Conservation Ecology of Sea Turtles

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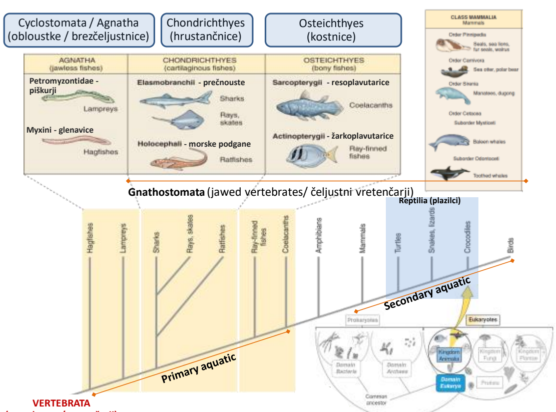
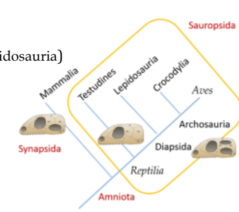


Secondary aquatic marine vertebrates

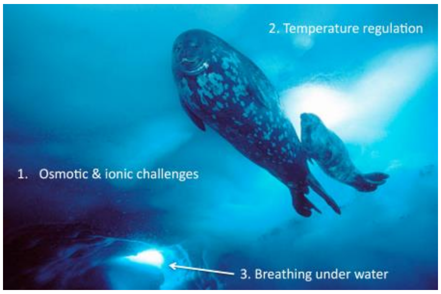
- breath air

Tetrapoda / Amniota:

- Synapsida: marine mammals (Mammalia)
- Sauropsida:
  - Sea turtles (Testudines)
  - Sea snakes and marine iguana (Lepidosauria)
  - Marine crocodyle (Crocodylia)
  - Marine birds (Aves)



Secondary aquatic marine vertebrates
Environmental stress



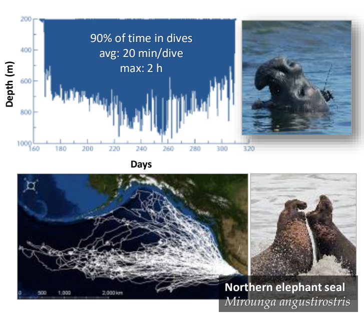
WEDELL SEAL

Secondary aquatic marine vertebrates
Adaptations

Adaptations to marine environment:

- Movement through the aquatic environment
- Adaptations to pressure (diving)
- Oxygen storage (breathing)
- Regulation of the body temperature
- Osmotic/ionic adaptations

Secondary aquatic marine vertebrates
Diving physiology



Secondary aquatic marine vertebrates

Diving adaptations

1) Adaptations to pressure
   - Mechanical effects of pressure
   - Changes in solubility of gasses (N_2, O_2)
2) Adaptations to oxygen storage
   - Oxygen stores
   - Changes in metabolism
   - Changes in blood flow (distribution of gasses)

- Convergent evolution in different evolutionary lineages of *breath-hold divers*

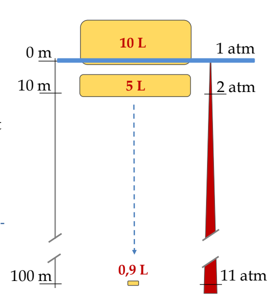
What is hapening in the process of diving?

- Intake of air (oxygen storage)
- Apnea (stop of breathing)
  - No air exchange btw. animal and environment
  - Exchange of gasses continues in lungs (alveoli) + celullar methabolisme
  - Voluntary and forced
- Bradycardia (reduction of heart frequency)
- Hipoperfusion (redistribution and reduction of the blood flow)
- Surfacing: brake down of lactates

Secondary aquatic marine vertebrates

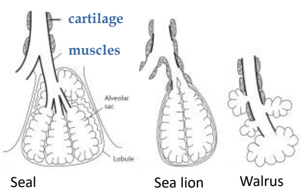
Adaptations to pressure

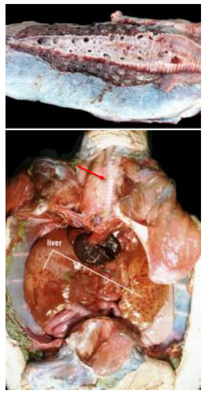
- Boyle's Law
  $P_1 V_1 = P_2 V_2$
- Changes in air volume most dramatic in the shallow dives: 10-20m
- Direct effects on cellular processes (nervous tissue, organs, membranes...): 500-1000m



Secondary aquatic marine vertebrates
Adaptations to pressure

- Adaptation in respiratory system
  - Straighten terminal airways
  - Lung collapse (alveoli)





HPNS
High pressure nervous syndrome

- In deep-diving speciea, with dives >500 m
- N_2 : nitrogen narcosis (euphoria, dezorientation)
- O_2 : blackout and death in partial pressure >1 atm
- Effects on tissues: higher absorption rates of N_2 and O_2 (saturation of tissues)

