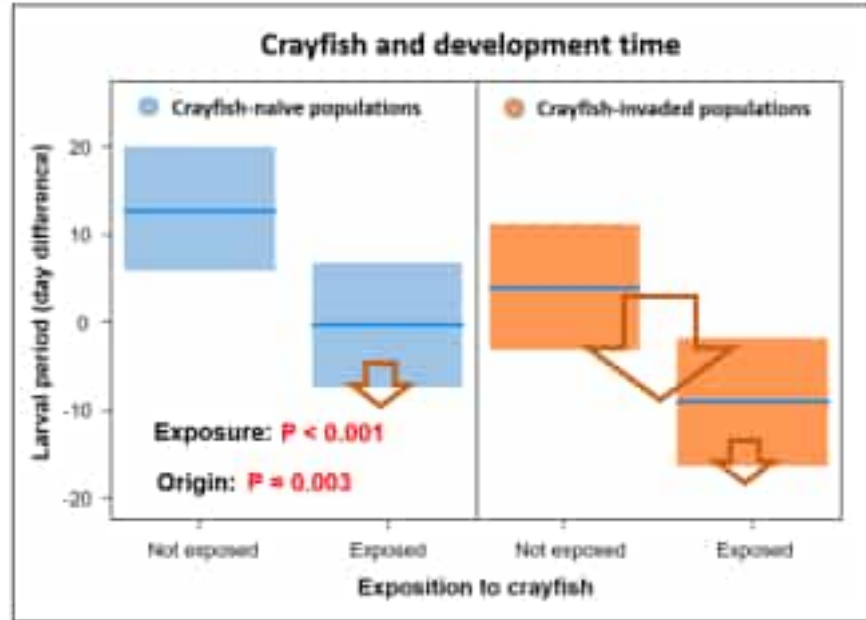
Anti-predator inducible defense associated to predator presence

Makarewicz et al. (2011), Biological Invasions

How do tadpoles respond?



Development time



Crayfish exposure increased development time

Crayfish-invaded populations constitutively showed a reduced larval period

Differences between foothill and lowland disappear

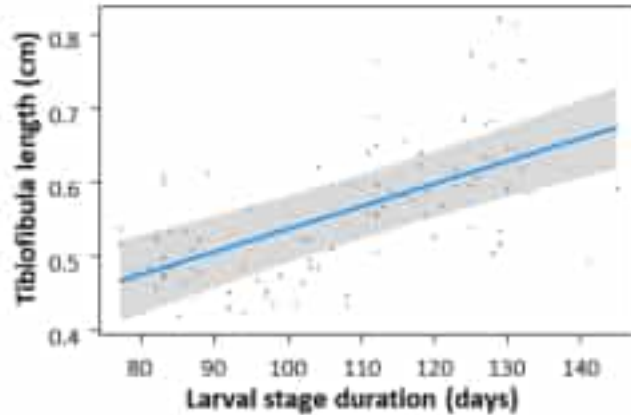
15-year after the invasion the crayfish is now the dominant selective force

Rapid adaptation

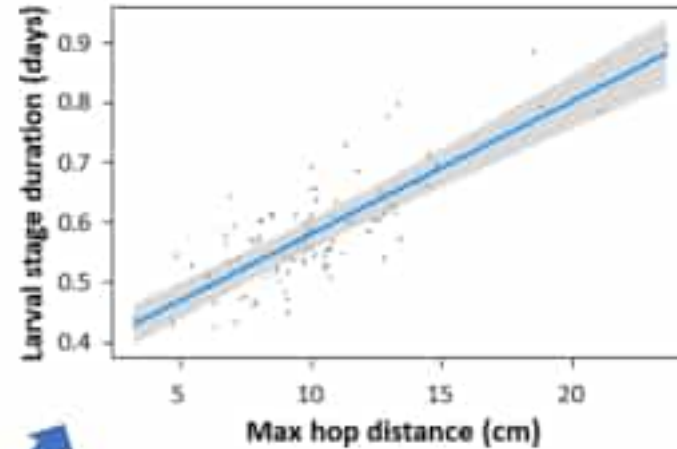
Melotto et al. 2020, Nat. Comm.

