# *Ekofiziologija životinja*

# *Predavač - prije i sad(e)*

Sad(e)

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**Biološki odsjek**
**Rooseveltov trg 6**
**tel. 6189 705 ili 4877 700**
**fax. 4826 260**
**E-mail: *ztadic@biol.pmf.hr***

Prije

***Područje znanstvenog rada:*** Ekofiziologija, ponašanje životinja, kemijska i bihevioralna ekologija gmazova (posebno zmija), kognitivne sposobnosti gmazova (gušteri i zmije). Evolucija složenih anatomskih i fizioloških svojstava gmazova, različiti aspekti ekologije i ponašanja zmija.

***Hobiji:*** Šetnje i boravak u prirodi; sociološki i filozofski aspekti interakcija ljudi i životinja; sociopolitički fenomeni Hrvatske i ostalih zemalja bivše Jugoslavije; povijesni, geopolitički i sociološki aspekti rata i ratovanja; filmovi talijanskih sineasta; ultrašund filmovi; Leteći Cirkus Monty Pythona; stripovi (posebice oni francusko-belgijske škole stripa); časopis MAD; kvalitetna domaća i strana vina i sirevi; mediteranska i azijska hrana; pub kvizovi (uglavnom ekipa “Poštena teligencija”)

***Internetska stranica:*** https://zaf.biol.pmf.unizg.hr/Tadic/
***Internetska stranica o bivšoj zbirci zmija:*** https://snakes.biol.pmf.unizg.hr/

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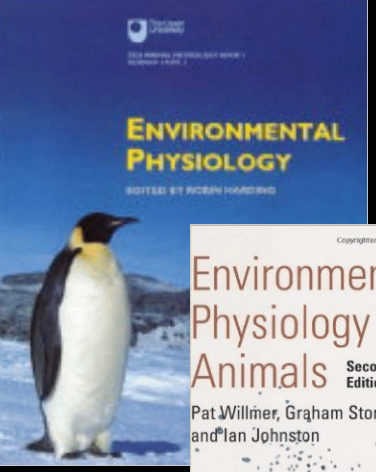
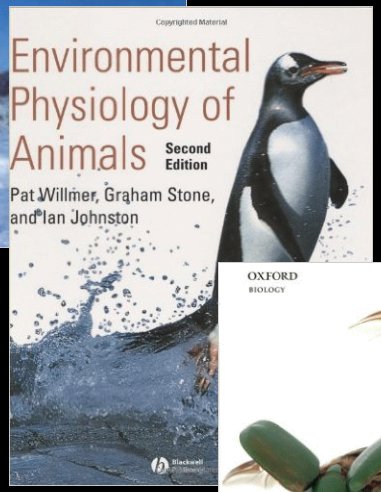
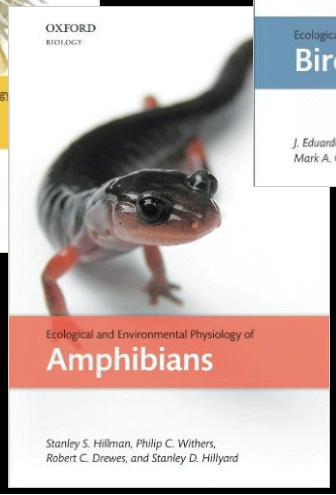
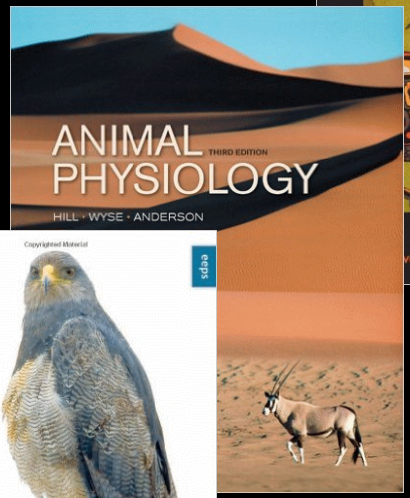
# Knjige i ostalo

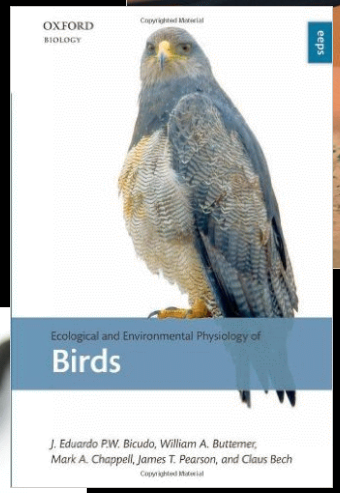
http://zaf.biol.pmf.unizg.hr/ecophys

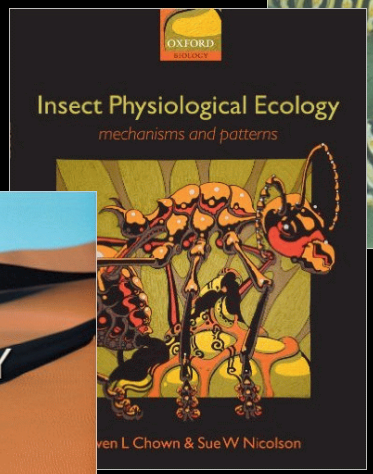


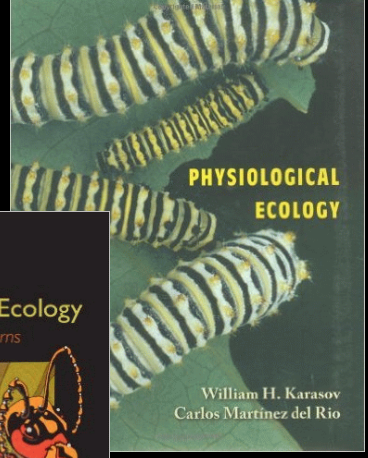



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*Oncorhynchus nerka*

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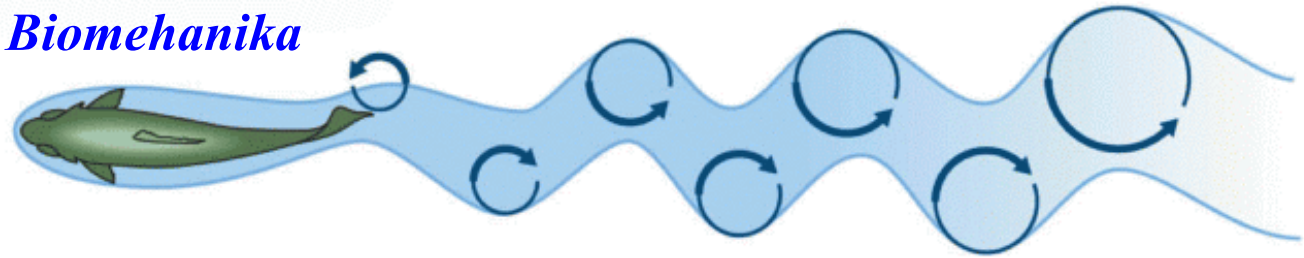
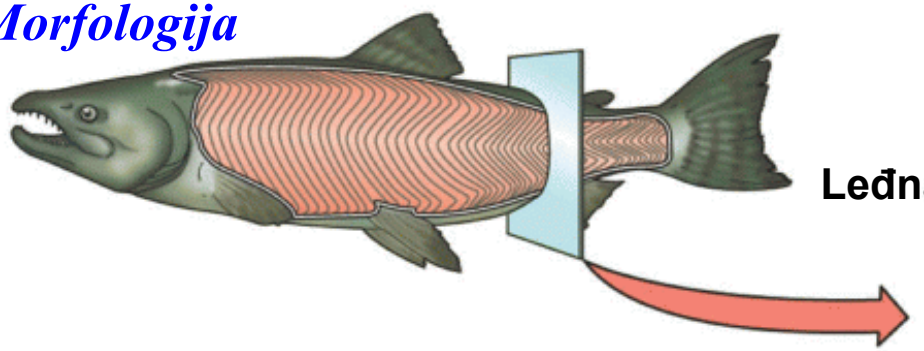
## *Biomehanika*



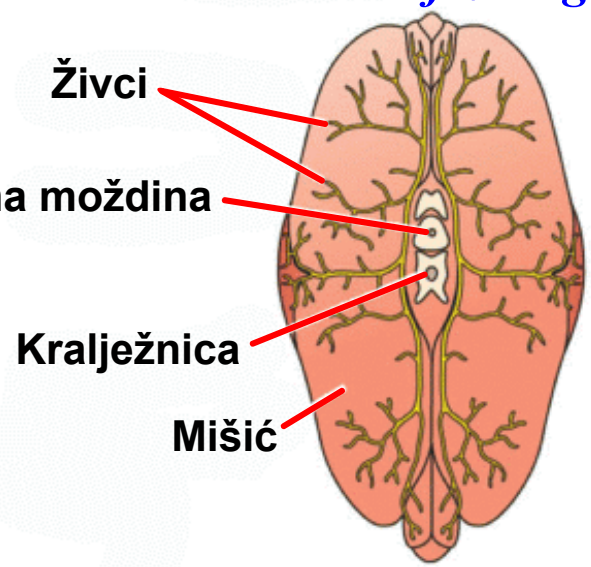
## *Fizika*

**Sila = masa X akceleracija**

## *Morfologija*



## *Sistemska fiziologija*

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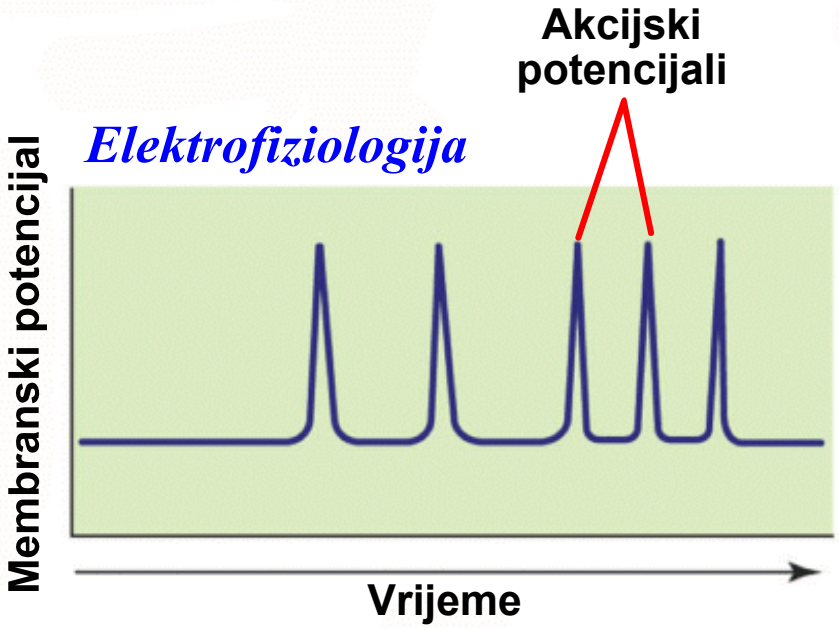
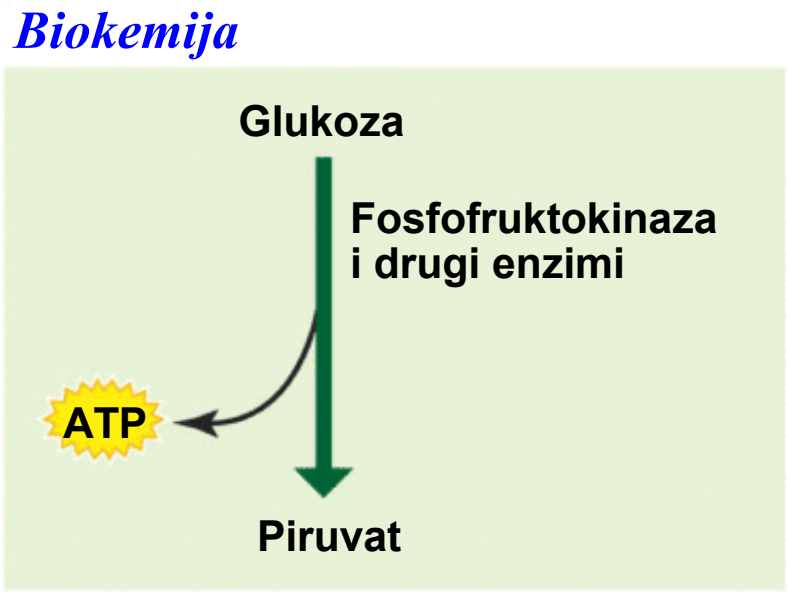
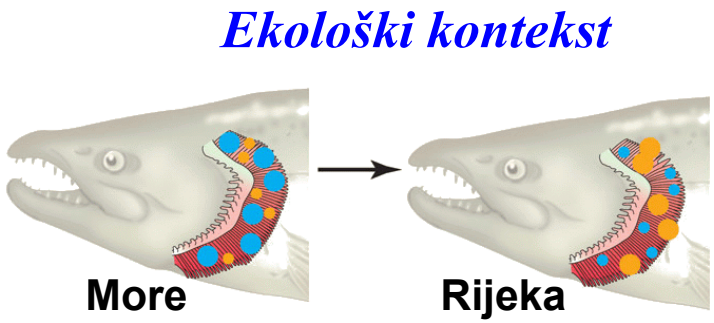
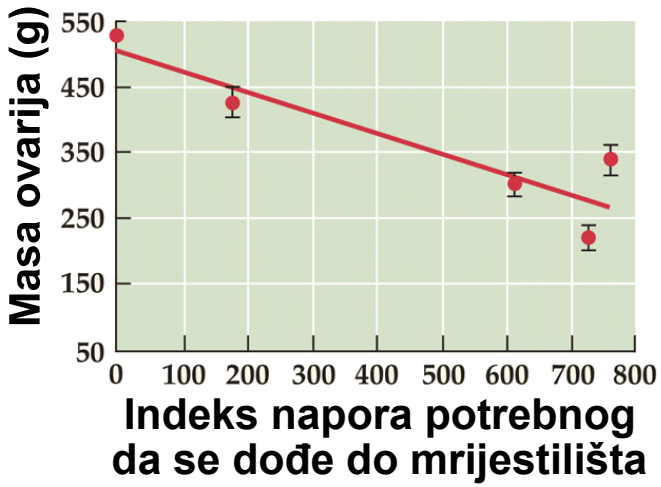



Veličina kruga pokazuje razinu aktivnosti

- Protein 1
- Protein 2

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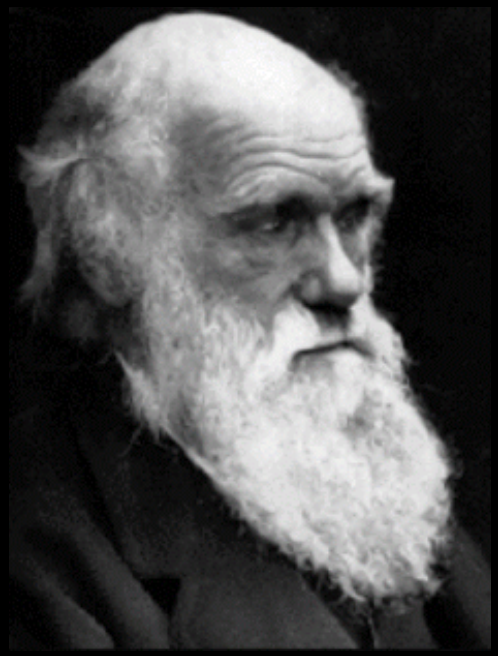
# Charles Darwin (1809 -1882)
# "The Origin of Species" (1859)



*"I have called this principle, by which each slight variation, if useful, is preserved, by the term natural selection."*

**The Origin of Species**

1. **Sve životinje imaju vrlo visoki reprodukcijski potencijal.**
2. **Resursi okoliša su ograničeni.**
3. **Životinje se natječu za resurse okoliša.**
4. **U svakoj populaciji postoji varijabilnost među jedinkama, a neka su varijabilna svojstva nasljedna. Neka od njih povećavaju vjerojatnost preživljavanja i razmnožavanja.**
5. **Jedinkama koje posjeduju ta nasljeđena svojstva povećava se vjerojatnost preživljavanja do trenutka kada će se moći razmnožavati. Pošto će ta njihova svojstva vjerojatno nasljediti njihovi potomci, frekvencija tih svojstava u populaciji će se povećati.**

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**“Borba za opstanak”**
**ili**
**“Preživljavanje najsposobnijih”**

**OBIČNA NOVINARSKA GLUPOST**

**Tko će “opstati”?**
**odn.**
**Tko je “najsposobniji”?**

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*Odgovor:* “Preživjeti” će onaj odn. “najsposobniji” je onaj koji ima najveći fitness!

*(biološki) Fitness* = broj potomaka koje tijekom života ostavi jedinka, a koje se uspiju razmnožavati.

# *Gdje je u ovoj situaciji interakcija ekologije, evolucije, fiziologije i biokemije?*

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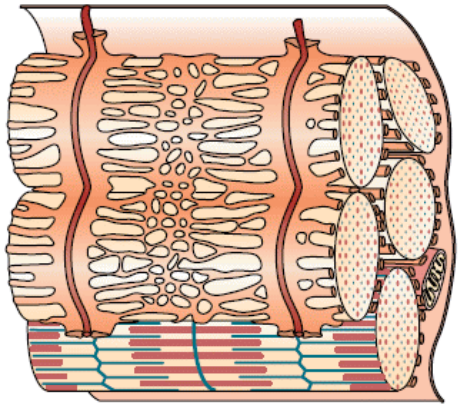
# *Ovdje!*

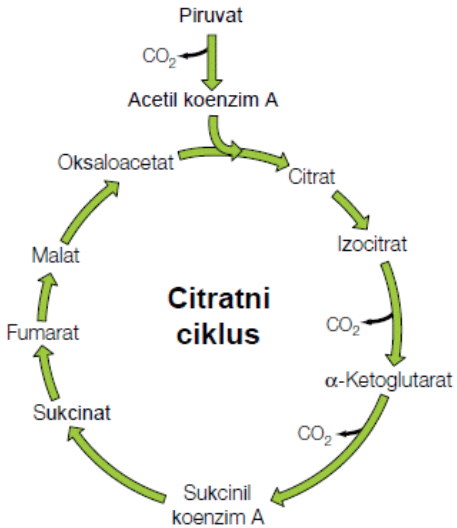
## Evolucijska i ekološka razina organizacije

**Neuspješan bijeg = smrt → lisičji ručak**

**Uspješan bijeg = preživljenje = razmnožavanje**

## Stanična razina organizacije






## Molekularna razina organizacije

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# *Što definira organizam?*

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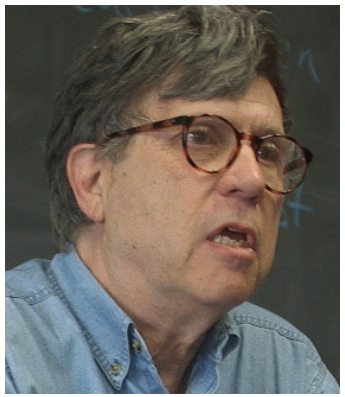
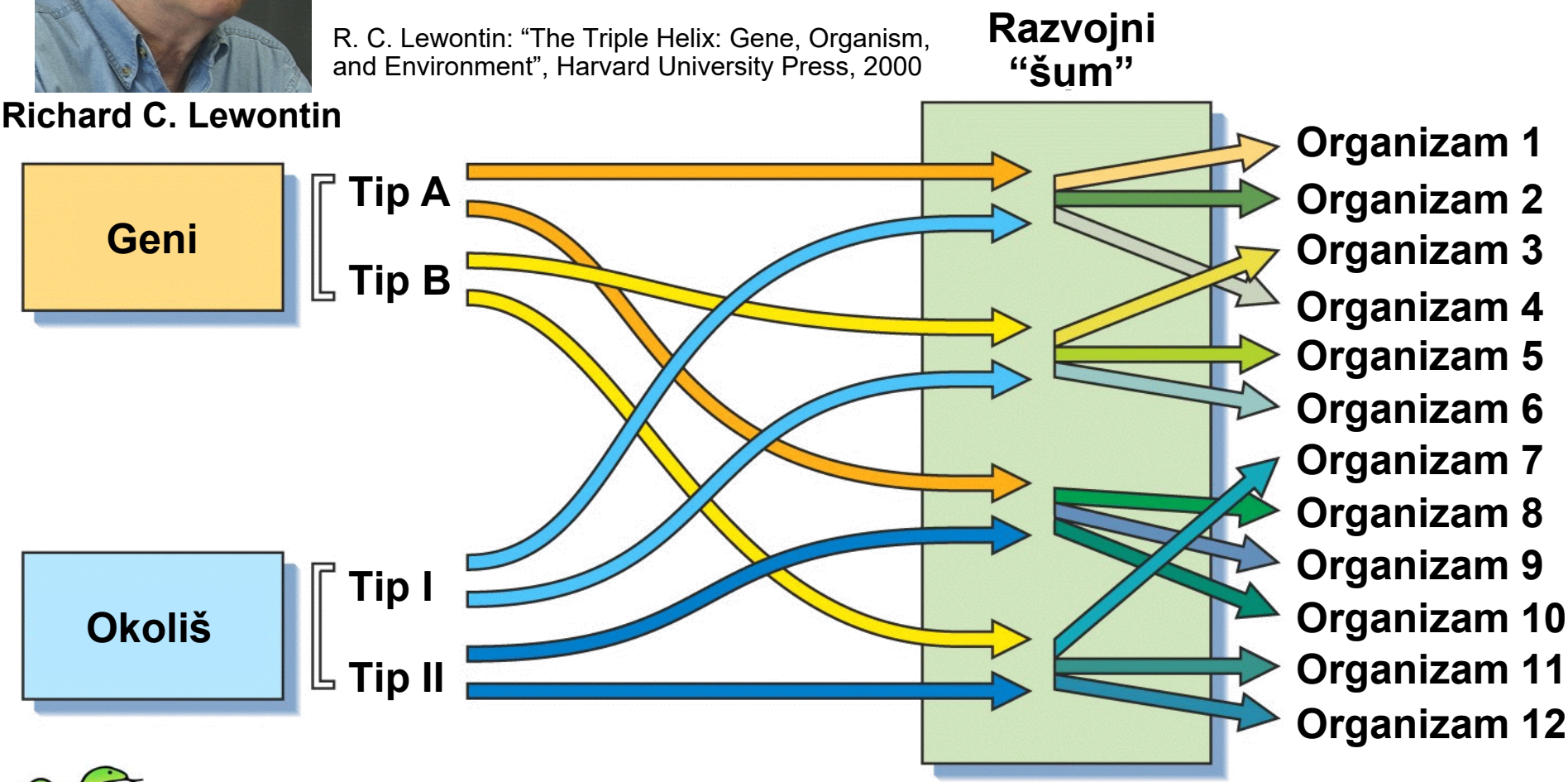
# *Organizam je definiran interakcijom gena, okoliša i razvojnoga "šuma"*