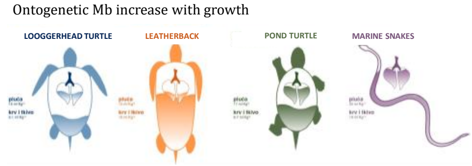
↓ **surfacing**

- Solubility of gasses in tissues decrease, gasses are being released in the form of bubles (decompresion sickness, *N_2 bands*)

Adaptations:
- Lung collapse (air in tracheas, no absorption in alveoli)
- Oxygen stored in tissues (Mb)

Aquatic Reptiles
Oxygen stores

- **Lungs** (air)
- **Blood** (Hemoglobin, Hb)
  - Higher hematocrit concentrations
  - Higher relative volume of blood in comparision to related terrestrial species
    - Humans: blood ≈ 7% body mass
    - Marine mammals: blood ≈ 10-20% body mass
- **Muscles** (Myoglobin, Mb)
  - Muscle Mb conc. 10-30x higher than in terrestrial species
  - Ontogenetic Mb increase with growth



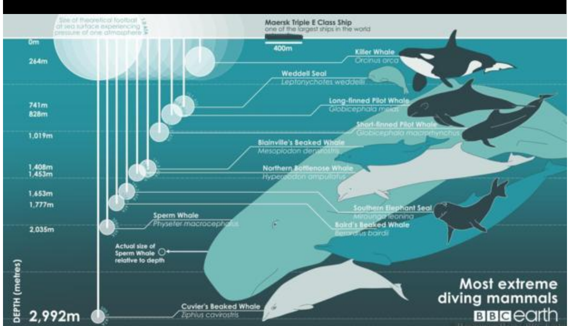
Secondary aquatic marine vertebrates

Diving metabolism

- Aerobic: glucose → CO_2 + H_2O + 38 ATP
  - ADL - *aerobic dive limits*
- Anaerobic: glucose → lactate + 2 ATP
  - 1/19 of energy
  - Lactate: toxic

Adaptations:

- Increased tolerance to lactates (high conc. of lactat-dehydrogenase) → increased tolerance of tissues to hypoxia
- *Body size*

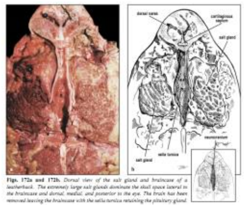


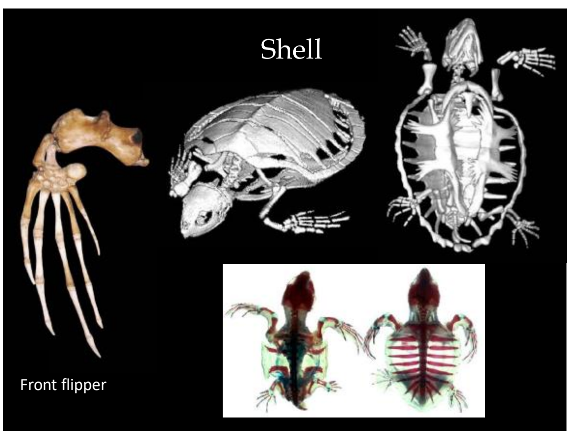
Sea turtles: Reptiles

- Ectotherms: Activity and distribution dependant upon environmental temperature
  - temperatre dependant sex determination (TDS)
- Secondary aquatic – breath air
- Skin covered with scales and scutes (keratinous layer of epidermis)

Adaptations
to marine environment

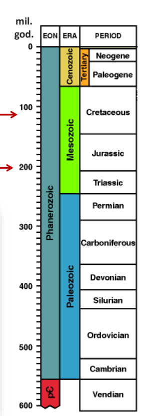
- shell: hydrodynamic shape
- front and hind legs → flippers
- can't contract/hide in the shell
- salt glands ("turtle tears")

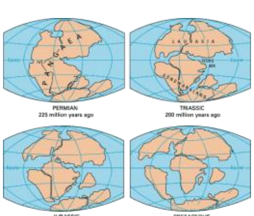




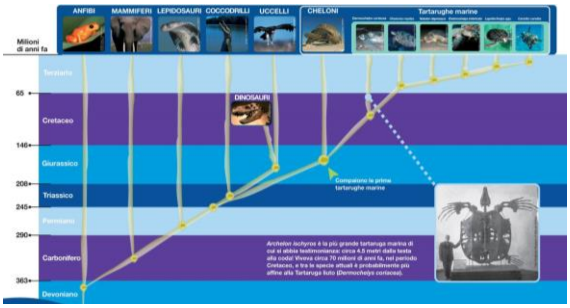
Evolution of sea turtles

- first turtles: before ≈ 200 mil. yrs.
- first sea turtles: before ≈ 110 mil. yrs.
  - *Santanachelys gaffneyi* (Brazil): ≈ 20 cm, hard shell, enlarged front flippers, salt glands



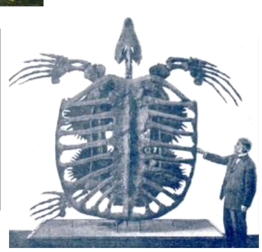


Origin of sea turtles



Archelon ischyros

- > 4 m
- > 2500 kg



Living sea turtles...