Carry-over effects at metamorphosis

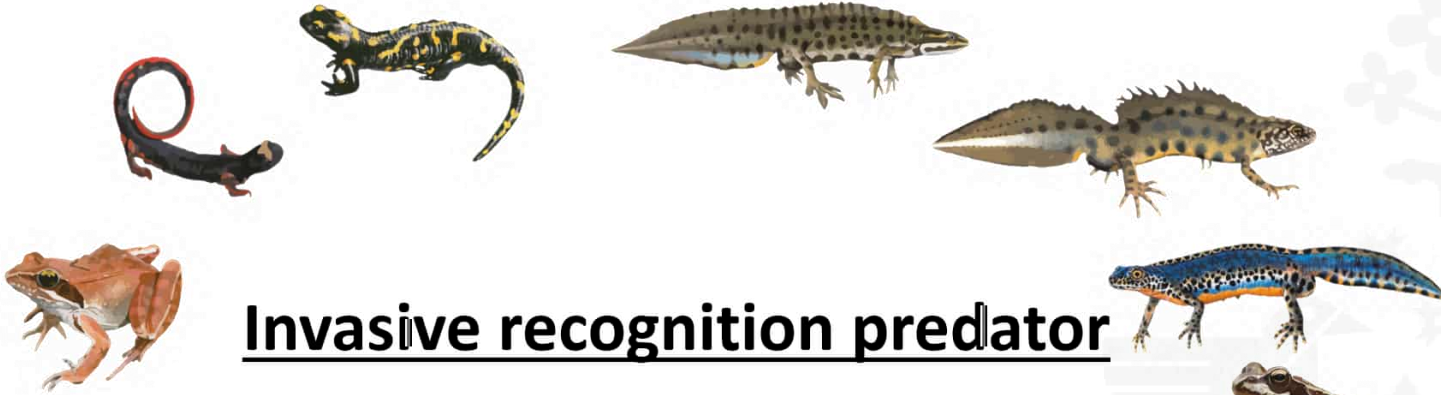
Developmental time and tibiofibula length



Tibiofibula length and jump performance

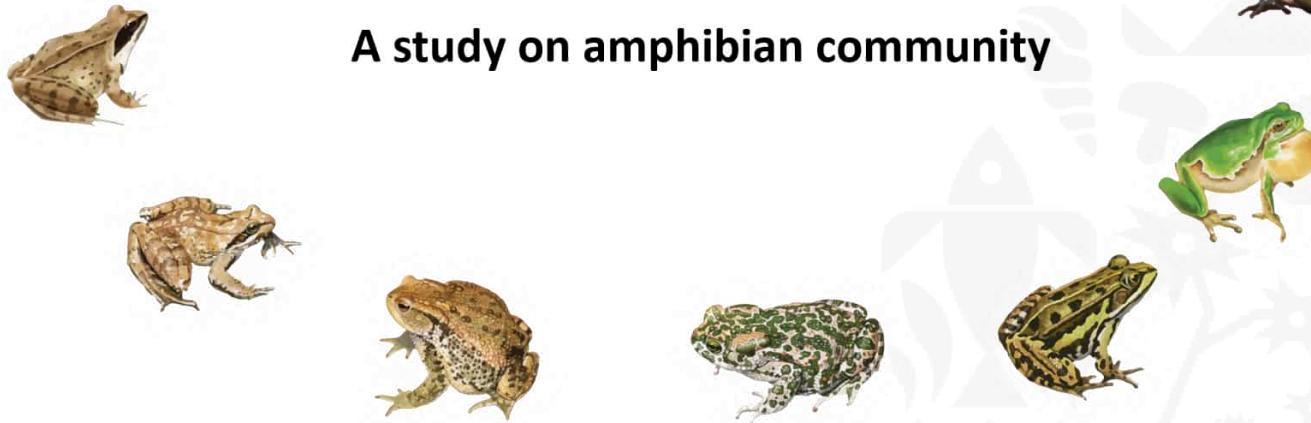


Melotto et al. 2020, Nat. Comm.