Richard C. Lewontin

R. C. Lewontin: "The Triple Helix: Gene, Organism, and Environment", Harvard University Press, 2000



# *Dva temeljna pitanja ekofiziologije:*

- Kako životinje izvode pojedine fiziološke funkcije? - ***mehanizam***
- Kako je pojedini mehanizam nastao? - ***evolucija mehanizma***

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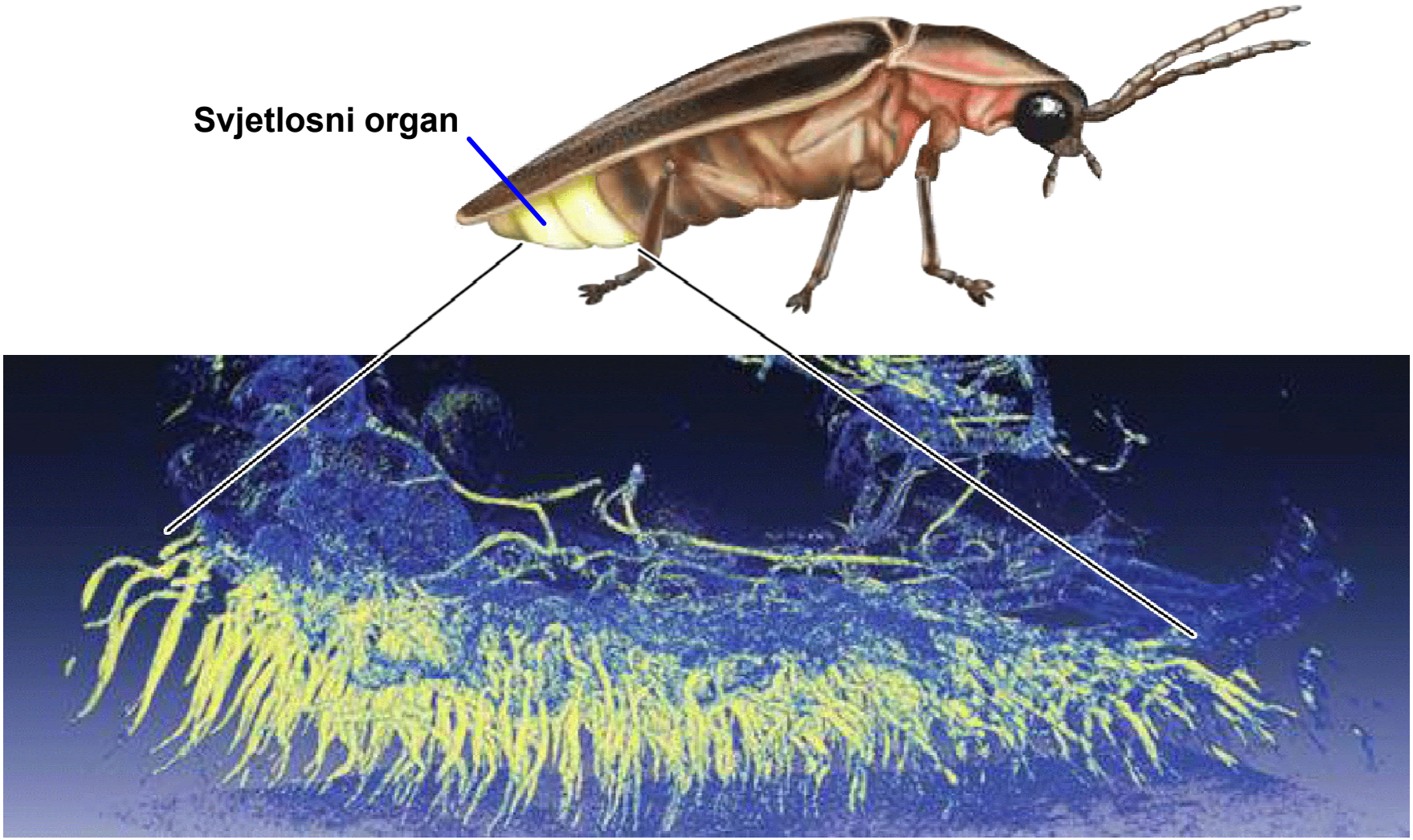
# *Svjetlost koju proizvode krijesnice*

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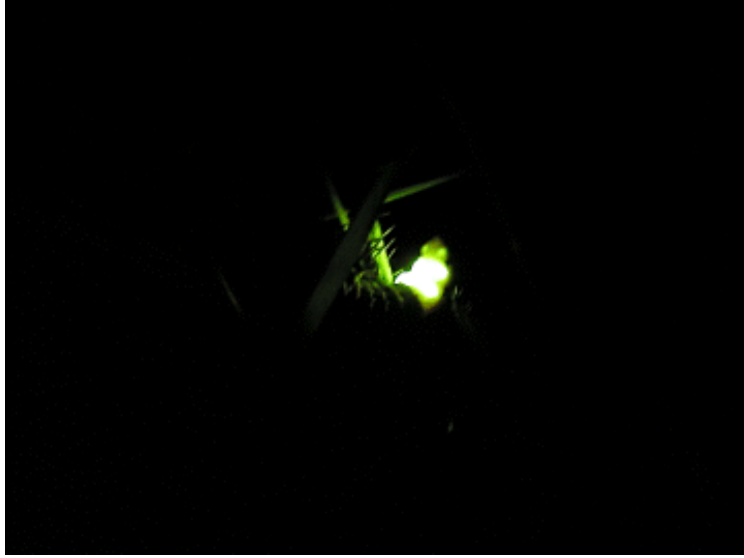
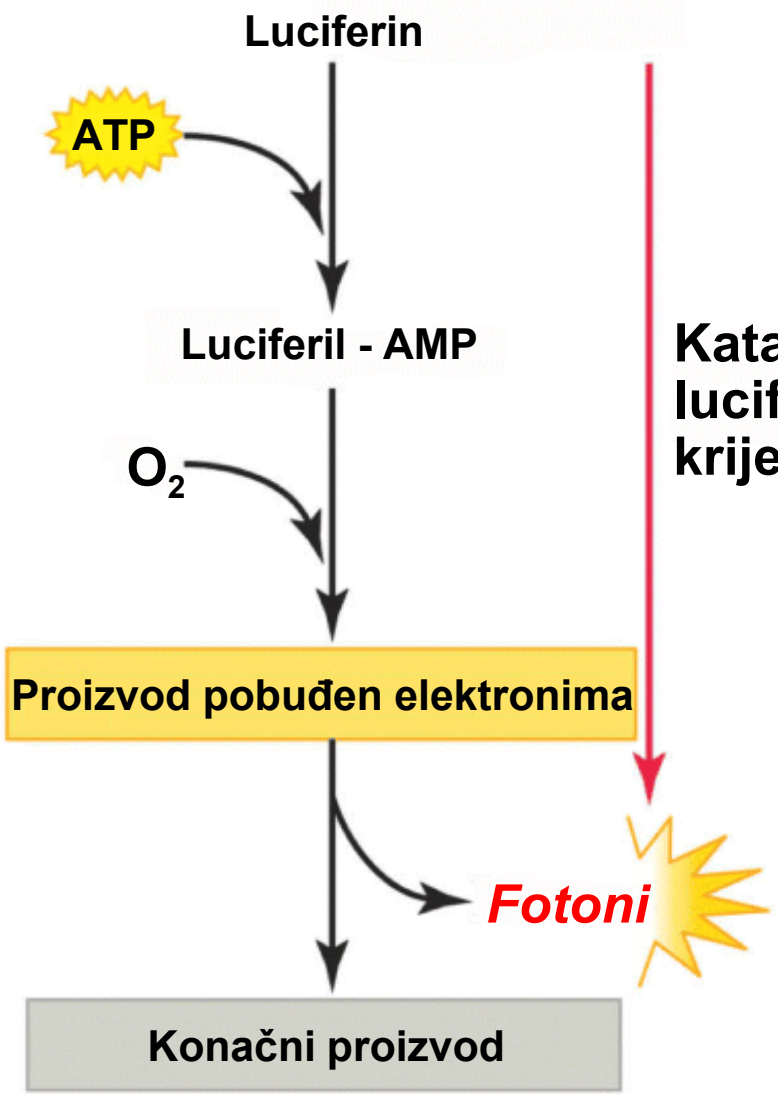
# *Mehanizam proizvodnje svjetlosti*



*Lampyris noctiluca*





Navizet I., Ya-Yun L., Ferré N., Roca-Sanjuán D., Lindh R. (2011) The chemistry of bioluminescence: An analysis of chemical functionalities. *ChemPhysChem* **12:** 3064 - 3076

Fraga H. (2008) Firefly luminescence: a historical perspective and recent developments. *Photochem. Photobiol. Sci.* **7:** 146 - 158

Day J. C., Tisi L. C., Bailey M. J. (2004) Evolution of beetle bioluminescence: the origin of beetle luciferin. *Luminiscence* **19:** 8 - 20

Viviani V. R. (2002) The origin, diversity, and structure function relationships of insect luciferases. *Cell. Mol. Life. Sci.* **59:** 1833 - 1850

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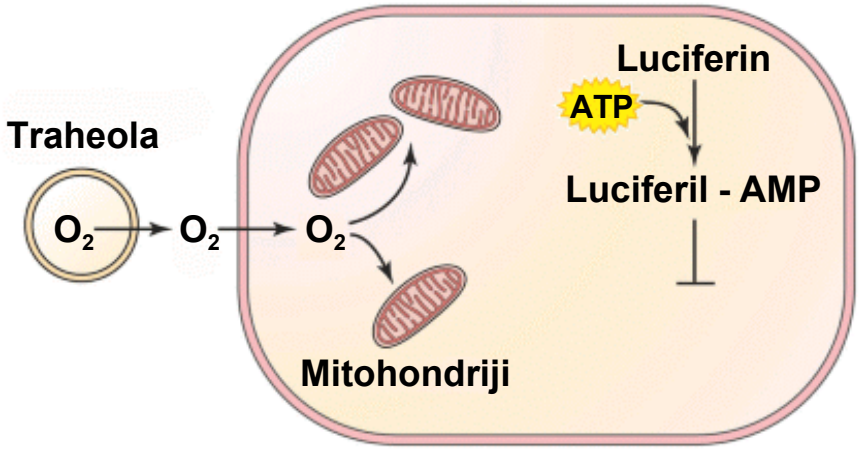
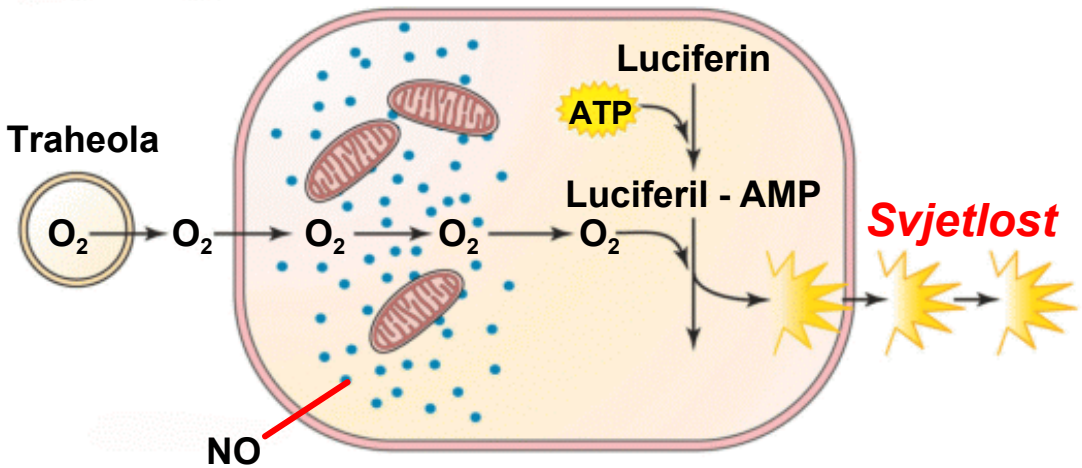
# *Faza tame*




# *Faza svjetla*




Aprille J. R., Lagace C. J., Modica-Napolitano J., Trimmer B. A. (2004) Role of nitric oxide and mitochondria in control of firefly flash. *Integr. Comp. Biol.* **44:** 213 - 219

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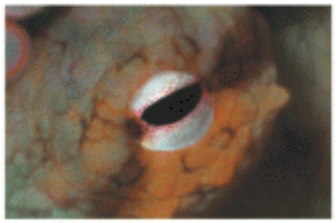
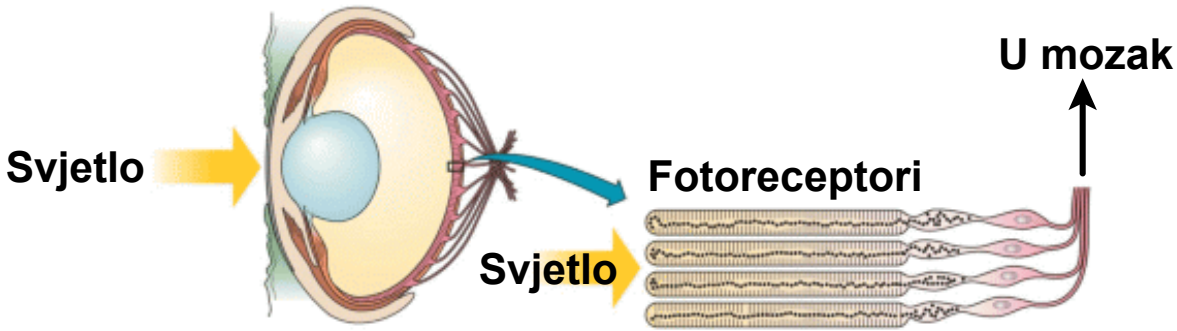
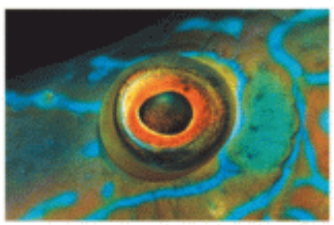
# *Konvergentna evolucija*

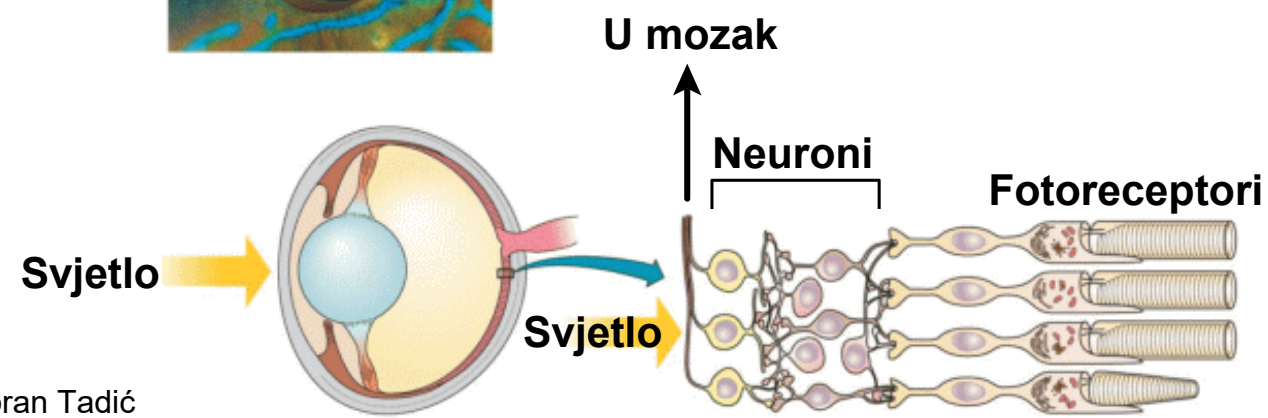
## Oči hobotnice






## Oči ribe






Gehring W. J. (2004) Historical perspective on the development and evolution of eyes and photoreceptors. *Int. J. Dev. Biol.* **48:** 707 - 717

Design by Zoran Tadić

# *Iste strukture, ali različitog razvojnog porijekla*

*Ovis musimon*

*Cervus elaphus*

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# *Nova konstrukcija obično je kompromis*

*Zalophus californianus*

*Tursiops truncatus*

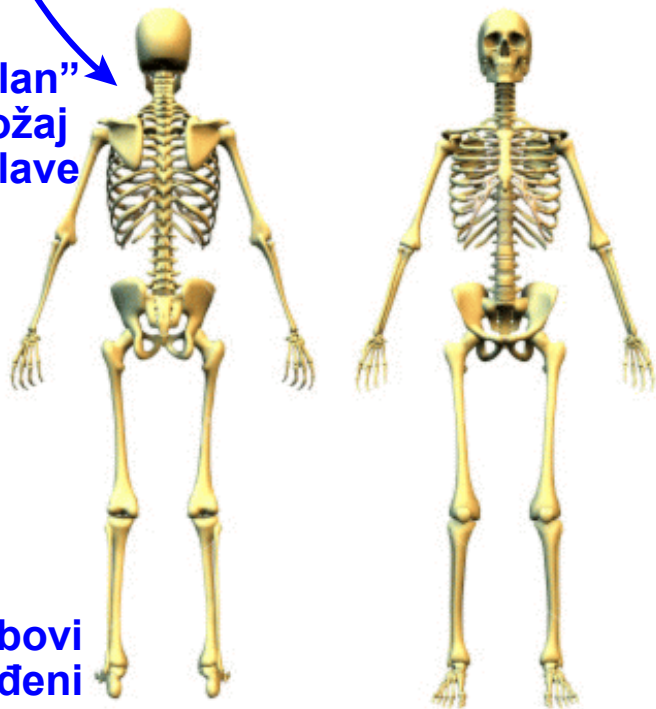
Jacob F. (1977) Evolution and tinkering. *Science* **196:** 1161 - 1166

"Pravilan" položaj glave

Zglobovi prilagođeni skakanju

*Felis catus*

"Nepravilan" položaj glave



Zglobovi neprilagođeni skakanju

*Homo sapiens*

Design by Zoran Tadić

# *Fiziologije*

- **Mehanistička** - mehanizmi
- **Evolucijska** - evolucija fizioloških procesa
- **Komparativna** - sinteza proučavanja fizioloških procesa u svih životinja
- **Ekofiziologija ili ekološka fiziologija** - fiziološki odgovor u različitim uvjetima okoliša
- **Integrativna** - sinteza proučavanja fizioloških procesa kroz različite razine organizacije, različite metode i različite vrste životinja (najčešće na cijelom organizmu)

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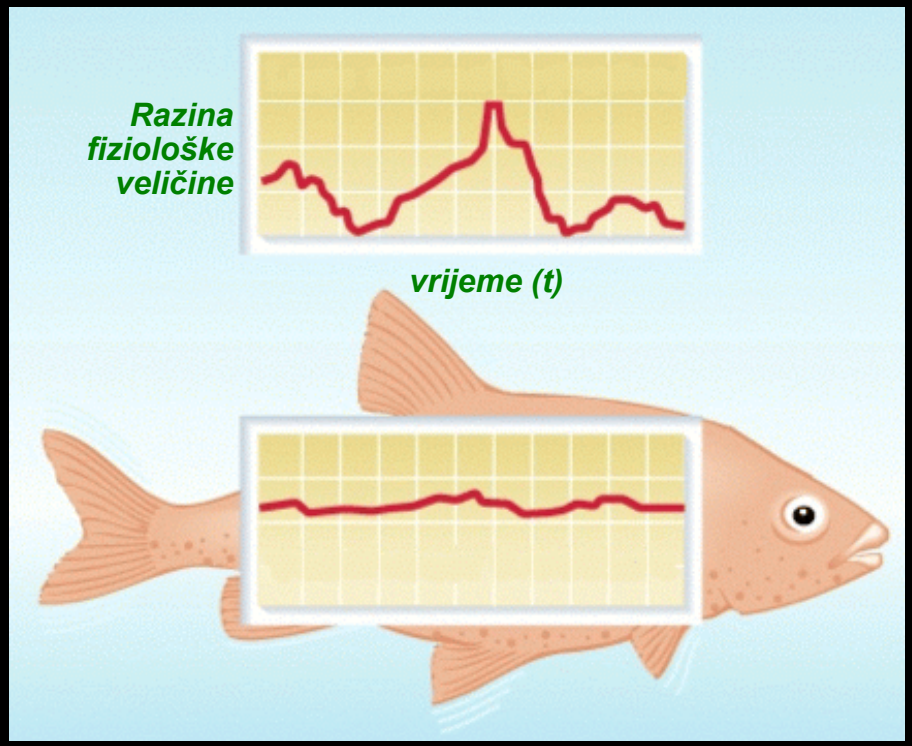
# *Važan fiziološki koncept 1: Homeostaza*