- ≈ 65-75 mil. yrs. old
- 600 mil. green turtles (*C. mydas*) in warm shallow Caribbean seas
- 5 mil. hawksbill turtles (*E. imbricata*) inhabited coral reefs

Christopher Columbus

1503 - discovered Cayman Islands, named the islands «*Las Tortugas*»

- "…*they* (sea turtles) *were present in such vast numbers that the dull sound of shells hiting each other could be heard for miles away*…."

Christopher Columbus

Systematic of sea turtles

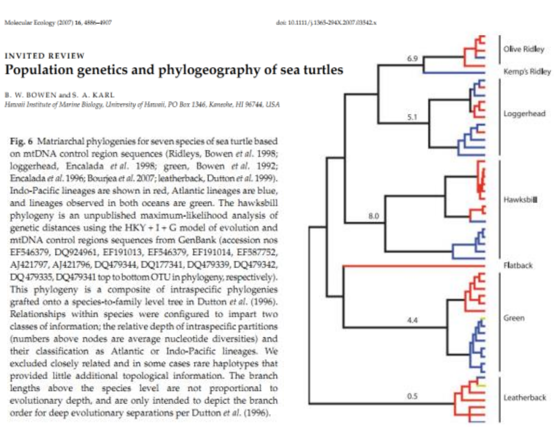
Two living families:

1. fam. Dermochelyidae (usnjače)
   - single species: leatherback turtle (*Dermochelys coriacea*)
   - shell covered with dark skin, with 7 longitudinal ridges
   - mosaic of small epidermal bones
2. fam. Cheloniidae (želve)
   - 6 species
   - shell covered with keratinous scutes

Dermochelys coriacea

Systematic of sea turtles

Family / Species	IUCN status	Assesment yr.
fam. Cheloniidae (želve)		
Loggerhead turtle/glavata kareta (*Caretta caretta*)	VU ↓	2015
Green turtle/orjaška črepaha (*Chelonia mydas*)	EN	2004
Hawksbill turtle/karetna želva (*Eretmochelys imbricata*)	CR	2008
Kemps ridley (*Lepidochelys kempii*)	CR	1996
Olive ridley (*Lepidochelys olivacea*)	VU ↓	2008
Flatback turtle (*Natator depressus*)	DD	1996
fam. Dermochelyidae (usnjače)		
Leatherback turtle / usnjača (*Dermochelys coriacea*)	VU ↓	2013



Molecular Ecology (2007) 16, 4886–4907 doi: 10.1111/j.1365-294X.2007.03542.x

INVITED REVIEW

Population genetics and phylogeography of sea turtles

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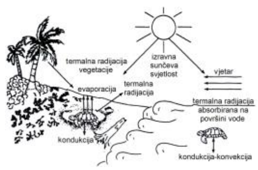
Fig. 6 Matriarchal phylogenies for seven species of sea turtle based on mtDNA control region sequences (Ridleys, Bowen *et al.* 1998; loggerhead, Encalada *et al.* 1998; green, Bowen *et al.* 1992; Encalada *et al.* 1996; Bourjea *et al.* 2007; leatherback, Dutton *et al.* 1999). Indo-Pacific lineages are shown in red, Atlantic lineages are blue, and lineages observed in both oceans are green. The hawksbill phylogeny is an unpublished maximum-likelihood analysis of genetic distances using the HKY + I + G model of evolution and mtDNA control regions sequences from GenBank (accession nos EF546379, DQ924961, EF191013, EF546379, EF191014, EF587752, AJ421797, AJ421796, DQ479344, DQ177341, DQ479339, DQ479342, DQ 479335, DQ479341 top to bottom OTU in phylogeny, respectively). This phylogeny is a composite of intraspecific phylogenies grafted onto a species-to-family level tree in Dutton *et al.* (1996). Relationships within species were configured to impart two classes of information; the relative depth of intraspecific partitions (numbers above nodes are average nucleotide diversities) and their classification as Atlantic or Indo-Pacific lineages. We excluded closely related and in some cases rare haplotypes that provided little additional topological information. The branch lengths above the species level are not proportional to evolutionary depth, and are only intended to depict the branch order for deep evolutionary separations per Dutton *et al.* (1996).

Thermal biology of marine ectotherms

Heat exchange:
- radiation
- conduction (body-surface heat exchange)
- convection (heat exchange among diferent medias)
  - body into the air or water

Reptiles *control* their T_b by:
- Thermoregulatory behaviour
- Morhphological characters
- Physiological processes



1. Physiology and thermoregulation

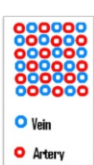
Cardiovascular Control / heating and cooling
- changes in heart rate
- peripheral circulation

Heat Production
- muscular production
- metabolic heat production (aquatic species)
- countercurrent heat exchange

Temperature sensors
- epiphysis (pineal complex) ⇒ melatonin ⇒ thyroxine

Countercurrent heat exchange in sea turtles

Leatherback turtle
- matrix form

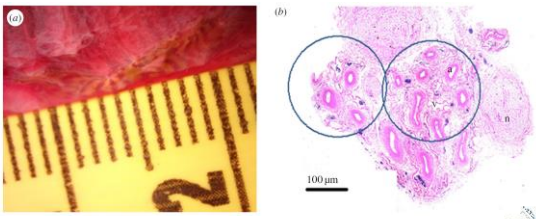


Loggerhead and green turtle
- radial form

BIOLOGY LETTERS

Topsy-turvy: turning the counter-current heat exchange of leatherback turtles upside down