Invasive recognition predator

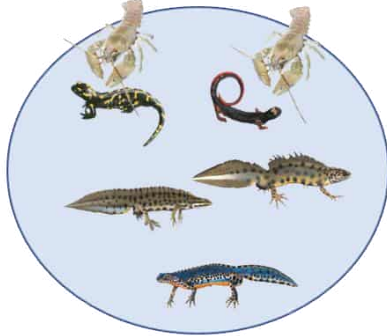
A study on amphibian community



Collection and housing of larvae

Melotto et al. 2021. Behav. Ecol.

5 urodele species



8 anuran species



24 individuals per species
from different populations

Mechanism of response?

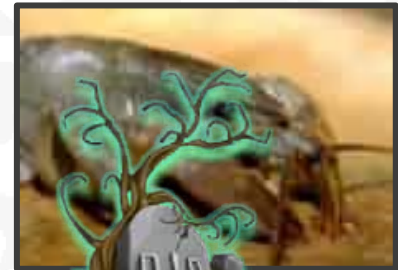
Coevolutionary history?

Variation among species

never in
contact with
invasive crayfish



Once hosting
native crayfish

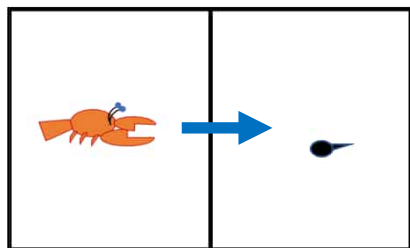
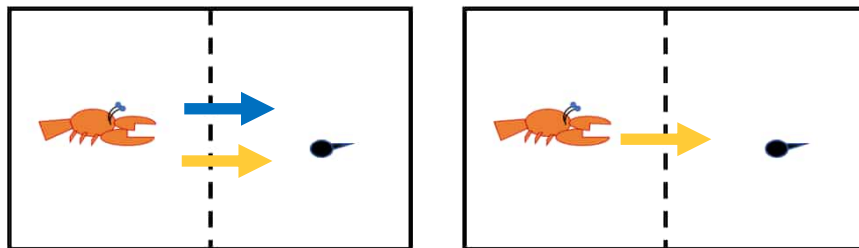


white-clawed crayfish
(*Austropotamobius
pallipes*)

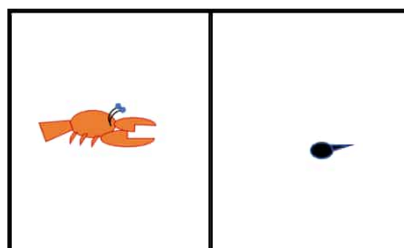
Predation risk exposure

Melotto et al. 2021. Behav. Ecol.