**Claude Bernard**
**(1813 - 1878)**

**Walter B. Cannon**
**(1871 - 1945)**

**Velike vanjske promjene**




**Male unutarnje promjene**

***"Unutarnji okoliš"***
***(Milieu intérieur)***

***Homeostaza***

Cannon W. B. (1929) Organization for physiological homeostasis. *Physiol. Rev.* **9:** 399 - 431

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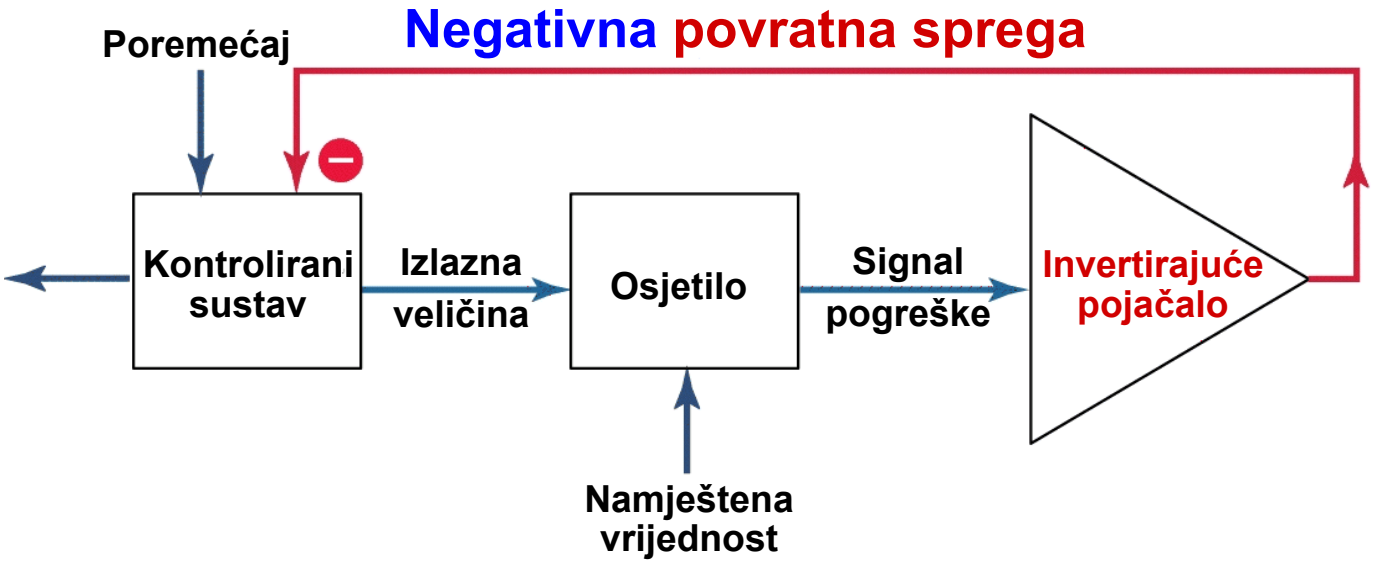
# *Važan fiziološki koncept 2: Povratna sprega*



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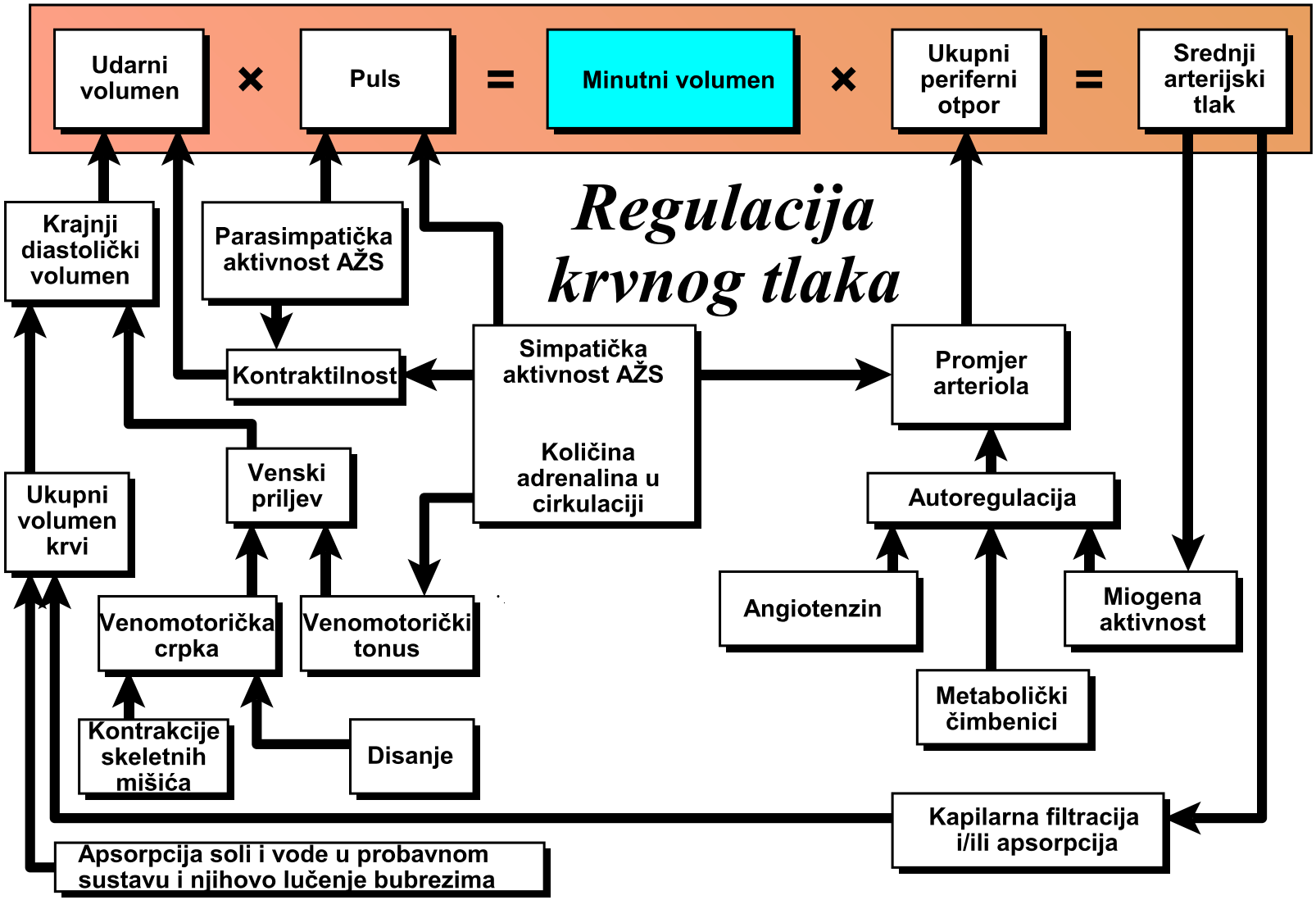
# *Važan fiziološki koncept 3: Višestrukost kontrolnih mehanizma (engl. redundancy)*




Design by Zoran Tadić

# *Integrativni pristup važan je za sve jer:*

- Temeljni principi rada organa jednaki su za veliku većinu kralježnjaka.
- Životinje su nas “naučile” kako rade ljudski organi (tzv. Krogh-ov princip) ➜ ekstrapolacija na ljude i njihovo zdravlje.
- Nove metode omogućile su bolje razumjevanje molekularnih procesa i pojasnile molekularne temelje fizioloških procesa, a interakcija organizma i okoliša pokazuje kako se organizam NA SVIM RAZINAMA plastično prilagođava ekološkoj situaciji.

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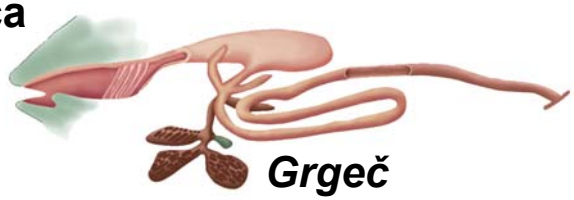
# *Točka 1: Jednaki principi rada*

***Paklara***

**Akcijski potencijali lignji = Akcijski potencijali većine životinja**

**Način stvaranja el. impulsa u srcu čovjeka = Način stvaranja el. impulsa u srcu žabe**

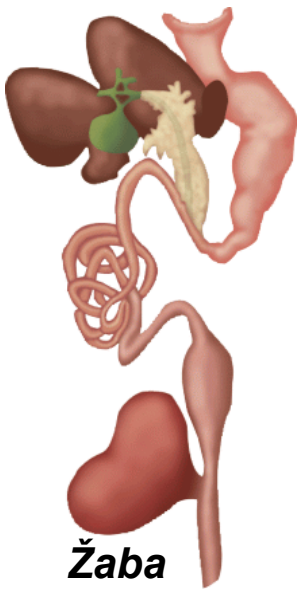
**Mehanizmi stvaranja ATP-a u ljudi = Mehanizmi stvaranja ATP-a u ptica**



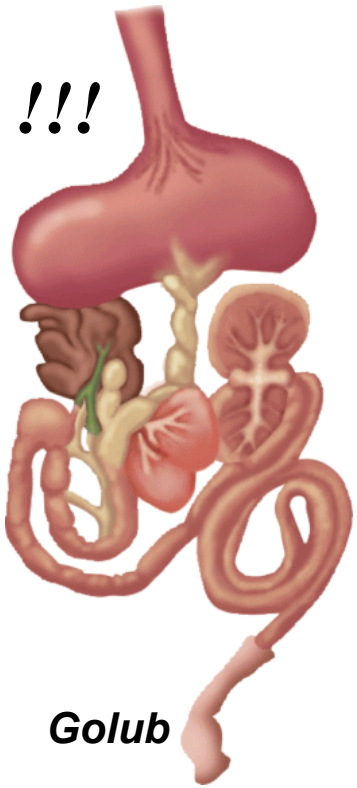
***Grgeč***

**itd, itd . . .**

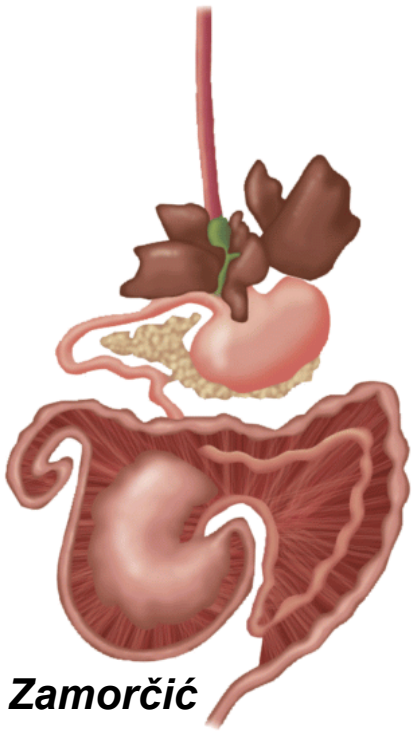
***Ali ima i razlika !!!***



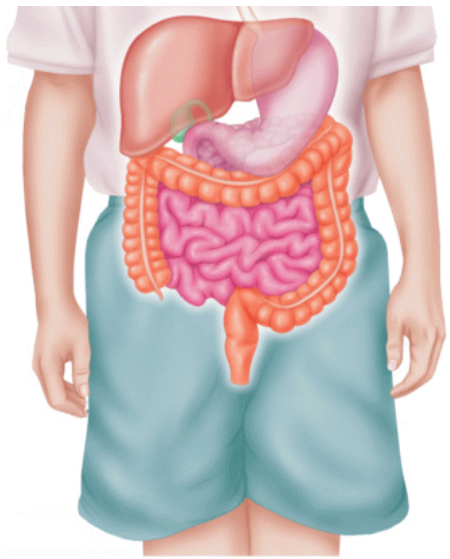
***Žaba***



***Golub***



***Zamorčić***



***Čovjek***

Design by Zoran Tadić

# *Točka 2: Krogh-ov princip*

**August Krogh**
**(1874 - 1949)**

**Nobelova nagrada za fiziologiju ili medicinu 1920. godine:**

**"za otkriće motoričkih mehanizama regulacije kapilarnog protoka"**

*"For such a large number of problems there will be some animal of choice or a few such animals on which it can be most conveniently studied."*

Krogh A. (1929) The progress of physiology. *Am. J. Physiol.* **90:** 243 - 251

**Lignje ➔ akcijski potencijali**

**Psi ➔ Sinusni i aortni mehanizmi regulacije disanja**

**Kornjače ➔ Mehanizmi izmjene plinova u plućima**

**Sova kukuvija ➔ Mehanizmi određivanja smjera dolaska zvuka**

**Bakterija *Thermus aquaticus* ➔ Razvoj metoda molekularne biologije (PCR)**

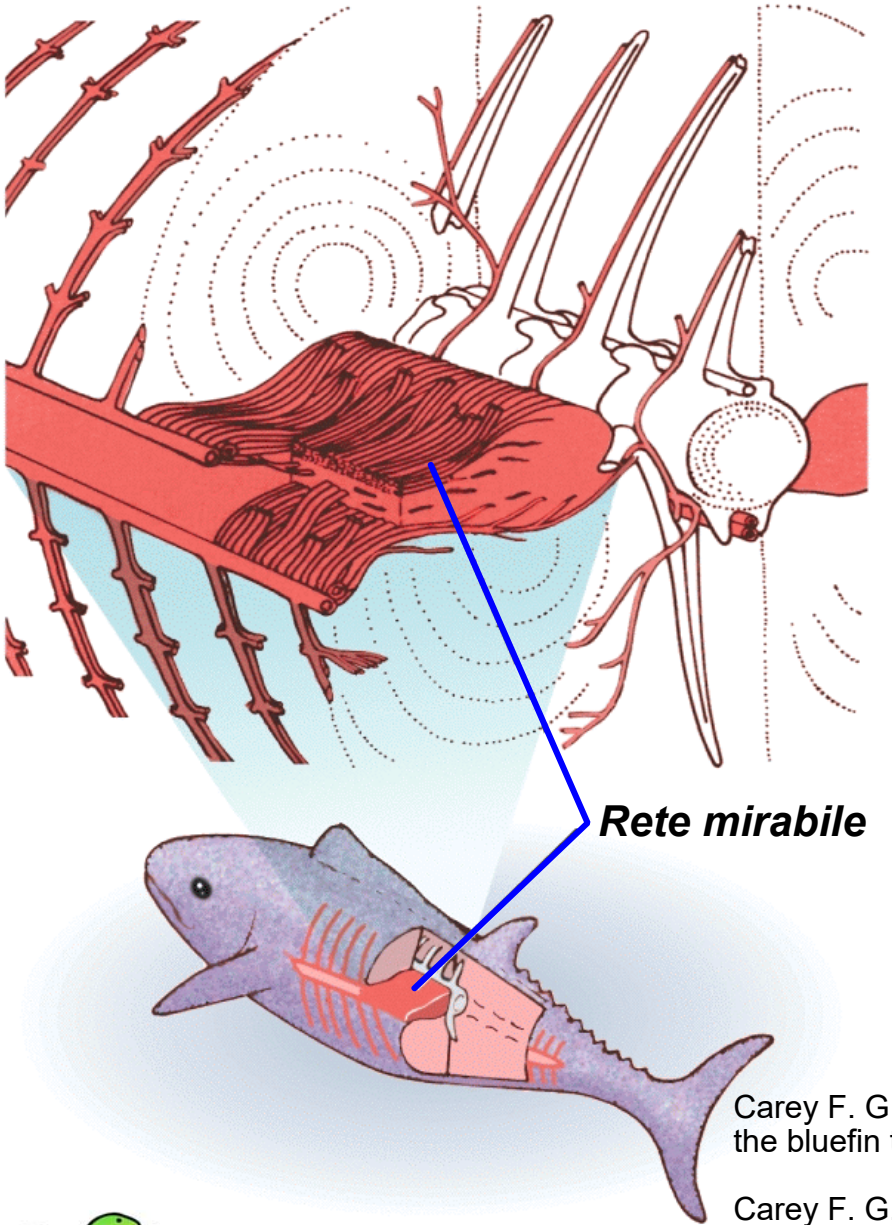
Design by Zoran Tadić

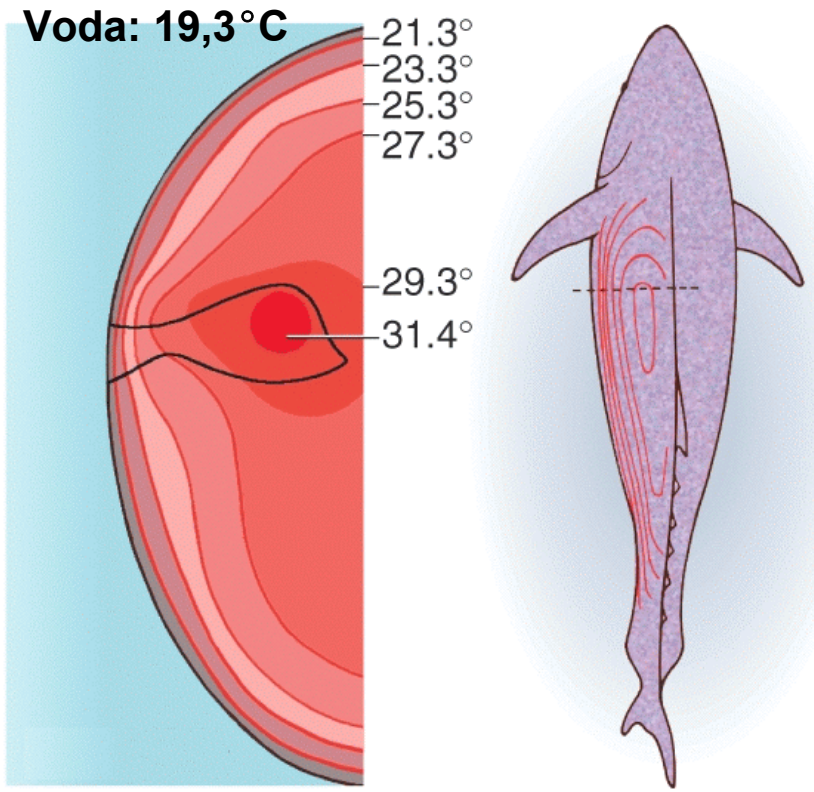
# *Začudna dražest integrativne fiziologije*

- Integracija razina analize
- Integracija znanstvenih disciplina
- Integracija preko različitih vrsta životinja

Design by Zoran Tadić

# *Integracija razina analize: Rete mirabile u tune*




Carey F. G., Gibson Q. H. (1983) Heat and oxygen exchange in rete mirabile of the bluefin tuna, *Thunnus thynnus*. *Comp. Biochem. Physiol.* **74A:** 333 - 342

Carey F. G., Teal J. M. (1969) Regulation of body temperature by bluefin tuna. *Comp. Biochem. Physiol.* **28:** 205 - 213