John Davenport[1], T. Todd Jones[2], Thierry M. Work[3] and George H. Balazs[2]



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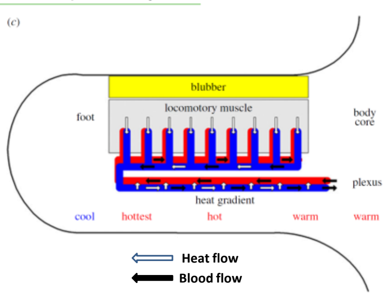
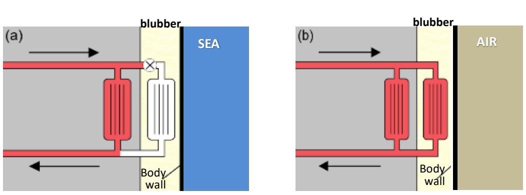




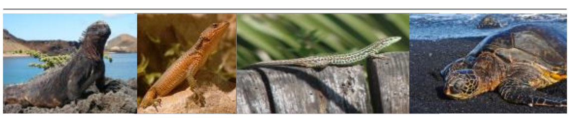
2. Control of T_b & morhphological characters

- morphlogical characters: e.g. crests
- dark colours: melanism

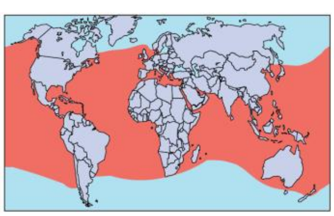
3. Thermoregulatory behaviour

- environmental heat loads vary with time and among (micro)habitats
- reptiles attempt to “buffer” variation by thermoregulatory behaviour:

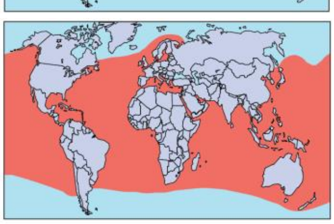
1. selection of thermally suitable (micro)habitats
2. restriction of activity time
3. adoption of specific positions and postures

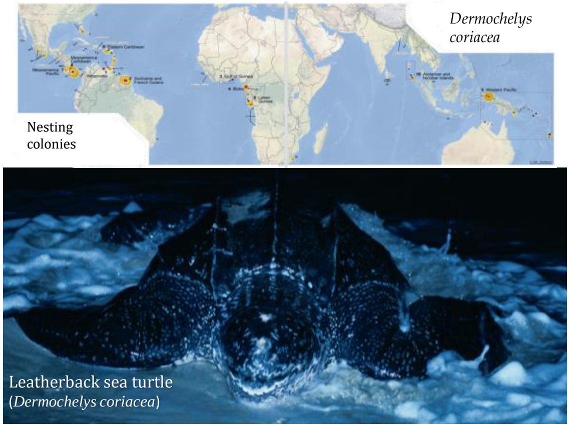


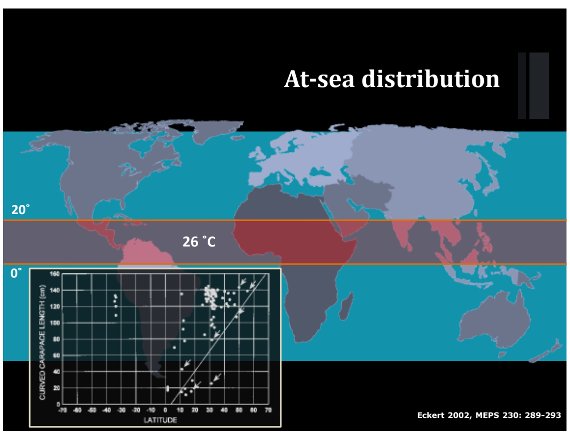
fam. Cheloniidae

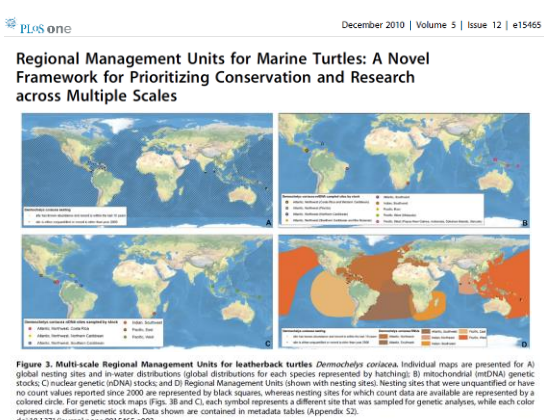


fam. Dermochelyidae



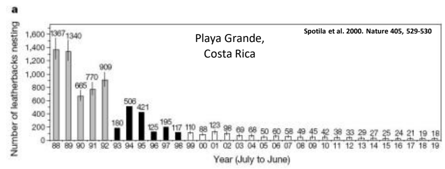





PLoS one December 2010 | Volume 5 | Issue 12 | e15465

Regional Management Units for Marine Turtles: A Novel Framework for Prioritizing Conservation and Research across Multiple Scales