Exposure to crayfish

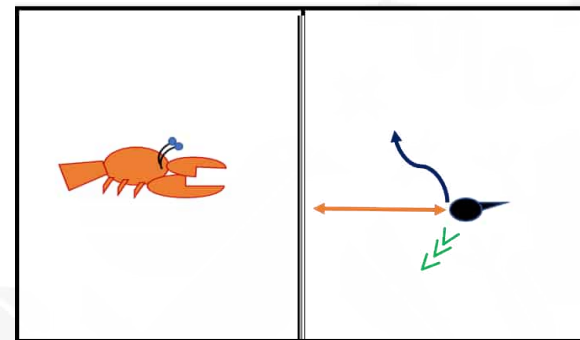


• Visual cues



• Chemical cues

Behavioural traits



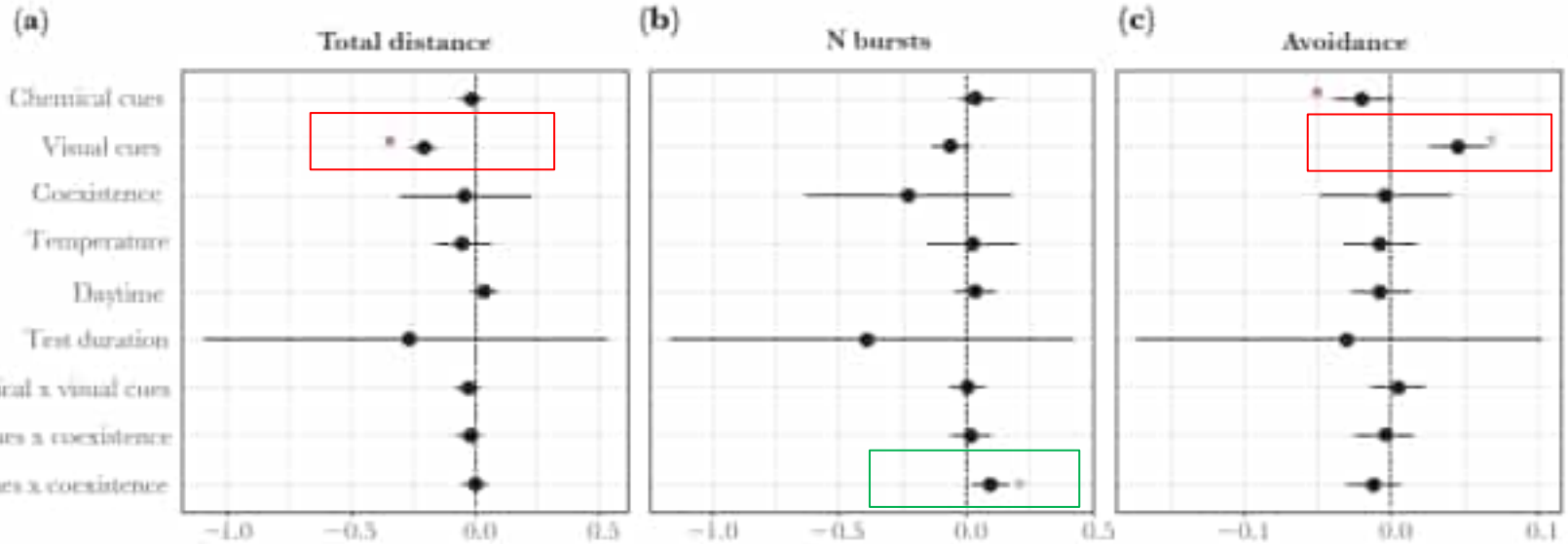
Distance moved

N Bursts

Avoidance

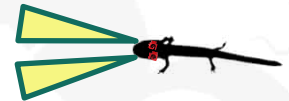
Invasive recognition predator

Melotto et al. 2021. Behav. Ecol.



Amphibians rely on visual cues to recognize the invasive crayfish

Generic recognition



Visual cues triggers refined responses in amphibians that coexisted with a native crayfish