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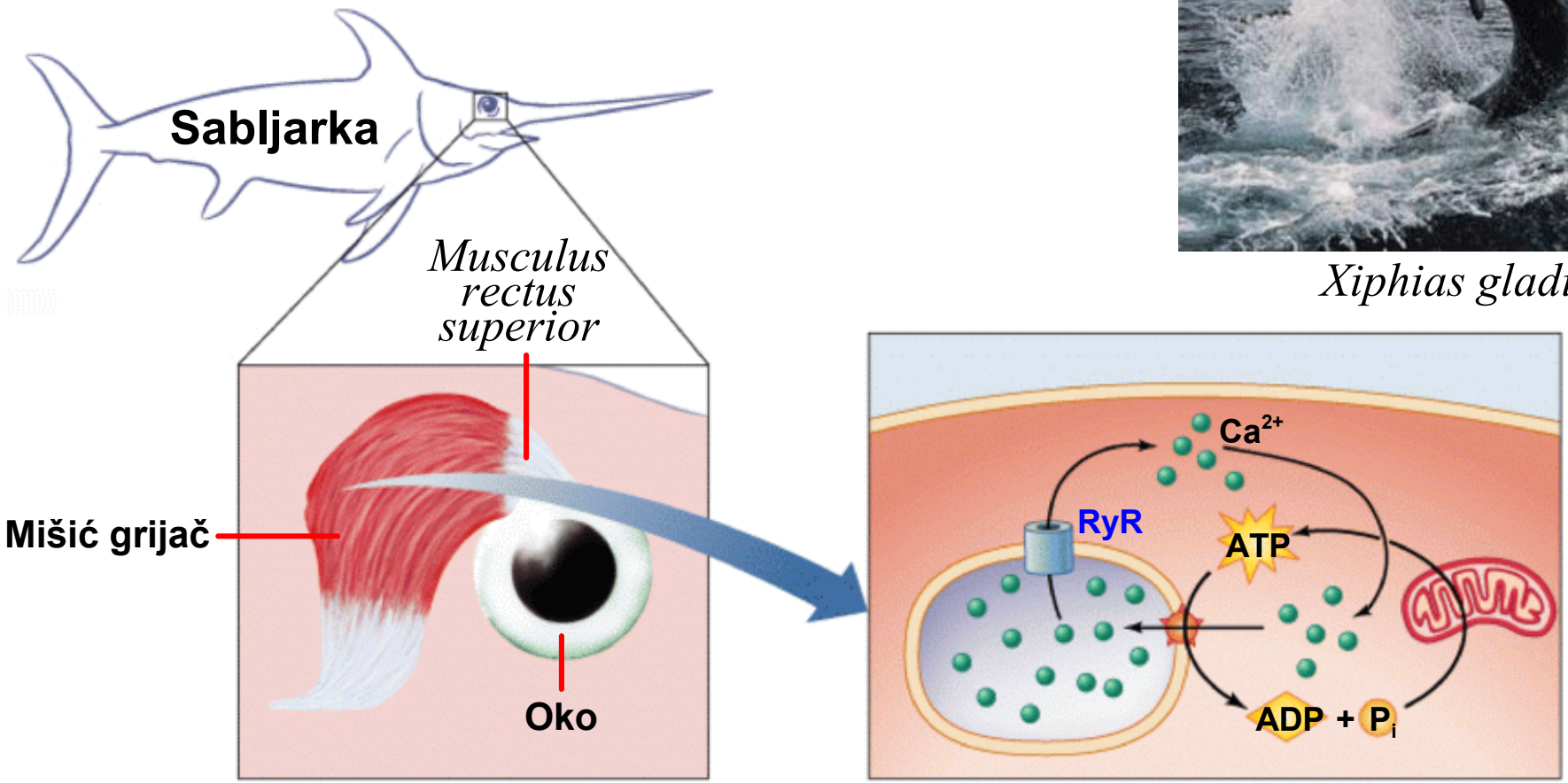
# *Integracija razina analize: Dobar vid sabljarke u hladnoj vodi*

*Xiphias gladius*




Fritsches K. A., Brill R. W., Warrant E. J. (2005) Warm eyes provide superior vision in swordfishes. *Curr. Biol.* **15:** 55 - 58

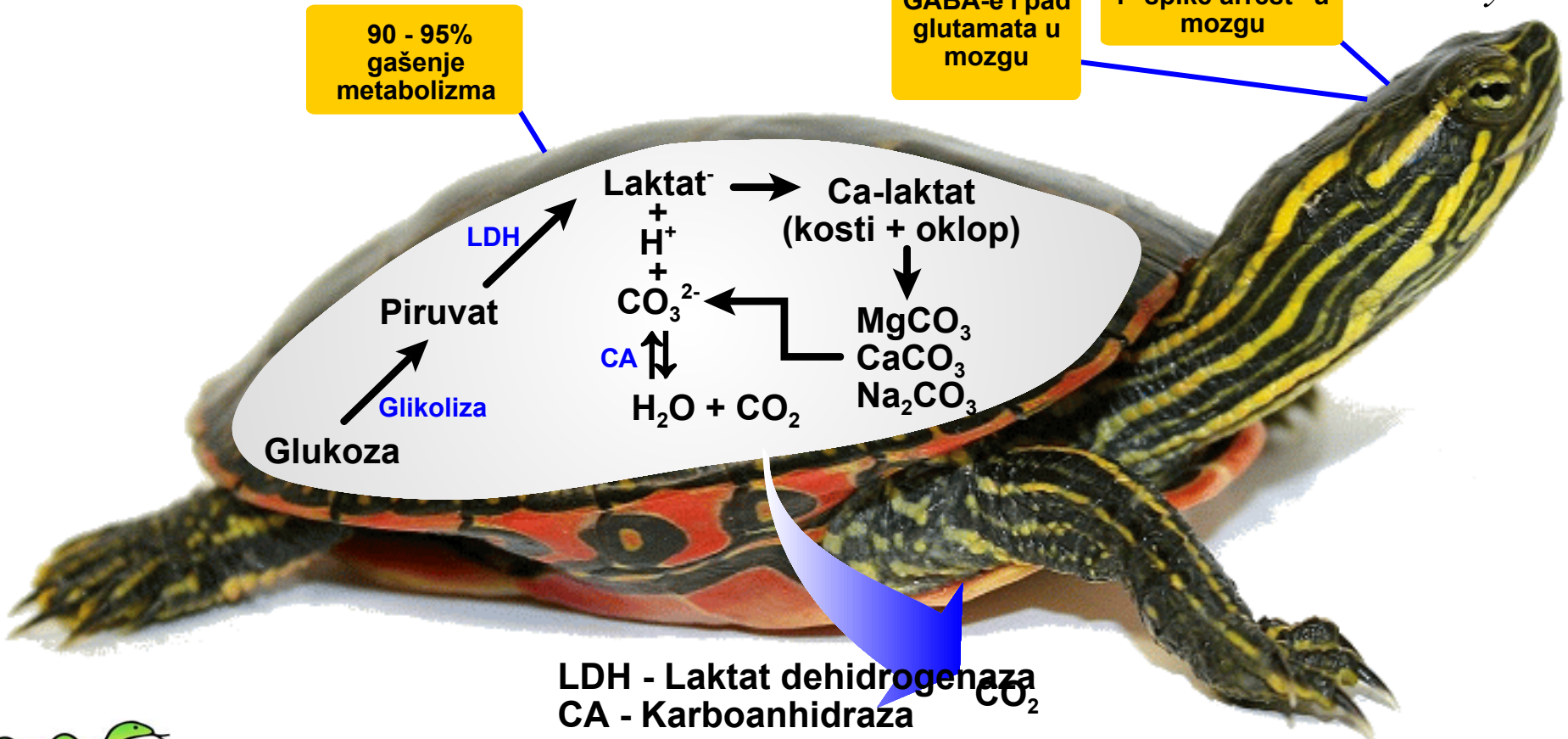
Design by Zoran Tadić

# *Integracija razina analize: Vodena kornjača u hibernaciji kao odličan pufer*

Jackson D. C. (2002) Hibernating without oxygen: Physiological adaptations of the painted turtle. *J. Physiol.* **543:** 731 - 737

Warren D. E., Jackson D. C. (2008) Lactate metabolism in anoxic turtles: An integrative review. *J. Comp. Physiol. B* **178:** 133 - 148

*Chrysemys picta*




Design by Zoran Tadić

# *Integracija razina analize: Karas kao pecara rakije, ali ne i kronični alkoholičar*

**Karas**
(*Carassius carassius*)

**Indukcija voljne hipotermije radi smanjenja metabolizma**

**Smanjeno kretanje radi maksimalne štednje energije**

**Mozak ostaje relativno aktivan. Povišenje GABA neuroprijenosnika.**

**Laktat**
**LDH**
**Piruvat**
**PDH**
**Acetaldehid**
**ADH**
**Etanol**

***Skeletni mišić***

**Mišići za pokretanje**

**Mozak**

**Škrge**

**Unutarnji organi**

**Krvna žila**

**Etanol**

**Jetra skladišti glikogen (30% ukupne mase)**

**Hemoglobin EKSTREMNO visokog afiniteta za $O_2$**

Bickler P. E., Buck L. T. (2007) Hypoxia tolerance in reptiles, amphibians, and fishes: Life with variable oxygen availability. *Annu. Rev. Physiol.* **69:** 145 -170

Design by Zoran Tadić

# *Intregracija znanstvenih disciplina*

*Gillichthys mirabilis*

Gracey A. Y., Troll J. V., Somero G. N. (2001) Hypoxia-induced gene expression profiling in the euryoxic fish *Gillichthys mirabilis*. *Proc. Natl. Acad. Sci. USA* **98:** 1993 - 1998

**mRNA iz jetre, mozga i srca**

↓

**cDNA**

↓

***DNA čip sa 5376 elemenata iz banki, za koje se zna da sadrže hipoksijom regulirane gene***

↓

**126 cDNA čija je aktivnost ovisna o hipoksiji**

Design by Zoran Tadić

# Žalosna priča o afričkim divljim psima

*Lycaon pictus*

**Prije**

**Kleptoparazitizam pjegavih hijena na afričkim divljim psima**

**Sada**

Design by Zoran Tadić

Istraživanje provedeno u Nacionalnom parku "Kruger" u Južnoj Africi. Čopor se satojao od 6 odraslih jedinki, 16 jednogodišnjih jedinki i 27 štenaca. Psi su lovili otprilike 3,5 sata dnevno.

Ubrizgano im je 5cm$^3$ $^2H_2{}^{18}O$. 48 i 96 sati nakon ubrizgavanja životinje su ulovljene i uzeto im je 5cm$^3$ krvi u kojoj je određena količina $^{18}O$ i $^2H$.

| Pas | Spol | Tjelesna masa (kg) | Dnevna potrošnja energije (MJ/dan) |
|---|---|---|---|
| 1 | Ž | 24 | 7,233 |
| 2 | Ž | 25 | 8,729 |
| 3 | Ž | 23 | 16,686 |
| 4 | M | 27 | 18,252 |
| 5 | M | 27 | 20,281 |
| 6 | M | 26 | 19,805 |

**Srednja dnevna potrošnja energije:** **15 299 = 3,5 kg mesa/dan**

Njemački ovčar 6,000 MJ/dan
Border collie 8,200 MJ/dan (težak 25 kg, radi 6 sati/dan)
Eskimo dog 47,000 MJ/dan (trka od 490 km)

Bazalni metabolizam afričkog psa od 25 kg = 3,400 MJ/dan

$$\text{Energetski utrošak u lovu} = \frac{15{,}299 - 3{,}400}{3{,}5}$$

Ako psi izgube 25% svoje lovine, morali bi loviti 12 sati svaki dan što je fiziološki neodrživo!!

***Afrički divlji psi žive na gonjoj granici fiziološke izdržljivosti!!!!***

Gorman M. L., Mills M. G., Raath J. P., Speakman J. R. (1998) High hunting costs make African wild dogs vunerable to kleptoparasitism by hyenas. *Nature* **391:** 479 - 480

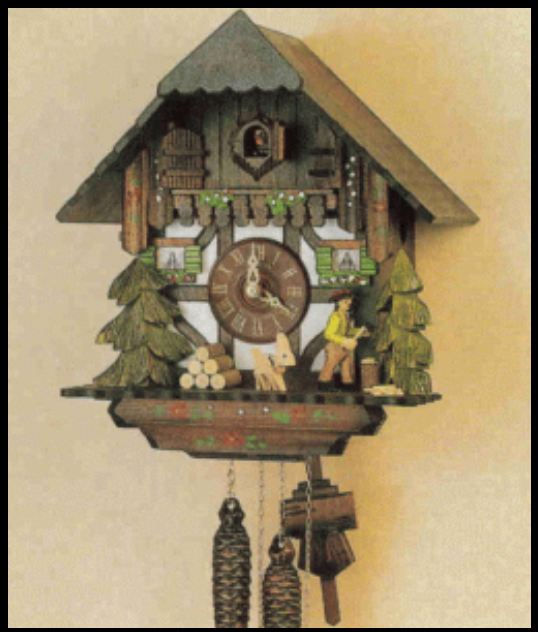
Design by Zoran Tadić

# *Životinje i njihove anatomsko-fiziološke značajke...*

- Strukturno su dinamične
- Otvoreni su visokoorganizirani sustavi koji trebaju enegiju za održavanje organiziranosti
- Prostor i vrijeme u kojem žive imaju važnu ulogu u njihovim životima

Design by Zoran Tadić

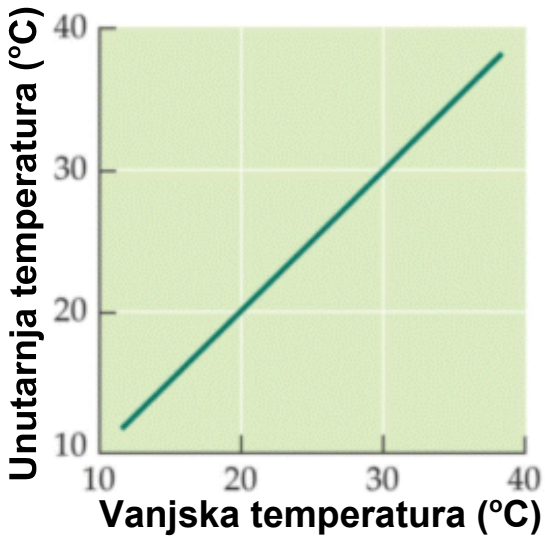
# *Strukturna dinamičnost*

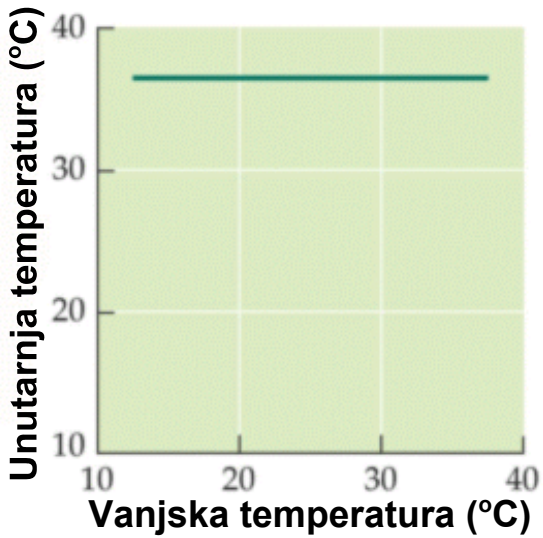


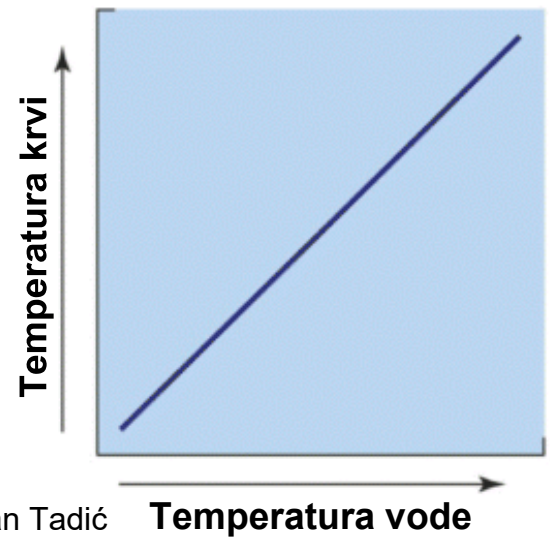
**Rudolf Schoenheimer**
**(1898 - 1941)**

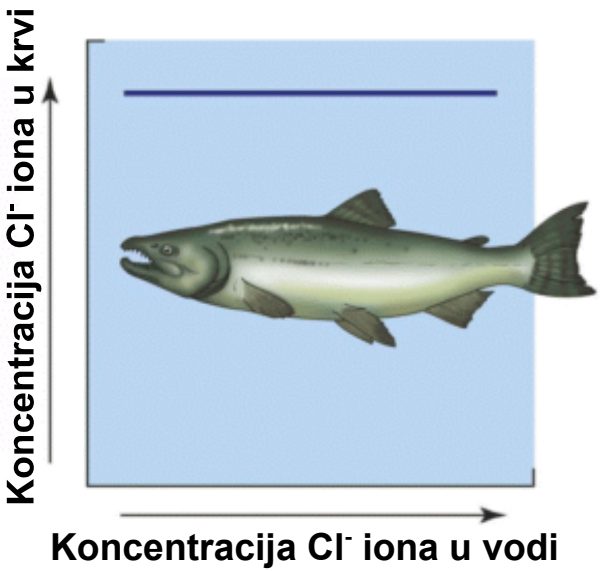
Design by Zoran Tadić

# *Otvoreni sustavi koji sa okolišem izmjenjuju tvari i dobijaju od njega energiju*




Design by Zoran Tadić

***Jedno pitanje za cienjeno občinstvo:***

# *Jel' bolje biti fiziološki regulator ili konformer?*

Design by Zoran Tadić

# *Vrijeme u fiziologiji*

***Fiziološke promjene koje su odgovor na promjene vanjskog okoliša***

- Akutne promjene (brze - kratko vrijeme)
- Kronične promjene (spore - dulje vrijeme)
- Evolucijske promjene

***Fiziološke promjene programirane iznutra, bez obzira mijenja li se ili ne vanjski okoliš***

- Razvojne promjene
- Promjene kontrolirane biološkim satovima

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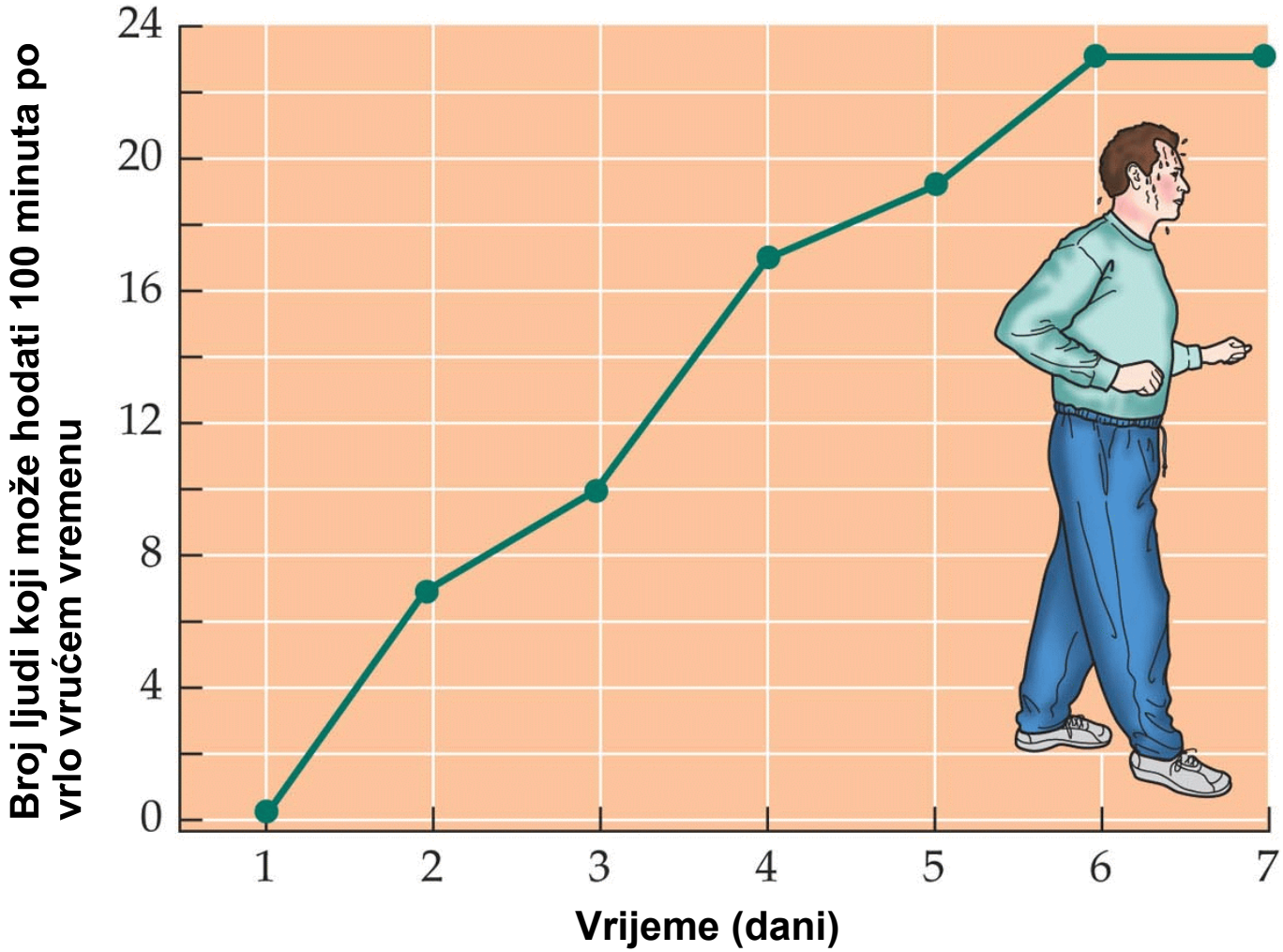
# *Akutne i kronične promjene u fiziologiji*




Pandolf K. B., Young A. J.: Environmental extremes and endurance performance. In: “Endurance in Sport” (R. J. Shephard, P.-O. Astrand, eds.), Blackwell Publishers, London, 1992, pp 270 - 282