Figure 3. Multi-scale Regional Management Units for leatherback turtles ***Dermochelys coriacea.*** Individual maps are presented for A) global nesting sites and in-water distributions (global distributions for each species represented by hatching); B) mitochondrial (mtDNA) genetic stocks; C) nuclear genetic (nDNA) stocks; and D) Regional Management Units (shown with nesting sites). Nesting sites that were unquantified or have no count values reported since 2000 are represented by black squares, whereas nesting sites for which count data are available are represented by a colored circle. For genetic stock maps (Figs. 3B and C), each symbol represents a different site that was sampled for genetic analyses, while each color represents a distinct genetic stock. Data shown are contained in metadata tables (Appendix S2).
doi:10.1371/journal.pone.0015465.g003



Population in the E Pacific:

1980: ≈ 4600 nesting females
2009: ≈ 900 nesting females

Sustainable bycatch
(1% antropogenic mortality/yr)

≈35 adult females/ yr

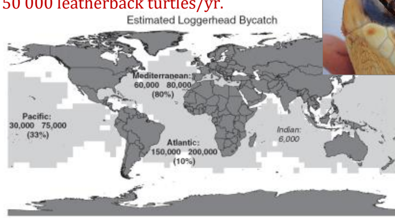
Bycatch E Pacific: 20.000 – 40.000/yr (!)

Ecology Letters, (2004) 7: 221–231 doi: 10.1111/j.1461-0248.2004.00573.x

REPORT

Quantifying the effects of fisheries on threatened species: the impact of pelagic longlines on loggerhead and leatherback sea turtles

- **pelagic longlines:**
  > 200 000 catches of loggerhead turtles/yr.
  > 50 000 leatherback turtles/yr.



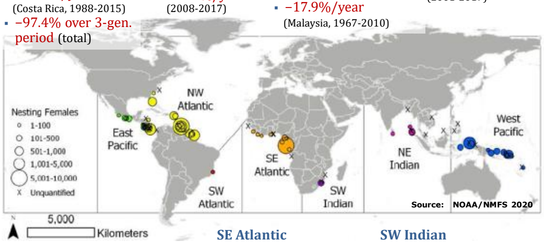
Lewison et al 2004. Ecol. Lett. 7: 221-231.

E Pacific
- N ≈ 755 nesting females
- >80% in Mexico and Costa Rica
- −15.5%/year (Costa Rica, 1988-2015)
- −97.4% over 3-gen. period (total)

NW Atlantic
- N ≈ 20,660 nesting females
- 70%: Trinidad, Fr. Guiana
- −9.32%/year (2008-2017)

NE Indian
- N ≈ 110 nesting females
- 80% in India: Andaman & Nicobar Isl.
- no clear trend
- −17.9%/year (Malaysia, 1967-2010)

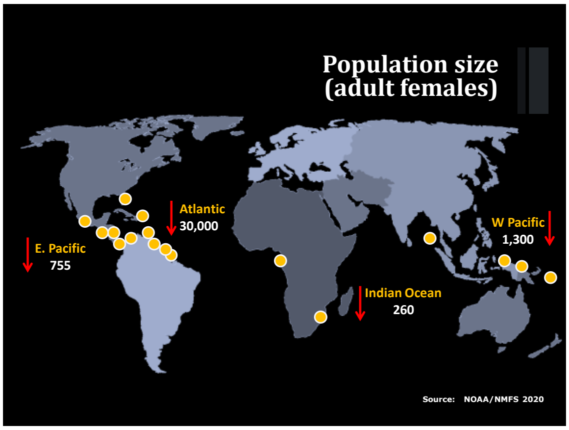
W Pacific
- N ≈ 1300 nesting females
- >90% in Indonesia
- −2.3 to −5.7%/year (2001-2017)



SW Atlantic
- N = 27 nesting females
- all nesting effort in Brazil
- +4.8%/year (1986-2016)

SE Atlantic
- N ≈ 9,200 nesting females
- 90% in Gabon
- −8.6%/year (2002-2015)

SW Indian
- N ≈ 150 nesting females
- >75% in S. Africa
- -0.3%/year (1973-2016)



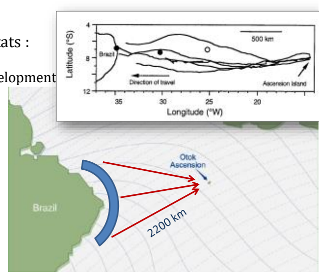
Reproduction

- reproductive migrations:
  - females from foragning ground → to reproductive habitats
  - males ?
  - *remigration interval*: 2-4 yrs

Constrains - reproductive habitats :
  - condition for adult activity
  - conditions for embryonic development
  - survival of hatchlings

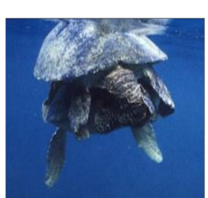
Evolution of migrations

- split-up of Gondwana (≈ 70 mil. yrs) → splitting of S America and Africa
- vulcanic activity → Ascension Isl. (7 mil. yrs) – 300 km from the land



Sex identification

- juveniles: sexual dimorphism not existent (!)
- adults (> 70 cm in loggerhead turtle): males develop longer tail!