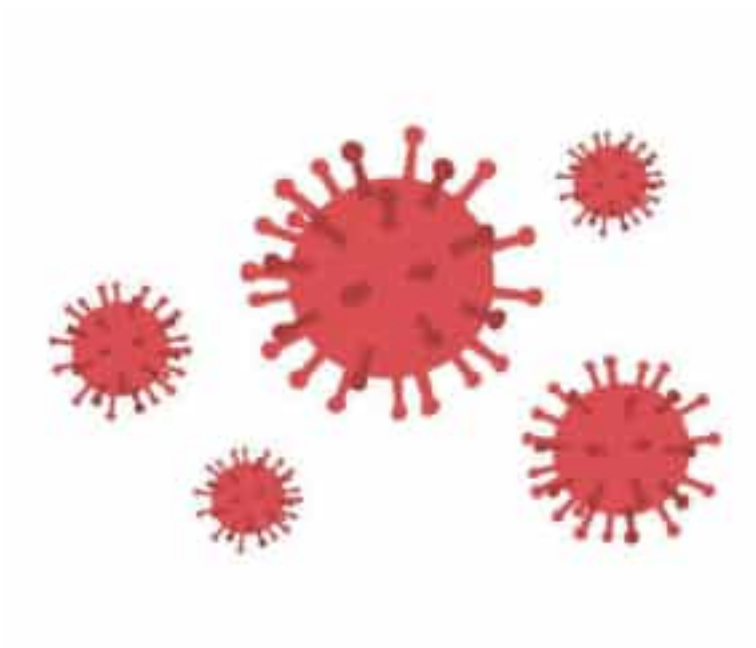
Coevolutionary history



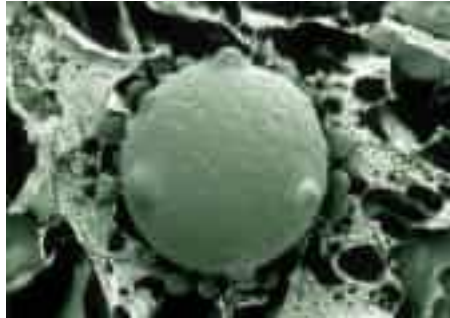
High variability in the response among species

	Coexisting with native crayfish	Total distance	Number of bursts	Avoidance
<i>S. astomandus</i>				
<i>S. perspicillata</i>				 
<i>I. vulgaris</i>				
<i>T. carnifex</i>				
<i>L. asperis</i>				
<i>R. latitatus</i>				
<i>R. dalmatins</i>				
<i>R. italicus</i>				
<i>R. longimanus</i>				
<i>P. kl. exulantis</i>				
<i>H. intermedia</i>			NA	
<i>B. bogis</i>				
<i>H. insidius</i>				

Novel pathogen spreading



Chytridiomycosis



chytrid fungus



Dead frogs killed from the amphibian chytrid fungus.