Design by Zoran Tadić

# *Abiotički ekološki čimbenici koji utječu na fiziologiju*

- Temperatura
- Voda
- Kisik

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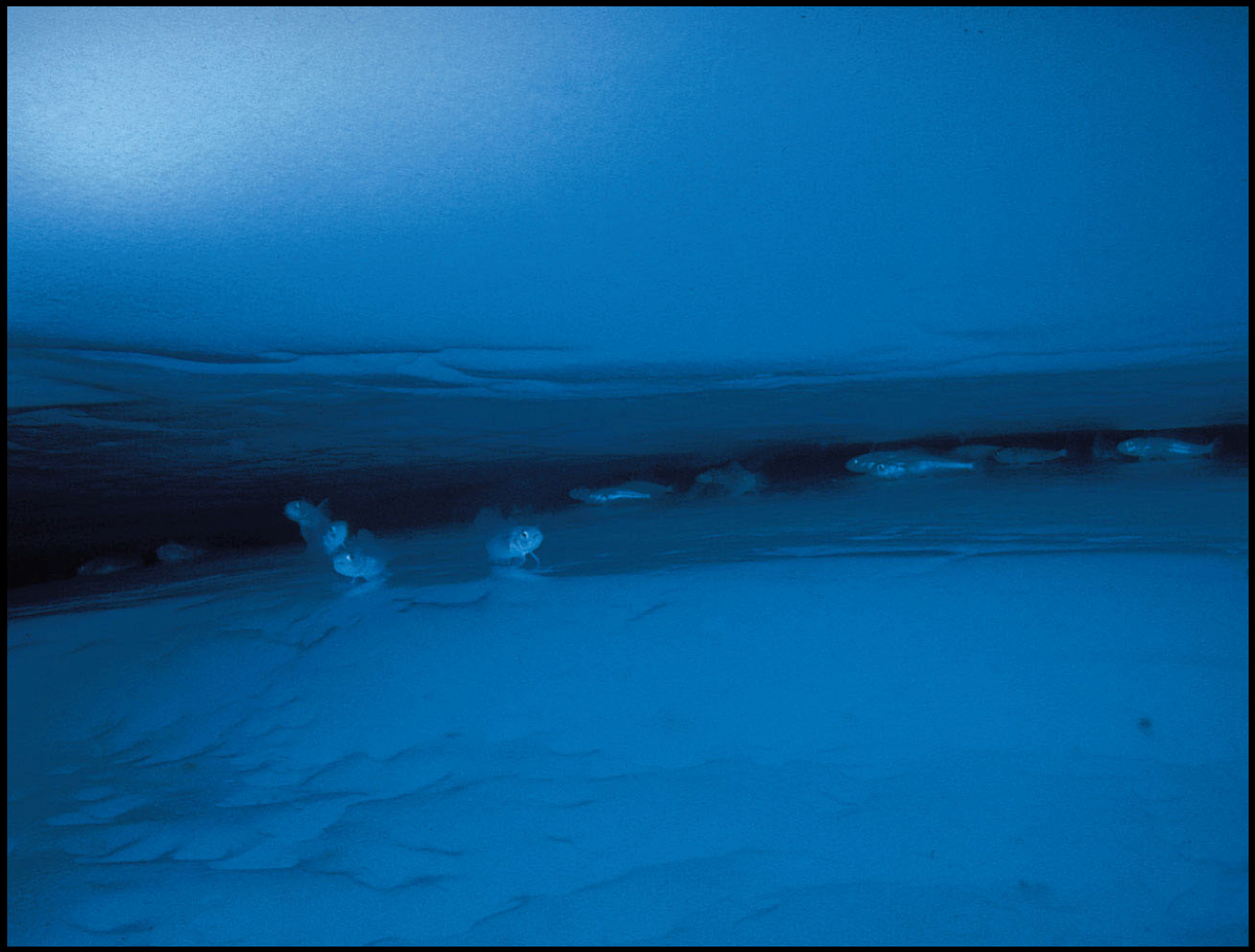
# *Najniža temperatura na kojoj mogu živjeti poikilotermi: -1,9°C*



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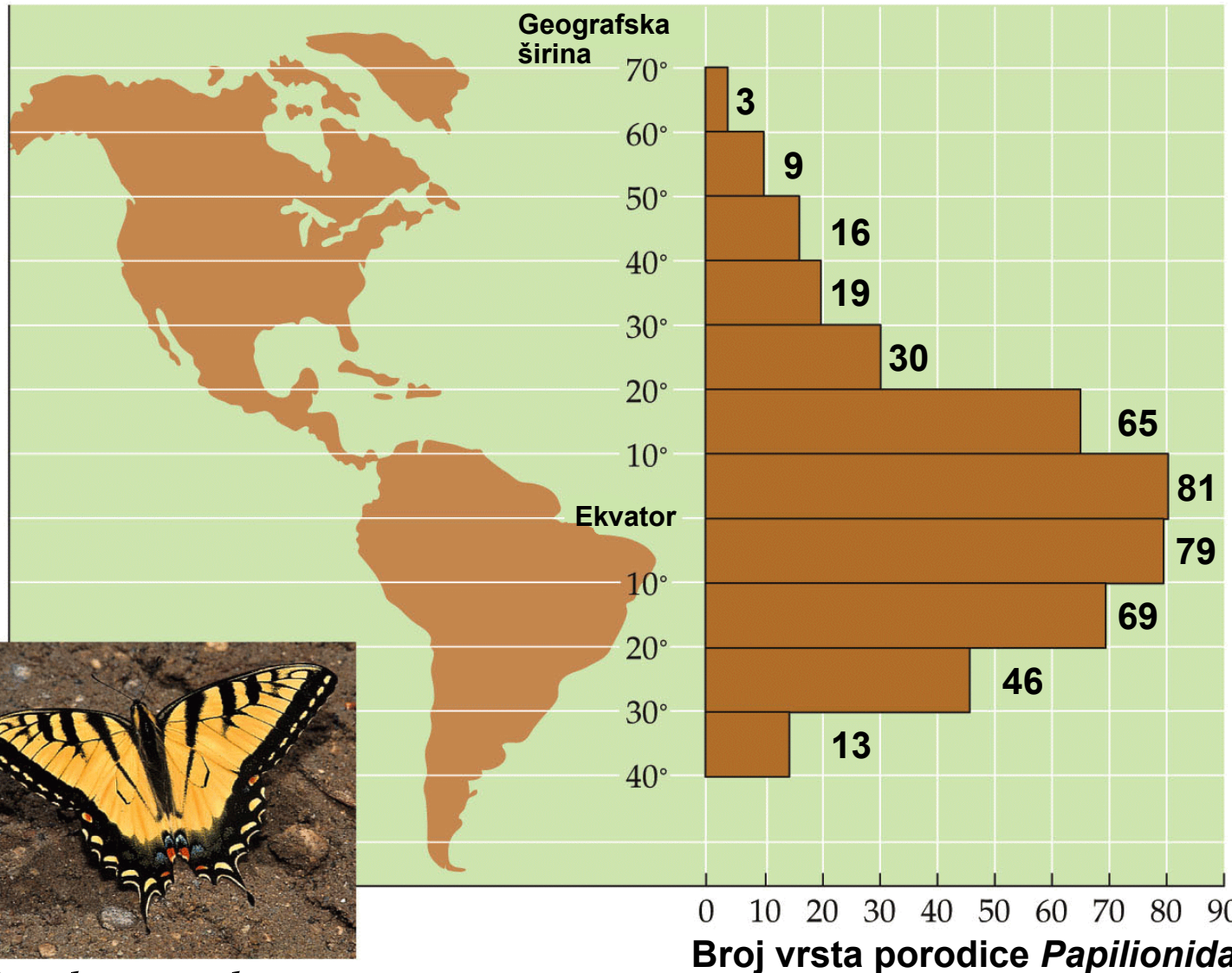
# *Učinak temperature na broj vrsta*




Scriber J. M. (1973) Latitudinal gradients in larval feeding specialization of the world Papilionidae (Lepidoptera). *Psyche* **80:** 355 - 373

*Papilio canadensis*

Design by Zoran Tadić

# *Kisik - plin života*

| Plin | % |
|---|---|
| Dušik | 78,09 |
| Kisik | 20,95 |
| Ugljični dioksid | 0,03 |
| Argon | 0,93 |
| Ukupno: | 100 |

Design by Zoran Tadić

# *Topljivost plinova u vodi na 15 °C*

| | |
|---|---|
| **Kisik** | **34,1 ml $O_2$ / l $H_2O$** |
| **Dušik** | **16,9 ml $N_2$ / l $H_2O$** |
| **Ugljični dioksid** | **1019 ml $CO_2$ / l $H_2O$** |

$$CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

Design by Zoran Tadić

# *Zrak vs. voda - fizička svojstva*

| | Voda | Zrak | Odnos voda/zrak |
|---|---|---|---|
| Koncentracija $O_2$ ($l\ O_2$ / l) | 0,007 | 0,219 | ~1:30 |
| Gustoća (kg / l) | 1 | 0,0013 | ~800:1 |
| Dinamička viskoznost (cP) | 1 | 0,02 | 50:1 |
| Toplinski kapacitet (J / l °C) | 4184 | 1,297 | ~3200:1 |
| Toplinska vodljivost (J / cm °C) | 0,005858 | $2,38 \times 10^{-4}$ | ~25:1 |
| Difuzijski koeficijent $O_2$ ($cm^2$ / s) | $25 \times 10^{-6}$ | 0,198 | ~1:300 000 |
| Difuzijski koeficijent $CO_2$ ($cm^2$ / s) | $18 \times 10^{-6}$ | 0,155 | ~1:11 000 |
| Volumen medija / volumen $O_2$ ($l$ / $l\ O_2$) | 143 | 4,8 | ~30:1 |
| Masa medija / volumen $O_2$ (kg / $l\ O_2$) | 143 | $6,2 \times 10^{-3}$ | ~23 000:1 |

Design by Zoran Tadić

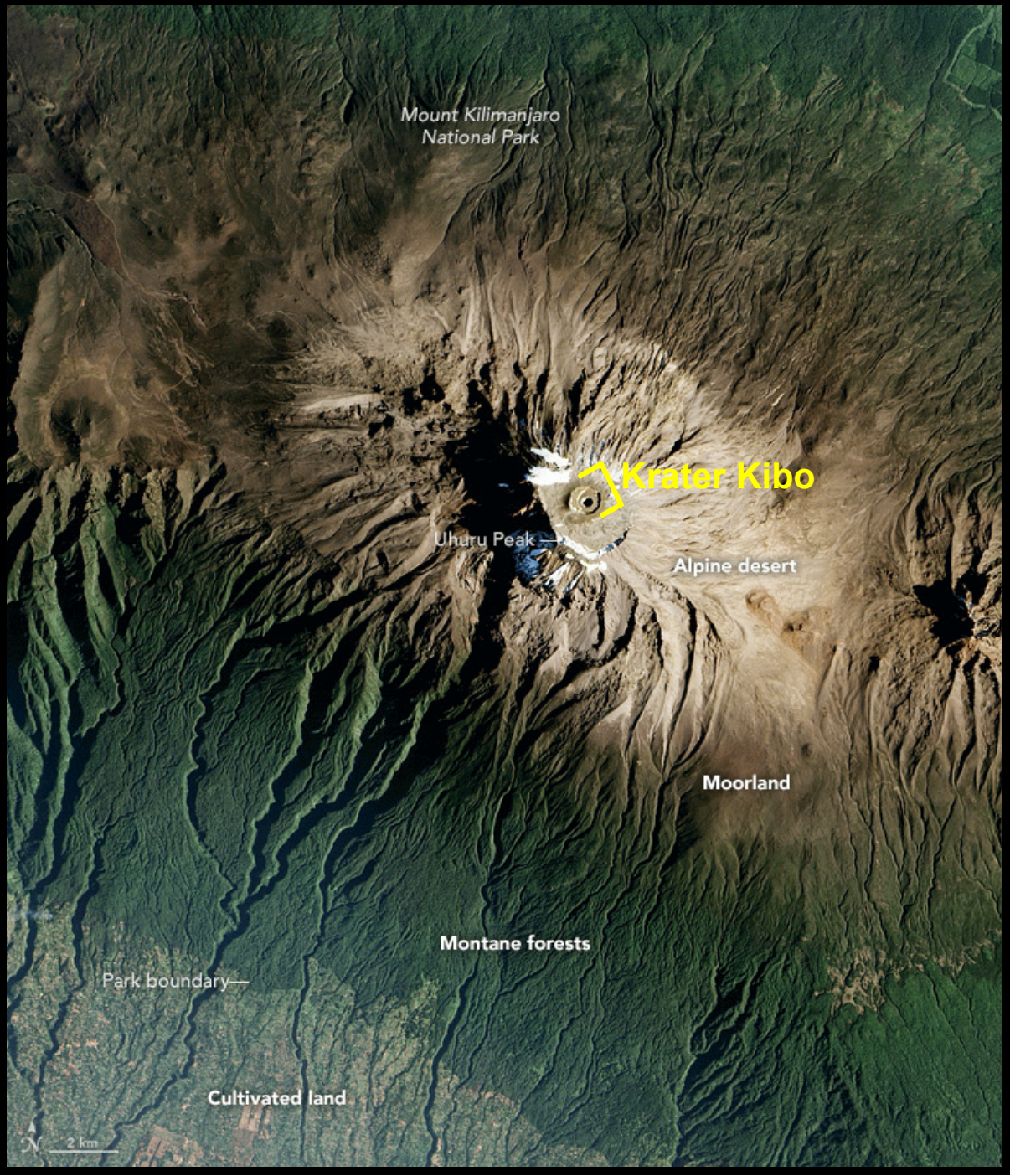
# *Velike nadmorske visine = mali parcijalni tlak $O_2$*

Na razini mora parcijalni tlak kisika je 21% od oko 760 mm Hg ≈ 159 mm Hg
Na Mt. Everestu je parcijalni tlak kisika 21% od oko 250 mm Hg ≈ 52 mm Hg

**Velike nadmorske visine - 1 500 - 3 500 m**
**Vrlo velike nadmorske visine - 3 500 - 5 500 m**
**Ekstremne nadmorske visine - iznad 5 500 m**

**“Zona smrti” - 8 000 m**

Design by Zoran Tadić




Design by Zoran Tadić

# *Ljudi su milenijima svjesni opasnosti odlaska na visoke planine. . .*

*Dok prelazismo Planinu Velike Glavobolje, Planinu Male Glavobolje te Crvenu Zemlju, ljudi dobiše groznicu, postadoše bijeli u licu te ih zahvati glavobolja i povraćanje. Magarci i mazge isto tako oboliše; mnoge se životinje kretahu s naporom po putevima, a neke se od bolesti survaše niz stijene.*