Chelonia mydas – green turtle

Nesting

- similar in all sea turtle species
- duration: 1 – 2 hours, *Ch. mydas*: 2 – 3 hr
  1) beach selection / ascending the beach
  2) excavating the body pit (5-10 min)
  3) digging the egg chamber (20 min)
  4) oviposition (20-30 min)
  5) filling the egg chamber (10 min)
  6) filling the body pit (10 min)
  7) returning to the sea

Beach selection

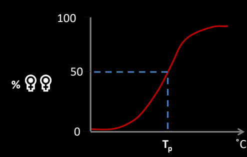
- accessible from the sea
- high enough to prevent inundation by tides or underlaying water table
- substrate (particle size) must facilitate gas difussion
- moist substrate and fine enough to prevent collapse of the egg chamber during construction
- Phylophatry: regional discrimination of *reproductive regions*
- Site fidelity: fine-scale homing to *beach*

Reproductive biology

- nest depth: 50–80 cm
- constant temperature (!)
- 80 – 120 eggs/ nest
- internesting interval: ≈ 10-14 days
- 2-4 nests per reproductive season (range: 1-9)
- remigration period: 2-4 yrs.

Embryonic development

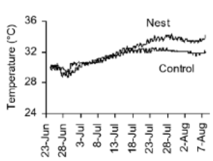
- fertility: >80%
- sex determination: TSD
- $T_p \approx 29$ °C (pivotal temperature)
- experimentaly established
- evolutionary conservative for different species and populations
- incubation period: 50-80 days (depending of the incubation temp.)
- hatching sucess: >80% (highly variable between populations/ beaches)

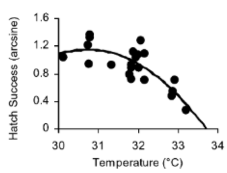


Thermal biology of nest

Loggerhead sea turtle (*Caretta caretta*), T_p = 29.3 °C, incubation: 52.6 days

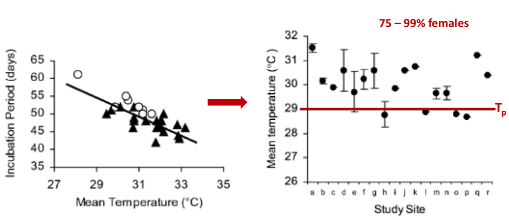
- nest depth: 50 cm
- daily variation of temperature: 0.3 – 1.4 °C (*temperature data loggers*)
- average nest temperature: 29.5 – 33.2 °C
- average temperaure durig *photosensitive period*: 29.3 – 33.7 °C



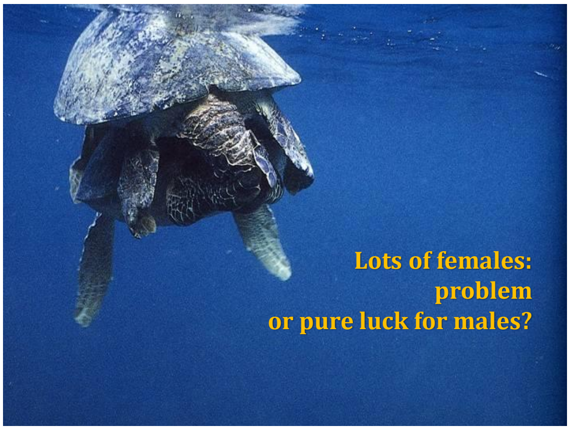


Loggerhead sea turtle, Mediterranean Sea:

Sex ratio of hatchling production



Cyprus: a. Alagadi; **Greece**: b. Bay of Chania; c. Kefalonia; d. Kyparissia Bay; e. Lakonikos Bay; f. Rethymno; g. Rhodes; h. Zakynthos; **Libya**: i. not specified; **Turkey**: j. Akyatan; k. Anamur; l. Dalyan; m. Fethiye; n. Gosku; o. Kizilot; p. Patara; **Egypt**: q. Sinai Peninsula; **Israel**: r. whole coastline.

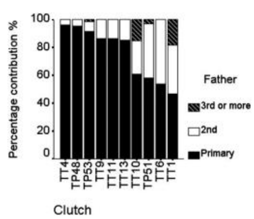


Sea turtles and polyandry

- **polyandry**: clutch fertilized by several males – *multiple paternity*
- microsatellite DNA analysis

Fitness benefits:
- secure fertilization
- selection of genetic material
- higher genetic variabiltz of offsprings

Costs to females:
- ↑ mortality risk
- ↑ predation risk
- ↑ energetic costs



Sea turtles and polyandry

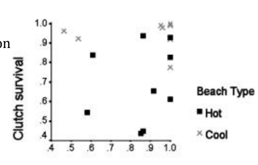
Ascension Island

- population density: 1000 turtles/km^2, shallow coastal waters
- **females** – actively control courtship by behavior (aggregation, avoidance, escape)
- **males** – can't force female on copulation