PHOTOGRAPH BY JOEL SARTORE, NAT GEO IMAGE COLLECTION

Batrachochytrium dendrobatidis, Bd

Targeting anurans

Supposed origin



Described in 1998



Likely spread due to amphibian trading

Batrachochytrium salamandrivorans, Bsal

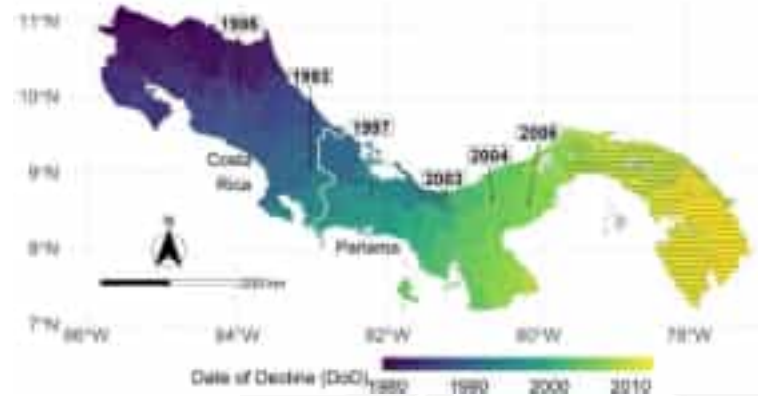
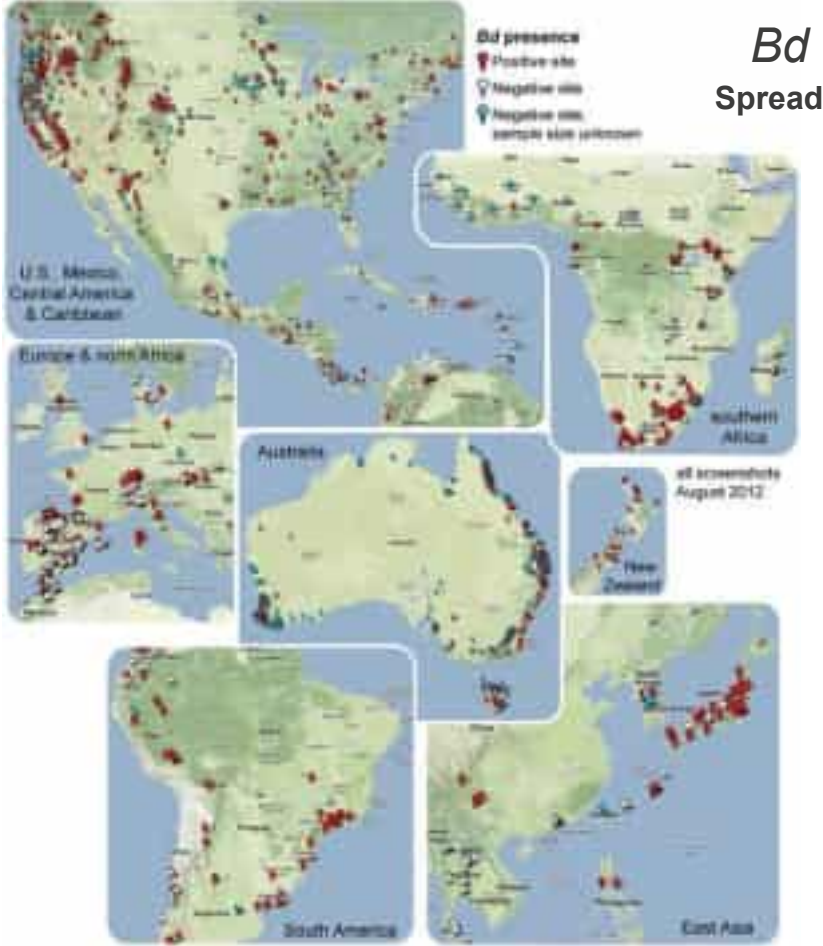
Targeting urodels

Supposed origin

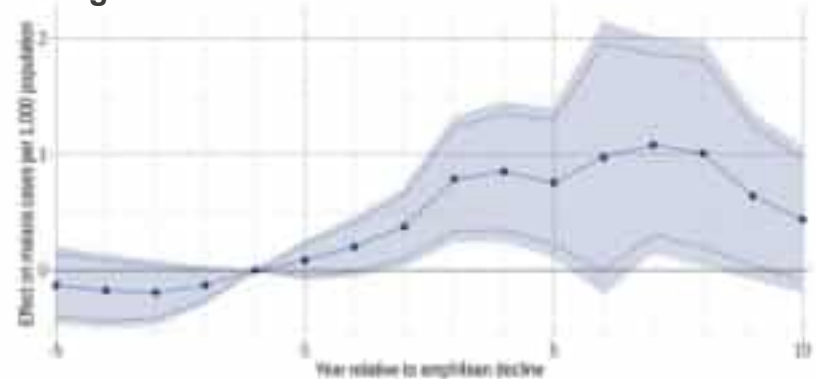


2013





Cascading effects directly affecting human health:



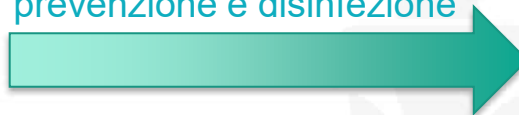
Olson et al. (2013) PlosOne

Springborn et al. (2022). Environ. Res. Lett.

Prevezione trasmissione patogeni



Importanza protocolli di
prevenzione e disinfezione



es. lavaggi con candeggina 1-5 %
(in relazione al patogeno, meglio 5 % per andare sul sicuro!!)



Many threats.... what can help?

Prevention

Early-detection & early-response (containment where eradication is unfeasible)

Preserve pristine ecosystem is also important (ecosystems in good shape respond better, and are both more resistant and more resilient)



Grazie dell'attenzione!

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