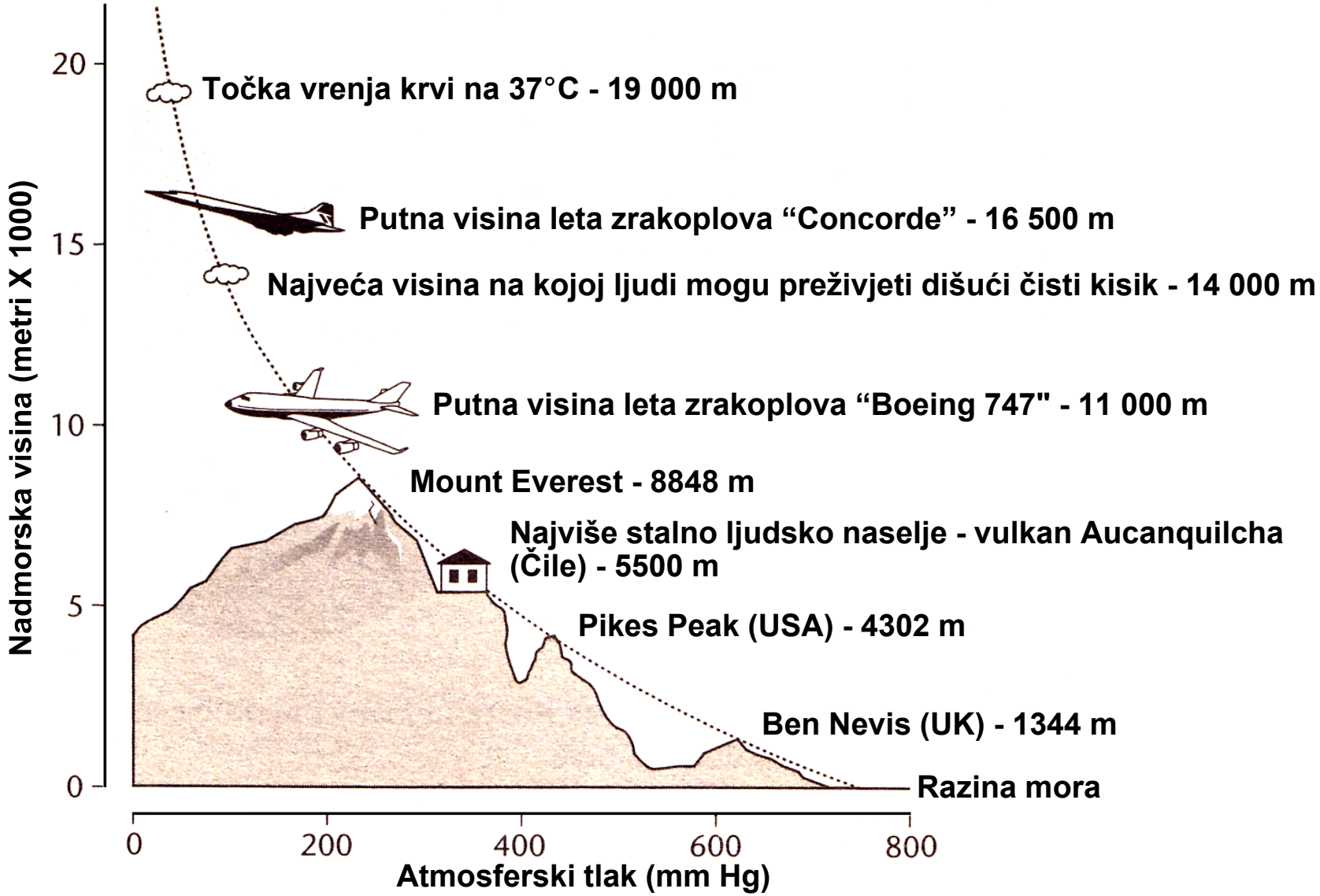
**Ch'ien Han Shu (37 - 32 pr. Kr.)**

Design by Zoran Tadić

# . . .ali to ih ne spriječava da tamo idu!

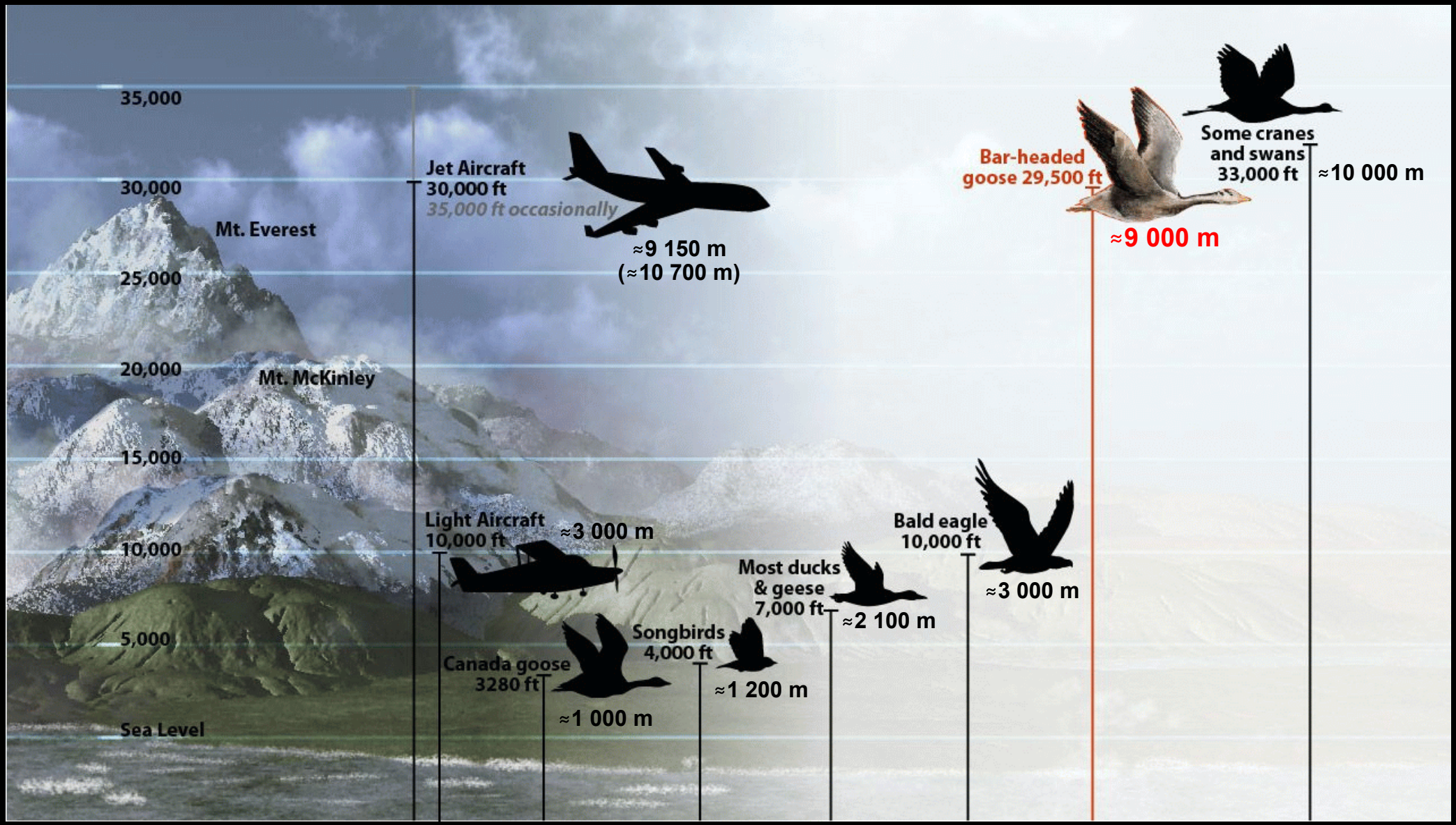
Design by Zoran Tadić

# *Odnos nadmorske visine i atmosferskog tlaka*



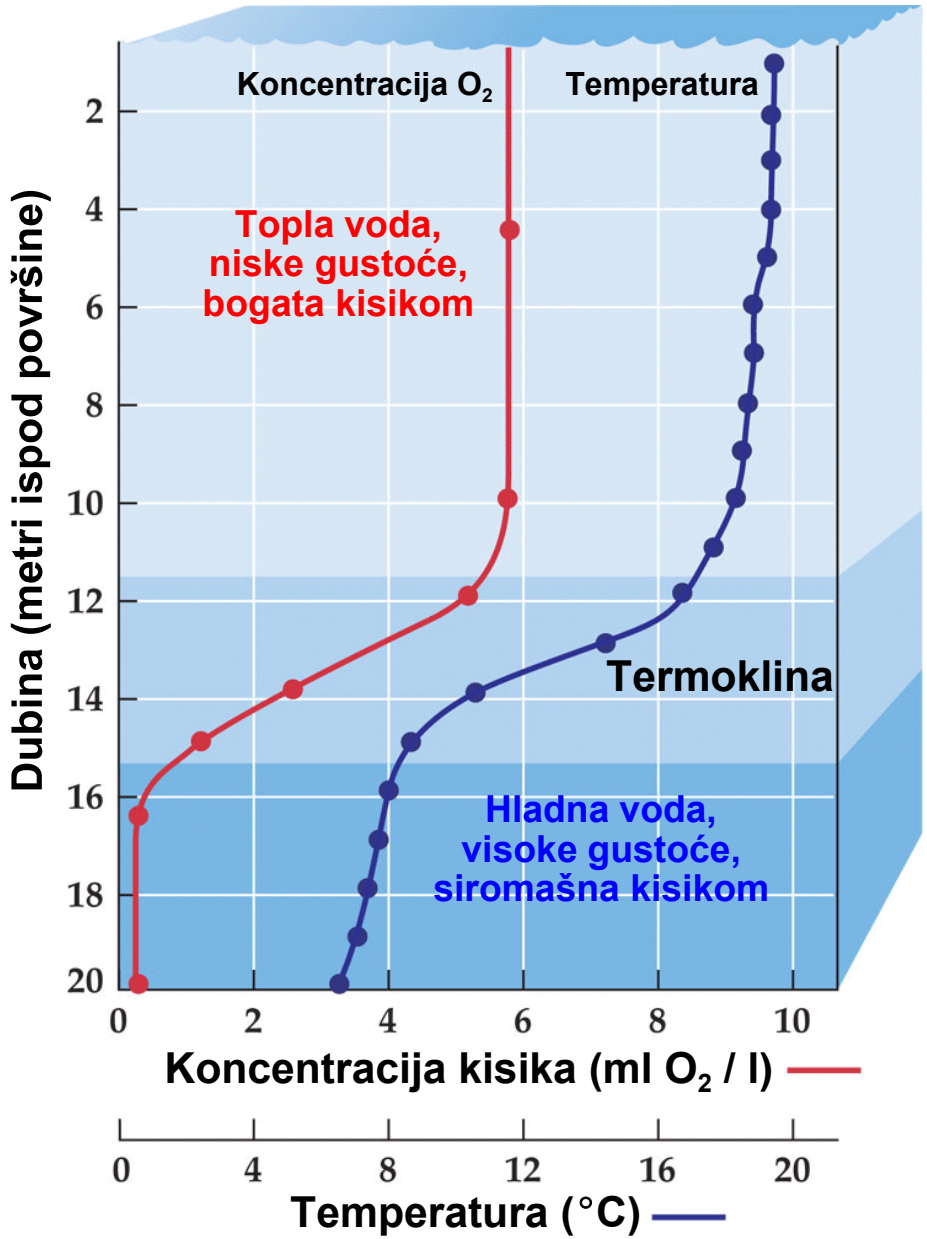

Design by Zoran Tadić

# Ptice lete na velikim nadmorskim visinama




Design by Zoran Tadić

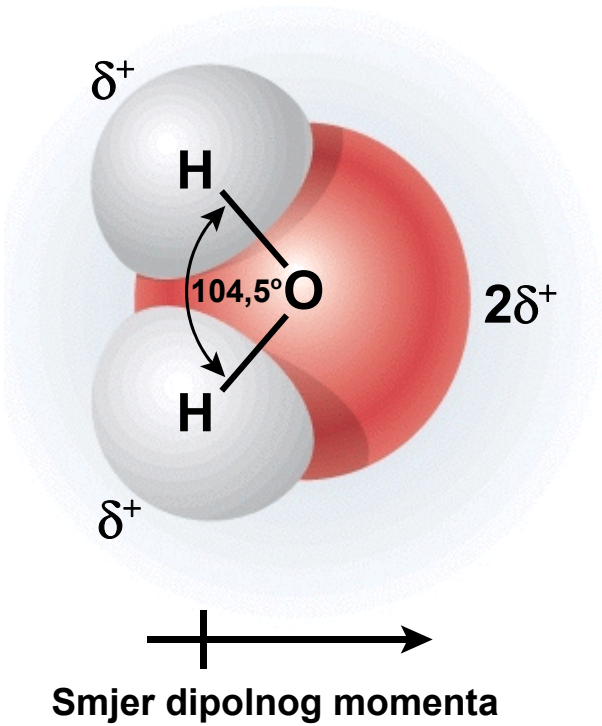
# *Problemi sa kisikom u jezerima*

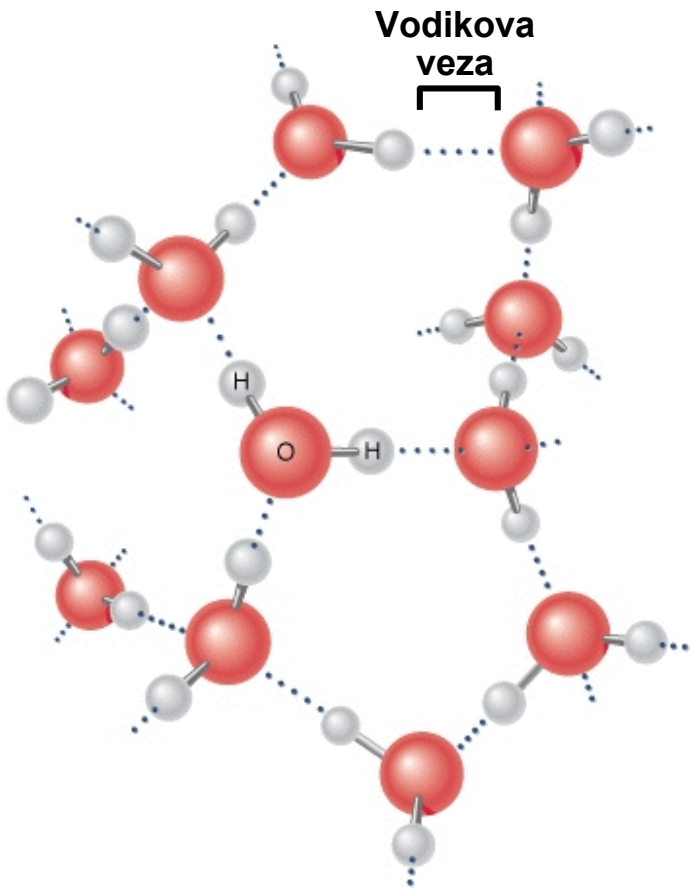



Design by Zoran Tadić

# *Voda - izvor života*

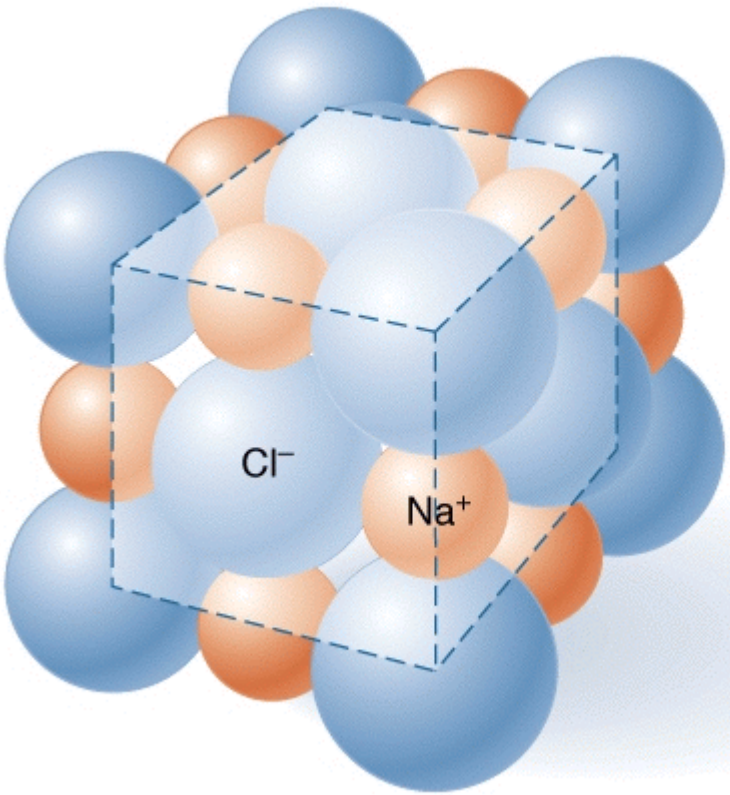
# *Sposobnost vode da podržava život leži u njenoj kemijskoj strukturi*

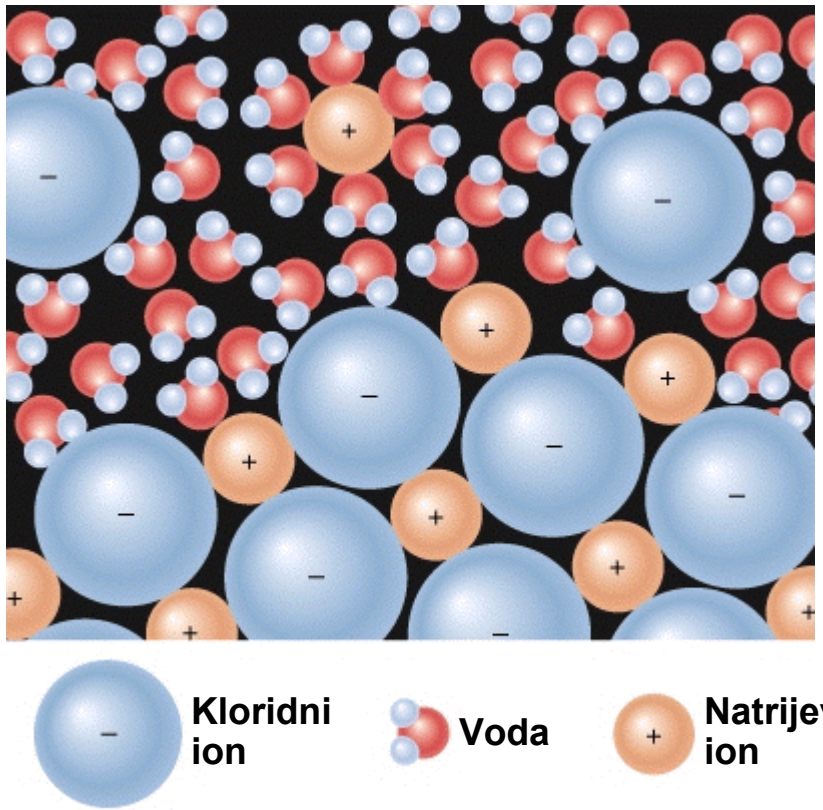


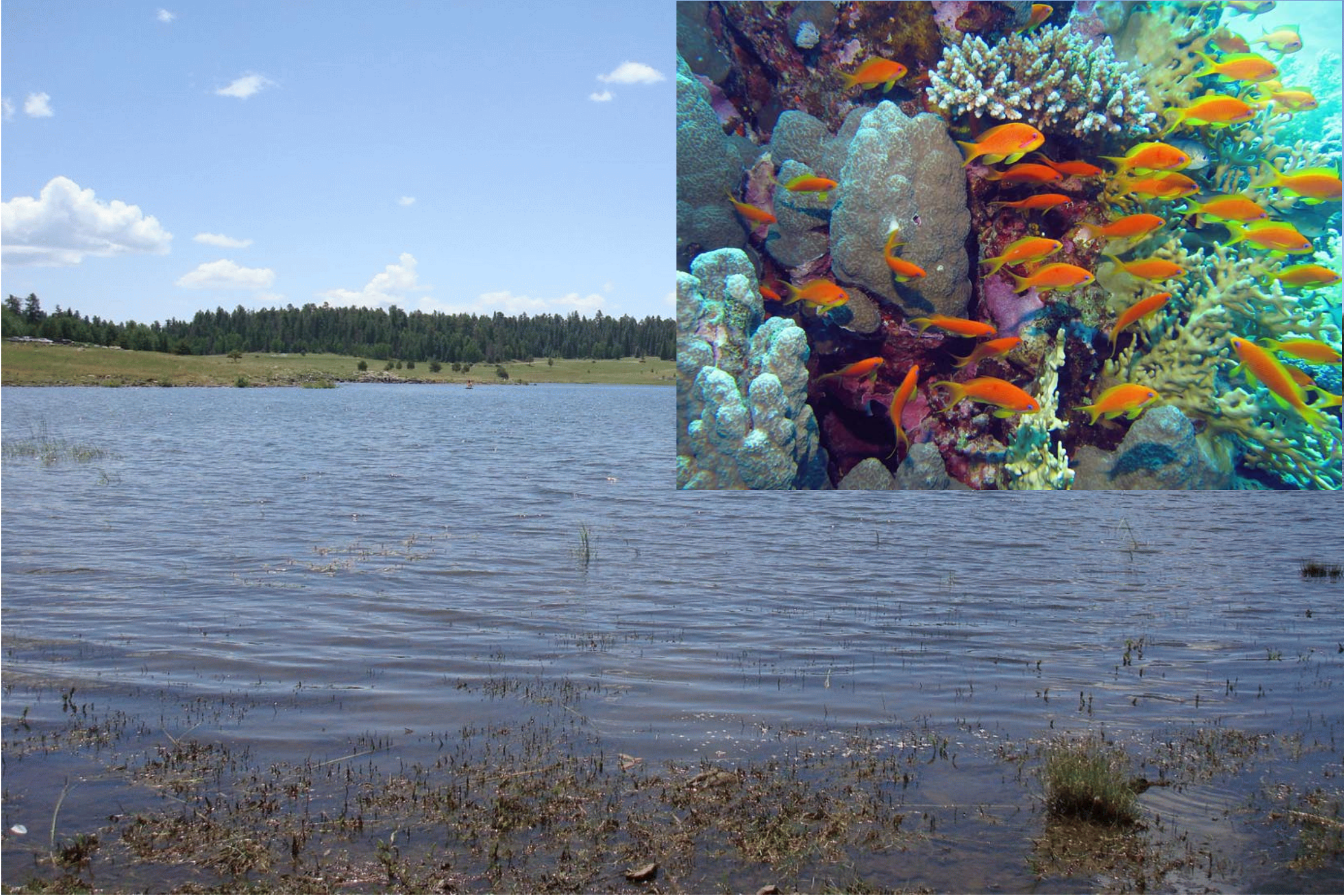

Design by Zoran Tadić

# *Voda - odlično otapalo polarnih tvari*

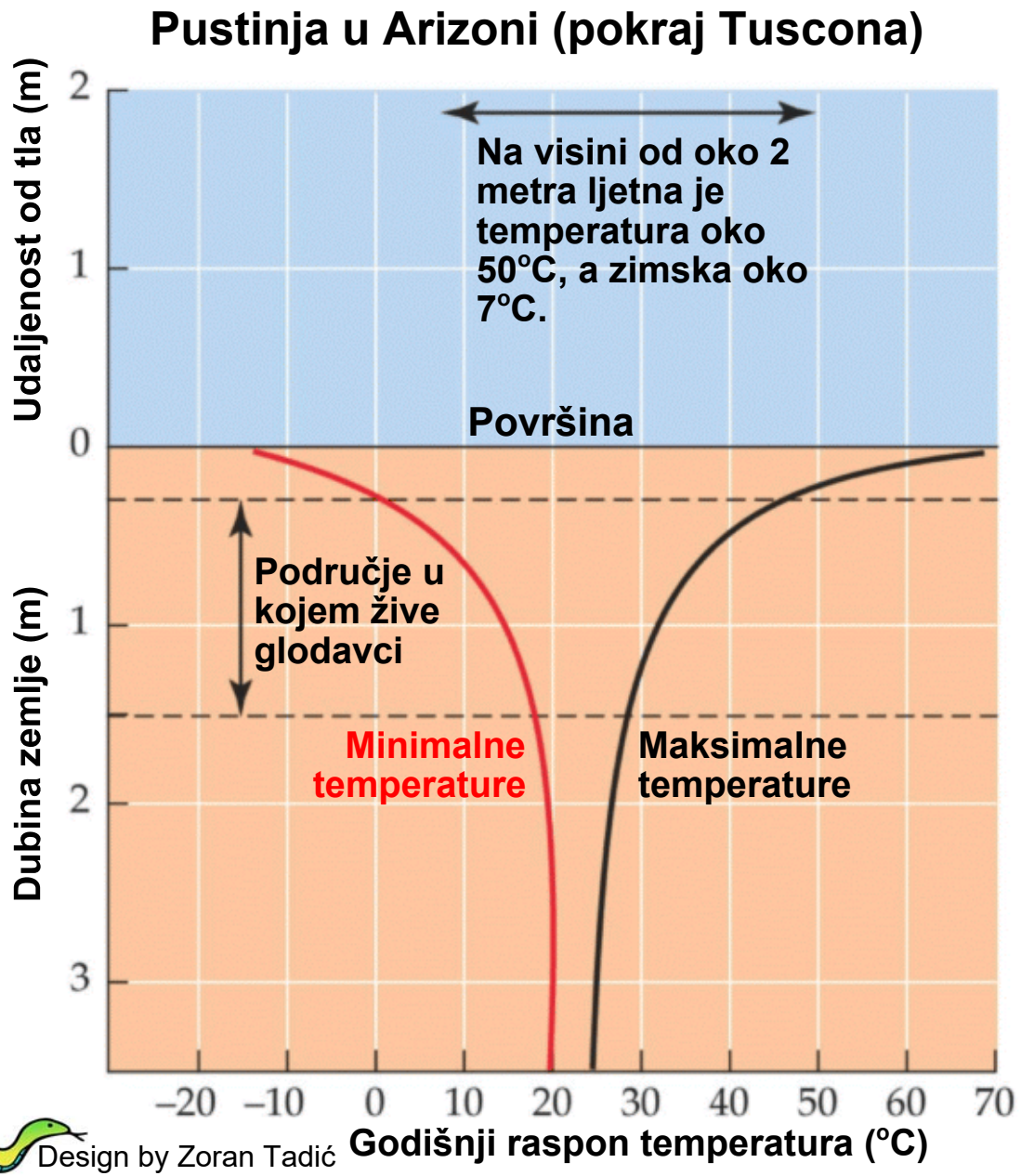



Design by Zoran Tadić



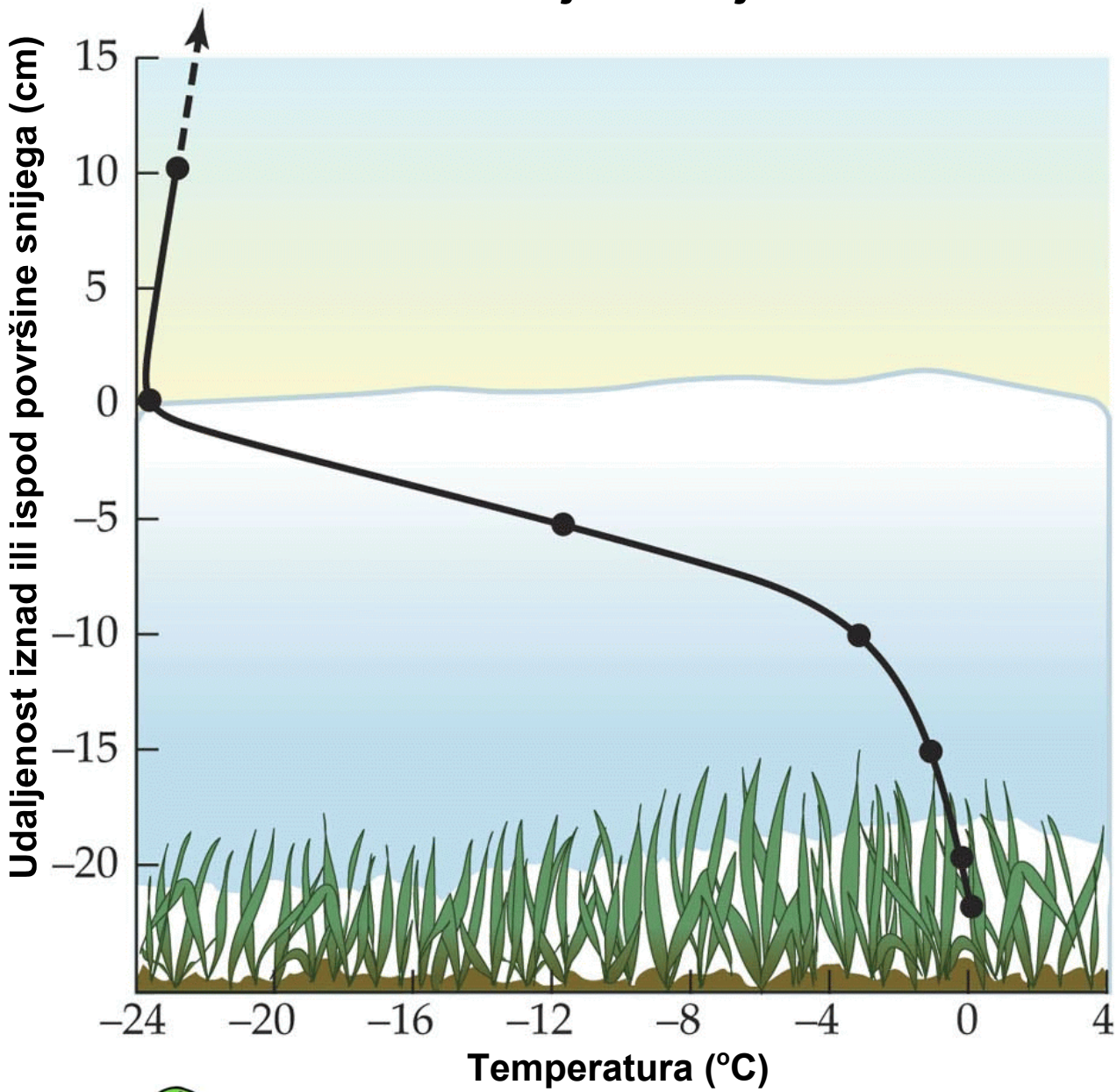
# *Važnost mikrookoliša u fiziologiji*



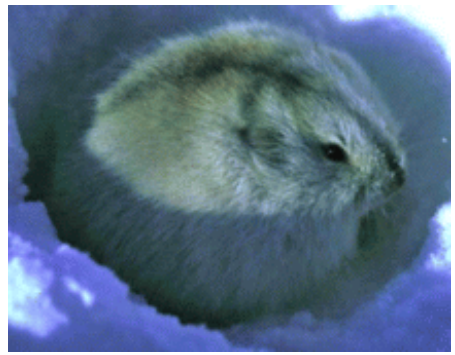
*Dipodomys merriami*

Misonne X. (1959) Analyse Zoogéographique des Mammifères de l'Iran. *Memoires 2me Série, no. 59, Institut Royal Sciences Naturelles de Belgique*, Brussels