Fitness benefit: *survival of nest*
- survival: <u>not</u> correlated with proportion of primary male (highest paternity %)
- dominant influence of nest position [dark (hot) sand – light (cool) sand]

↓

Females <u>reject</u> more than one copulation, <u>unless</u> the avoidance costs are higher than the mating costs



Molecular Ecology (2007) doi: 10.1111/j.1365-294X.2007.03426.x

High frequency of multiple paternity in the largest rookery of Mediterranean loggerhead sea turtles

JUDITH A. ZBINDEN,* CARLO R. LARGIADÈR,† FABIO LEIPPERT,* DIMITRIS MARGARITOULIS‡ and RAPHAËL ARLETTAZ*
*Zoological Institute, Division of Conservation Biology, University of Bern, Baltzerstrasse 6, 3012 Bern, Switzerland, †Institute of Clinical Chemistry, Inselspital, University Hospital, University of Bern, 3010 Bern, Switzerland, ‡ARCHELON, the Sea Turtle Protection Society of Greece, Solomou 57, 10432 Athens, Greece

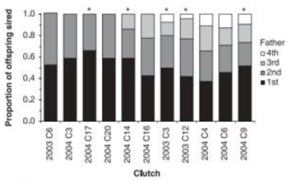


Fig. 1 Relative contribution of fathers to clutches being sired by two to four males. Shown are average values over multiple solutions. From mothers where two clutches were sampled, only the clutch with the higher number of offspring sampled is included. Asterisks above columns designate clutches with skewed paternal contributions.

Molecular Ecology (2007) doi: 10.1111/j.1365-294X.2007.03426.x

High frequency of multiple paternity in the largest rookery of Mediterranean loggerhead sea turtles

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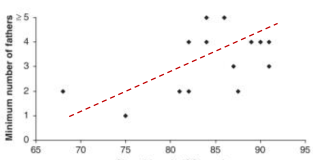

Fig. 2 Number of fathers detected in 14 clutches plotted against female body size (CCL: curved carapace length). From mothers where two clutches were sampled, only the clutch with the higher number of offspring sampled is included.

PROCEEDINGS OF THE ROYAL SOCIETY B
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Turtle mating patterns buffer against disruptive effects of climate change

Lucy I. Wright[1], Kimberley L. Stokes[1], Wayne J. Fuller[2], Brendan J. Godley[1], Andrew McGowan[1], Robin Snape[1,3], Tom Tregenza[1] and Annette C. Broderick[1,*]
[1]Centre for Ecology and Conservation, University of Exeter, Cornwall Campus, Penryn TR10 9EZ, UK
[2]Marine and Fisheries Research Institute, European University of Lefke, Gemikonagi, Lefke, North Cyprus Mersin 10, Turkey
[3]North Cyprus Society for Protection of Turtles, PK65, Kyrenia, North Cyprus, Mersin 10, Turkey

Operational sex ratios

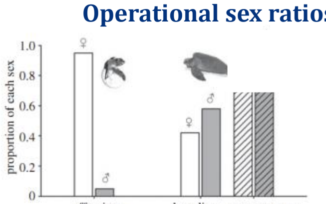


Figure 1. Sex ratios and monogamy of green turtles. The figure shows the proportions of female (un-shaded) and male (shaded) offspring and breeding adults for the 2008 nesting season at our study site. Also shown (hashed) are the proportions of breeding adults that were monogamous at the study site, i.e. the proportion of females that had a single sire for their offspring and the proportion of males that only sired offspring from one female at this rookery (note: use of the term 'monogamy' in this figure relates only to the Alagadi rookery; males may have mated with additional females at other nesting sites within the wider Mediterranean population). Offspring sex is estimated from incubation durations [23] and includes all clutches that hatched successfully at this site in 2008.

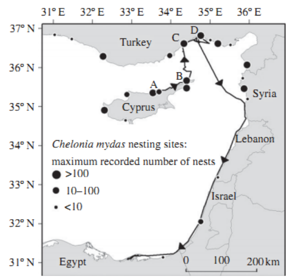
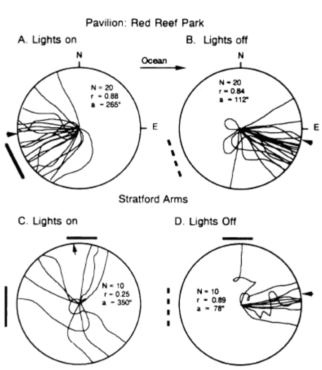


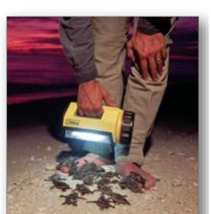
Figure 2. Route of an adult male green turtle that was released post-breeding at Alagadi Beach, Cyprus and tracked to Egypt via the Turkish coast. Major green turtle nesting beaches along the route are labelled (A–D): (A) Alagadi and the Cyprus North beaches, 8–9th June. (B) North Karpaz beaches, 10–11th June. (C) Alata, 14th June. (D) Kazanlı, 15–26th June. Data for nesting numbers are taken from the literature [22,41–43].