# Noć u ožujku na sjeveru Švedske



*Lagopus muta*



*Lemmus lemmus*

**Zračni prostor ispod snijega (subnivealni prostor)**

Coulianos C.-C., Johnels A. G. (1963) Note on subnivean environment of small mammals. *Ark. Zool.* **15:** 363 - 370

Design by Zoran Tadić

# *Evolucija je . . .*

***promjena frekvencije gena kroz evolucijsko vrijeme.***

Design by Zoran Tadić

# *Slučaj jako može utjecati na evolucijske promjene*

Design by Zoran Tadić

# *Ključno pitanje evolucije je . . .*

## *Da li je došlo do adaptacije?*

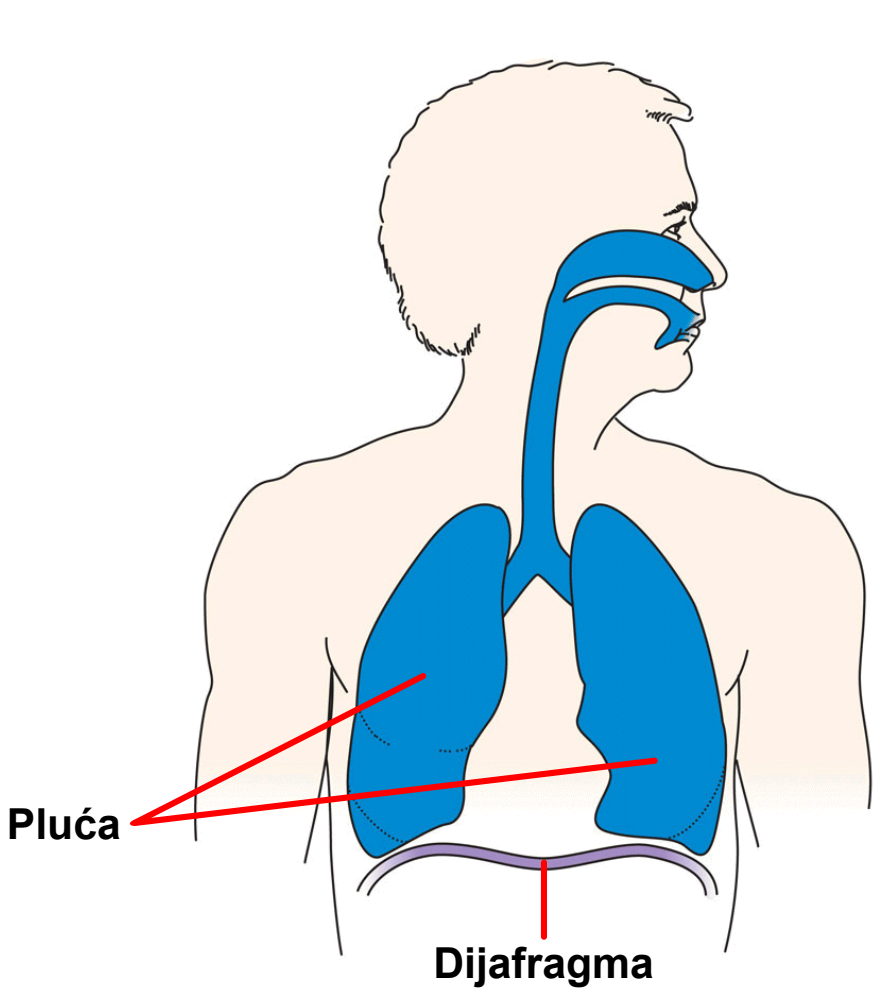
Design by Zoran Tadić

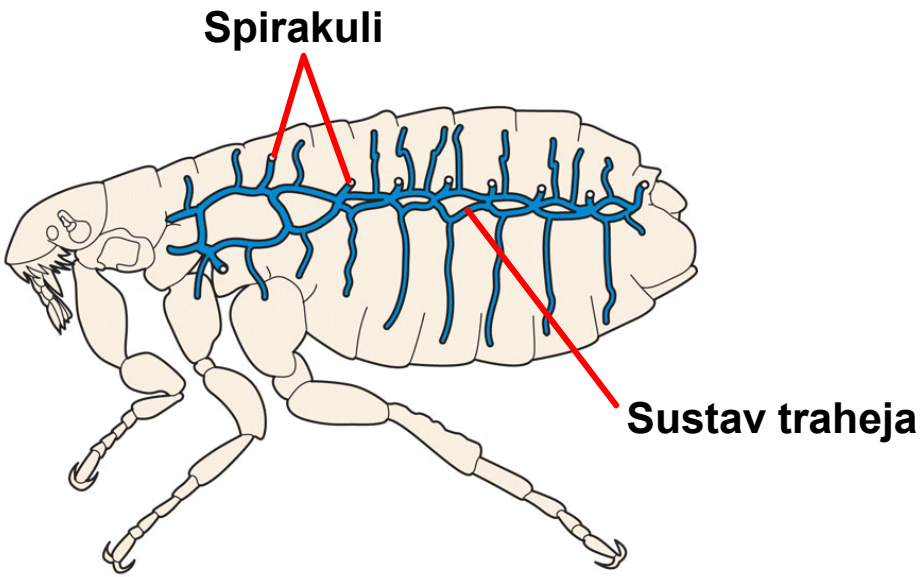
# *Kako istraživati evolucijske procese u fiziologiji?*

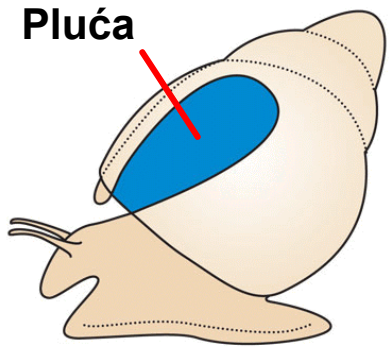
- Komparativni pristup
- Umjetna selekcija
- Individualne varijacije populacija divljih životinja
- Uporaba genski modificiranih životinja

Design by Zoran Tadić

# *Komparativni pristup*



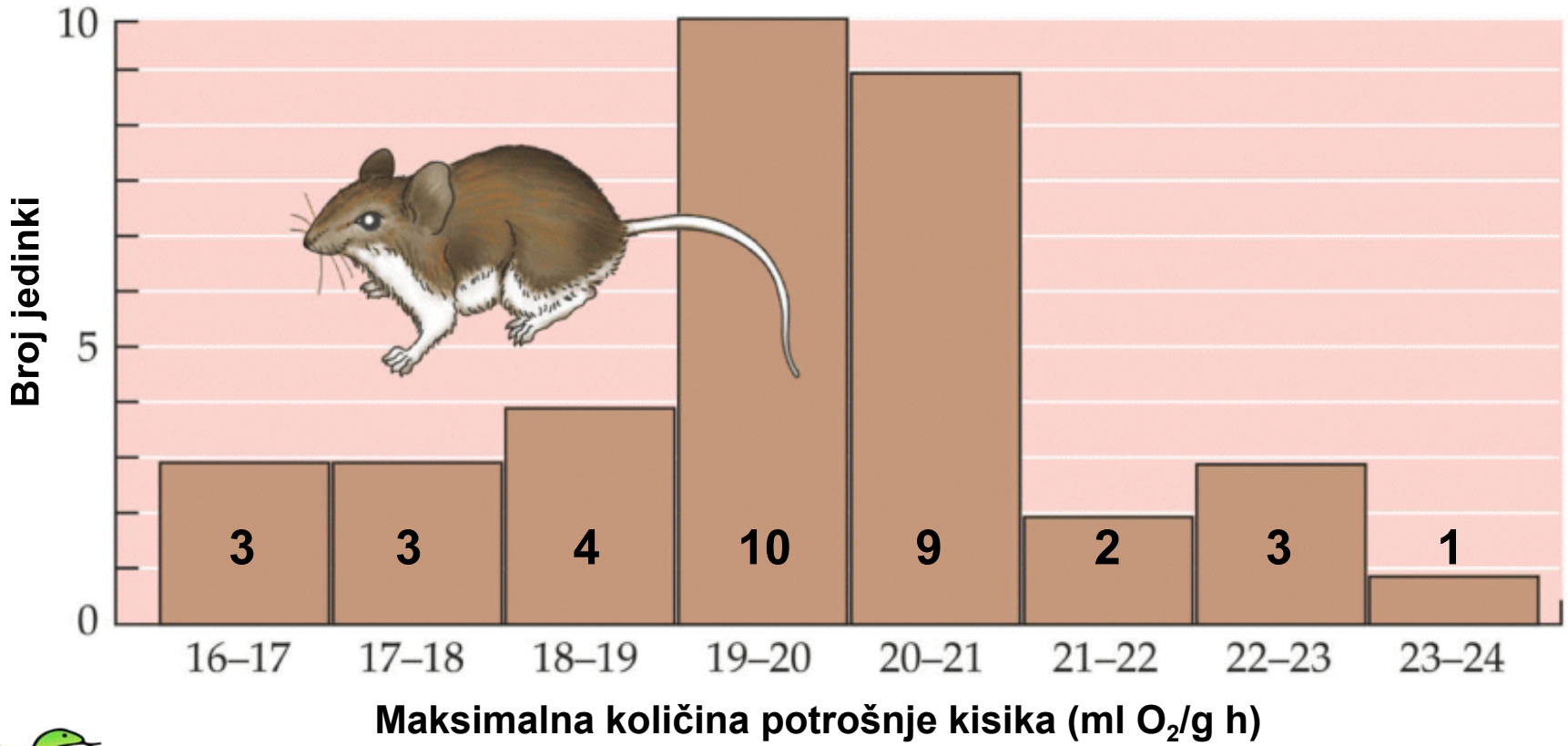



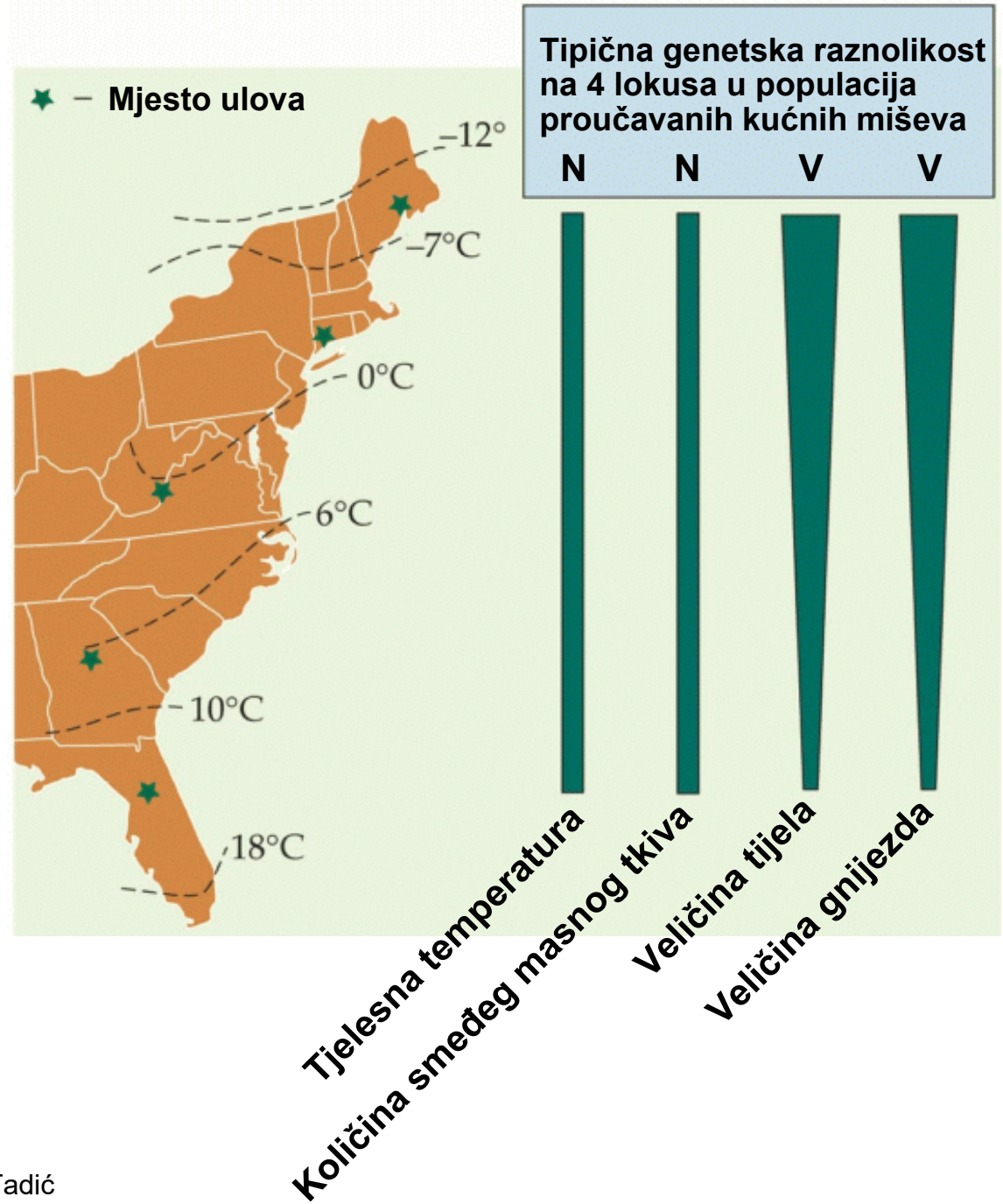

Design by Zoran Tadić

# *Fiziološke varijacije u jedinki iste populacije*

Hill R. W. (1983) Thermal physiology and energetics of *Peromyscus*: ontogeny, body temperature, metabolism, insulation, and microclimatology. *J. Mammal.* **64:** 19 - 37

*Peromyscus maniculatus*

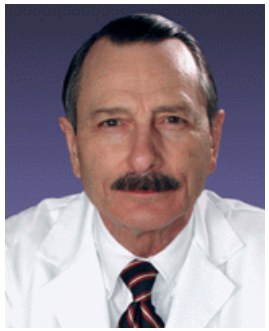




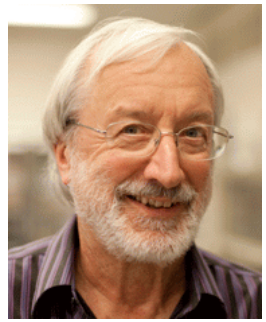

Lynch C. B. (1992) Clinal variation in cold adaptation in *Mus domesticus*: verification of predictions from laboratory populations. *Am. Nat.* **139:** 1219 - 1236

Design by Zoran Tadić

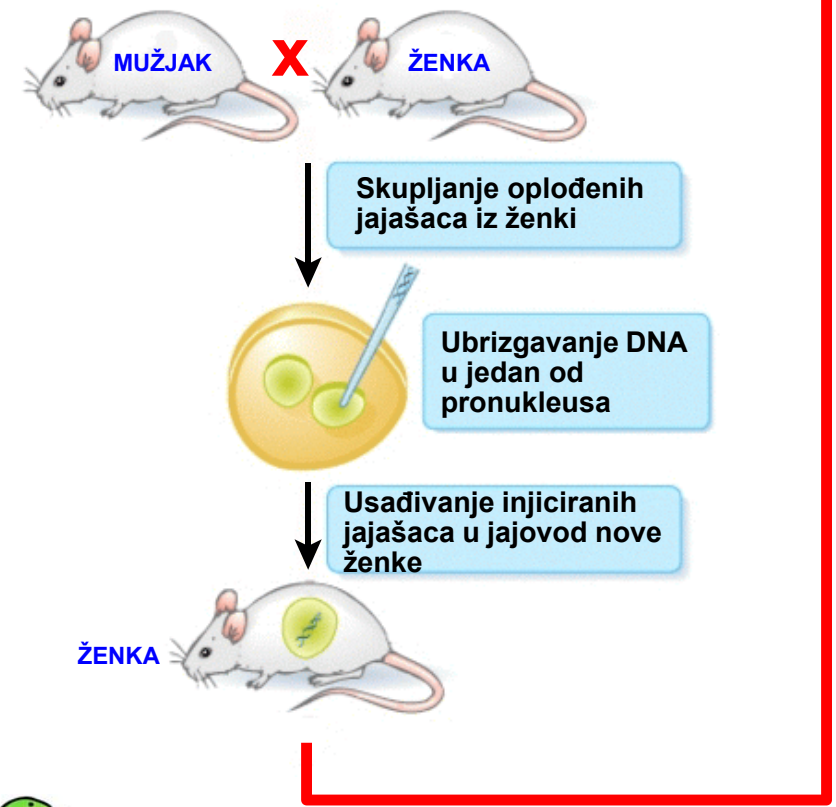
# *Proizvodnja transgenskih miševa ubrizgavanjem DNA u oplođena mišja jajašca*



Ralph L. Brinster

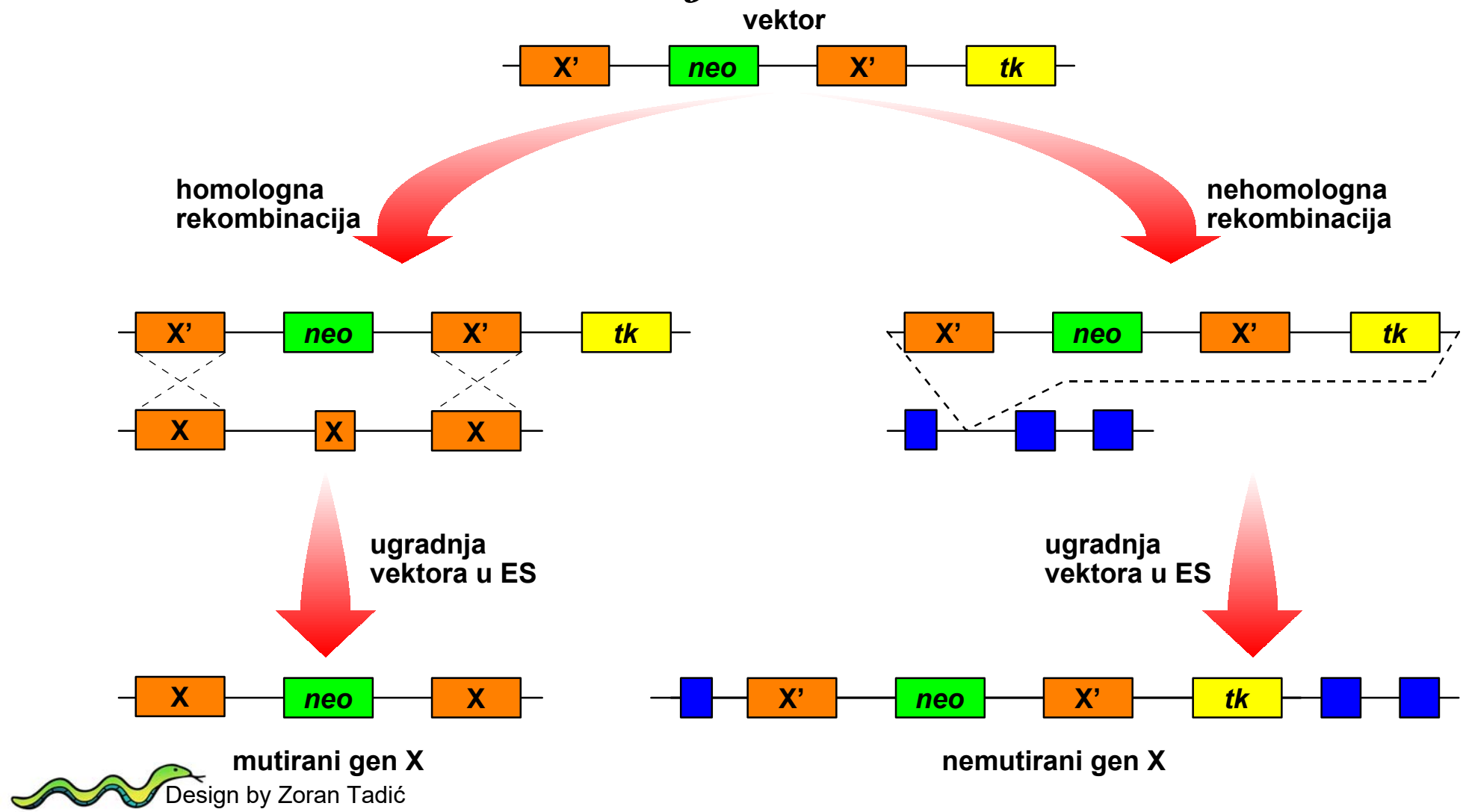


Richard D. Palmiter




Design by Zoran Tadić

# *Proizvodnja transgenskih miševa manipulacijom embrijskih matičnih (ES) stanica: 1. homologna rekombinacija u ES stanicama*

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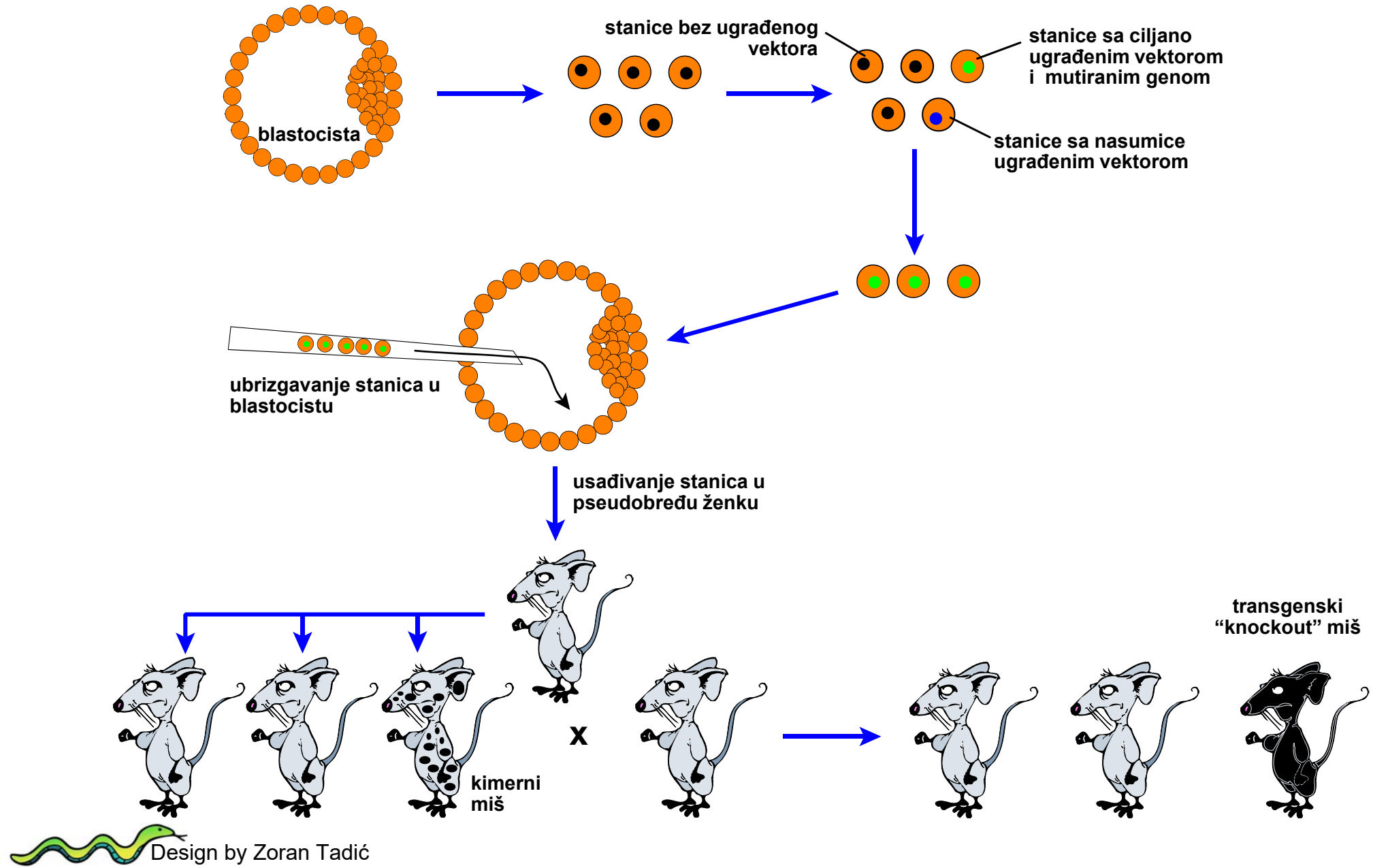
# 2. proizvodnja transgenskih "knockout" miševa

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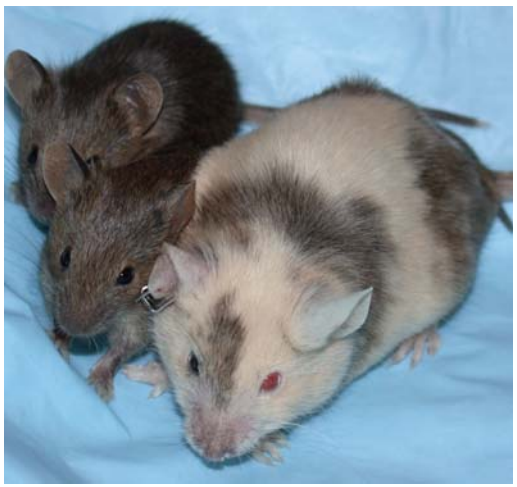
Mario R. Cappechi

Martin J. Evans

Oliver Smithies
(1925 - 2017)

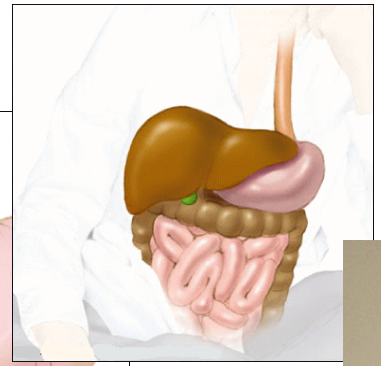


## Nobelova nagrada za fiziologiju ili medicinu 2007. godine:

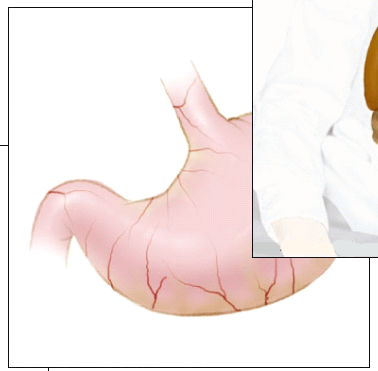
**“Za njihova otkrića oko unošenja specifičnih genskih modifikacija u miševe uporabom embrijskih matičnih stanica”**

# *Zašto nam treba znat SVE? - Prvi dio: Hijerarhija organizacije i funkcije*

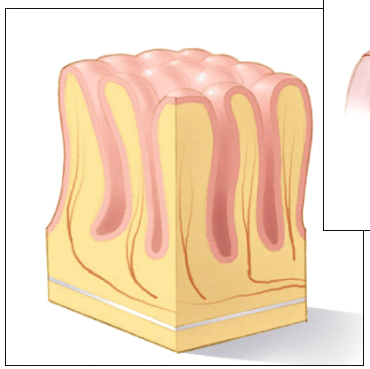
***Veliki problem!***



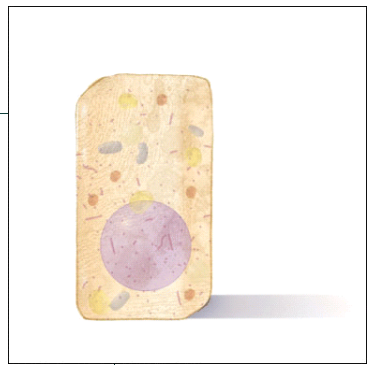
**Razina organskih sustava**



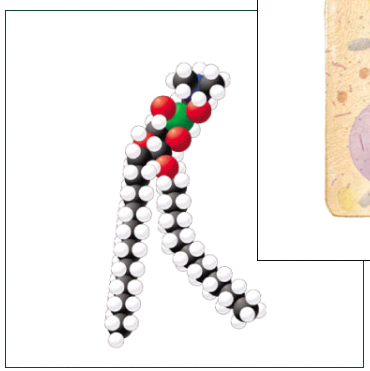
**Razina organa**



**Razina tkiva**



**Razina stanica**



**Razina molekula**

**Razina organizma**

**O k o l i š** ⟷

***Jako važno!***

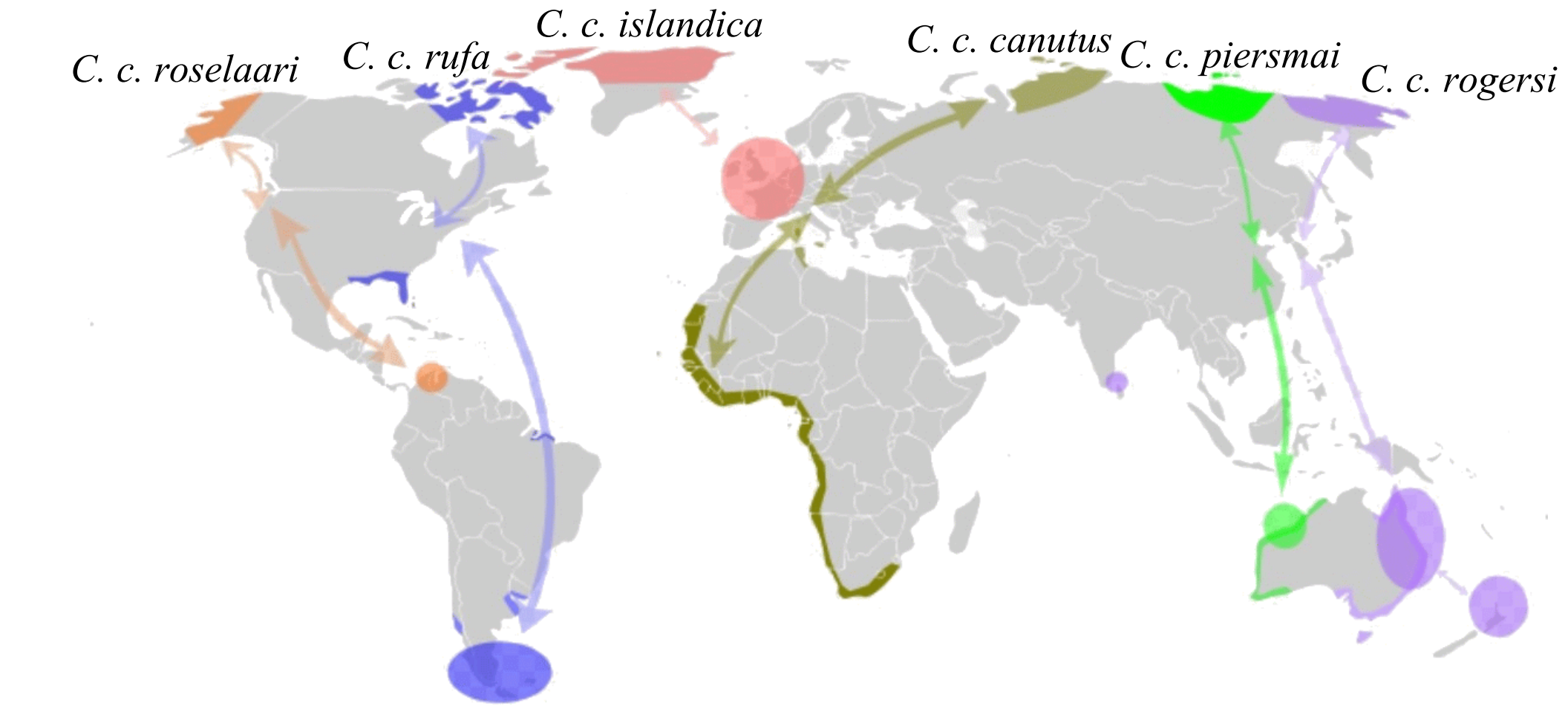
Design by Zoran Tadić

# *Zašto nam treba znat SVE? - Drugi dio: Kratka priča o rđastom žalaru*

**Rđasti žalar (*Calidris canutus*)**

Design by Zoran Tadić

# *Migracijski putevi rđastog žalara*

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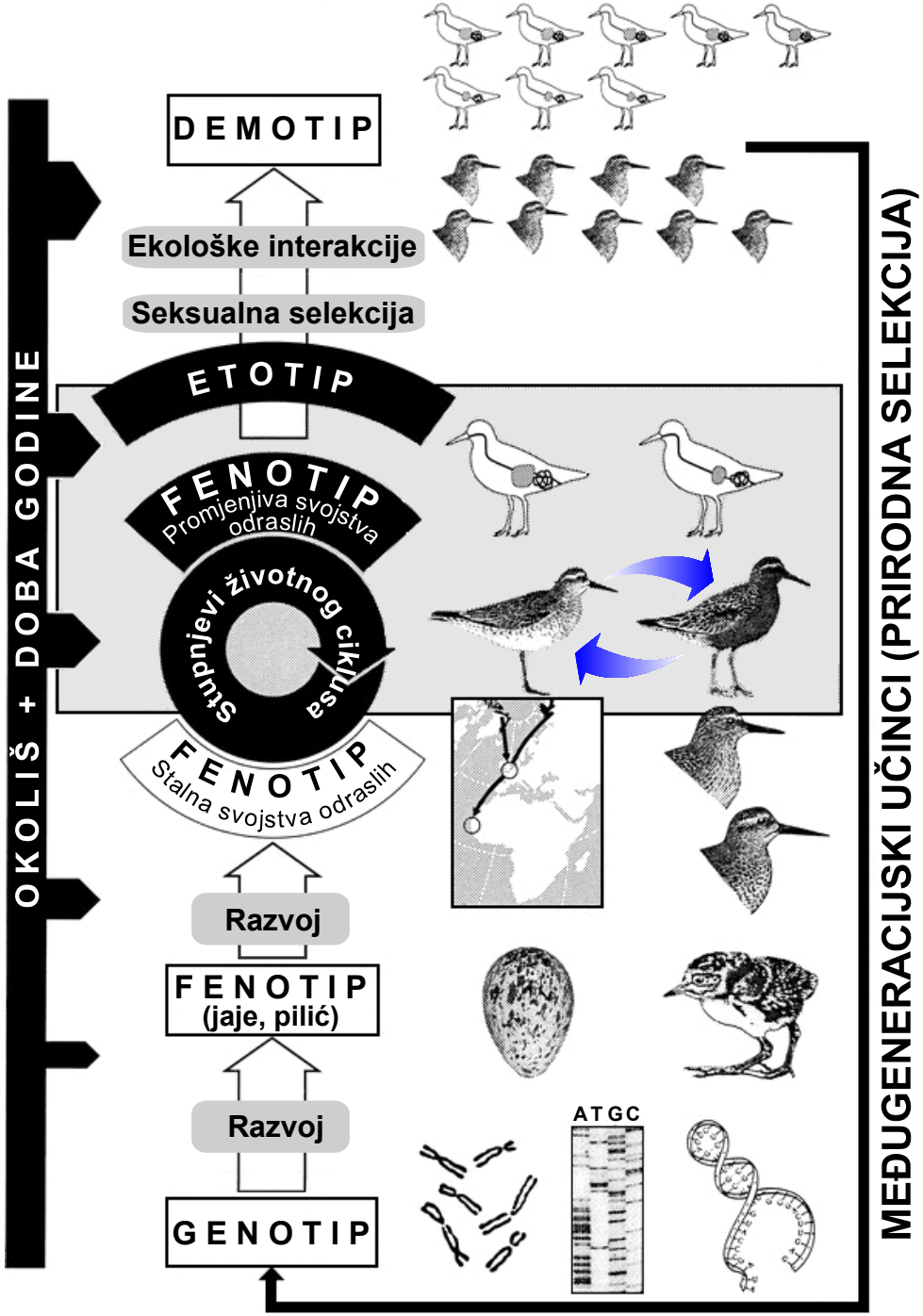
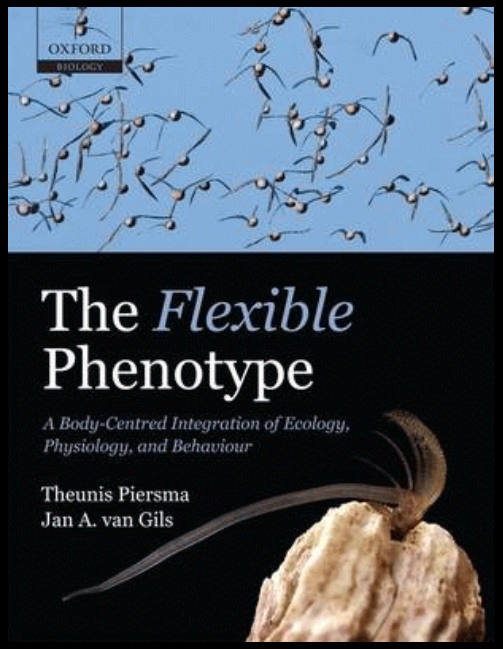


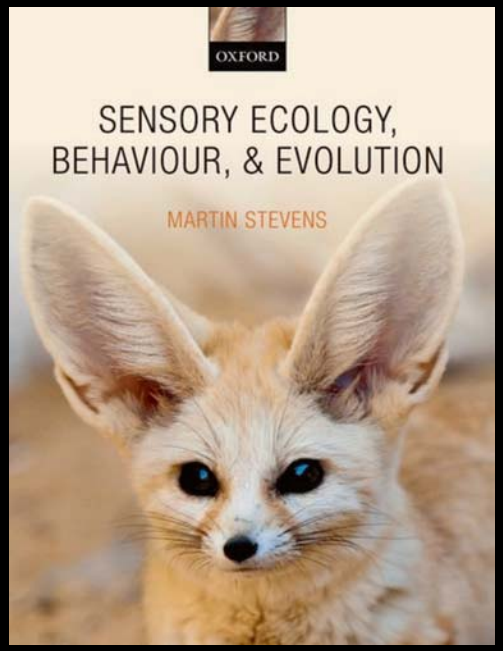

Piersma T. (2002) Energetic bottlenecks and other design constraints in avian annual cycles. *Integr. Comp. Biol.* **42:** 51 - 67

Design by Zoran Tadić

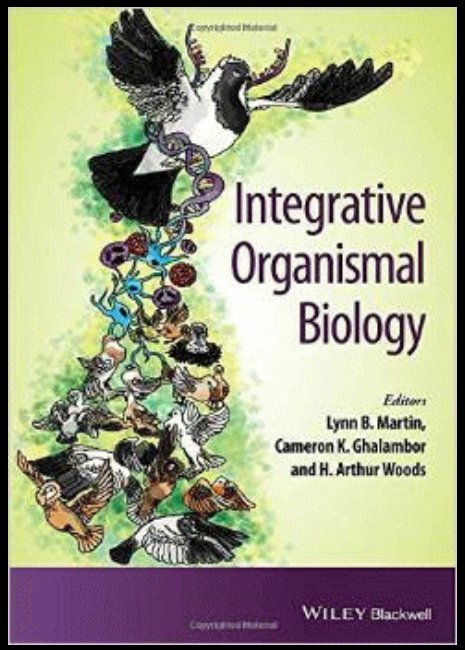
# *I zato. . .*




T. Piersma, J. A. van Gils: "The Flexible Phenotype", Oxford University Press, 2011




M. Stevens: "Sensory Ecology, Behaviour & Evolution", Oxford University Press, 2013




L. B. Martin, C. K. Ghalambor, H. A. Woods: "Integrative Organismal Biology", Wiley Blackwell, 2015