Wright et al. 2012. Proc. Royal Soc.

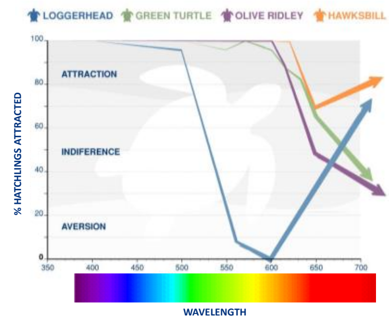
Orientation and navigation

- sea finding: visual cues
  - orientation toward the brighter, lower oceanic horizon



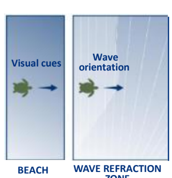


Orientation response to colored ligth from hatchlings from four species of sea turtles



Orientation and navigation

- sea finding: visual cues
  - orientation toward the brighter, lower oceanic horizon
- nearshore waters (wave refraction zone): wave orientation
  - 24-48 *swiming frenzy* (→ open ocean)



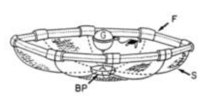


FIGURE 1A. Floating cage used to determine directional preferences of tethered hatchlings. Cage base plate (BP) is attached by a swivel and line to the globe (G); S, support for underwater net and base plate; F, hollow PVC frame providing flotation.

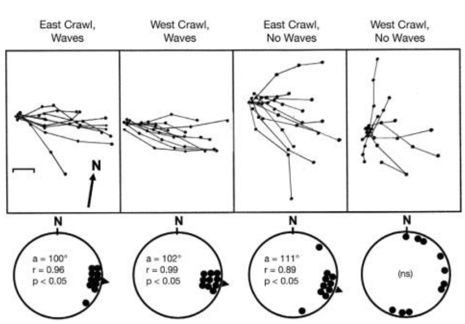
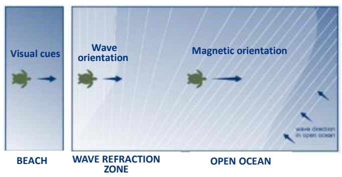


Fig. 2. Top panels: swimming paths and distances achieved over 15 min for hatchlings that initially crawled east or west for 2 min. Scale bar: 50 m. Bottom panels: orientation by the turtles in each treatment in the presence or absence of waves. a, ►: mean angle; r: r-vector; ns: not significant. Probabilities are based upon the outcome of Rayleigh tests

Orientation and navigation

- sea finding: visual cues
  - orientation toward the brighter, lower oceanic horizon
- nearshore waters (wave refraction zone): wave orientation
  - 24-48 *swiming frenzy* (→ open ocean)
- open ocean: magnetic orientation



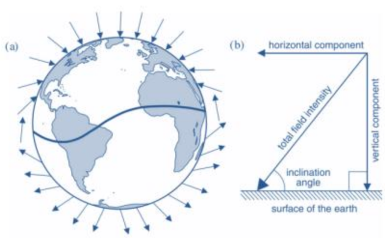
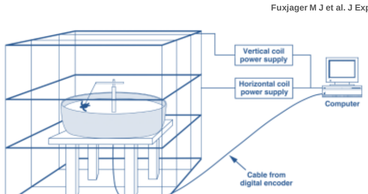


Figure 1. (a) Diagrammatic representation of the Earth's magnetic field illustrating how field lines (represented by arrows) intersect the Earth's surface, and how inclination angle (the angle formed between the field lines and the Earth) varies with latitude. At the magnetic equator (the curving line across the Earth), field lines are parallel to the Earth's surface and the inclination angle is 0°. The field lines become progressively steeper as one travels north toward the magnetic pole, where the field lines are directed straight down into the Earth and the inclination angle is 90°. (b) Diagram illustrating four elements of geomagnetic field vectors that might, in principle, provide marine animals with positional information. The field present at each location on Earth can be described in terms of a total field intensity and an inclination angle. The total intensity of the field can be resolved into two vector components: the horizontal field intensity and the vertical field intensity. (Whether animals are able to resolve the total field into vector components, however, is not known.)

Schematic of the experimental apparatus, including the orientation arena, magnetic coil structure and data-acquisition system.

Fuxjager M J et al. J Exp Biol 2011;214:2504-2508



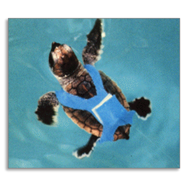
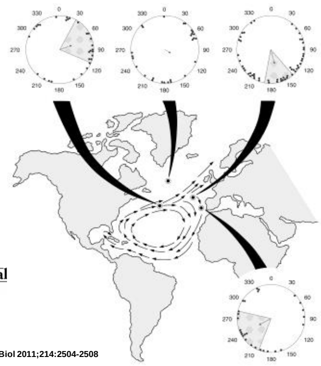


Diagram of hatchling orientation responses to magnetic fields that exist at different locations (indicated by circled dots) in the North Atlantic Ocean.



The Journal of Experimental Biology

Fuxjager M J et al. J Exp Biol 2011;214:2504-2508

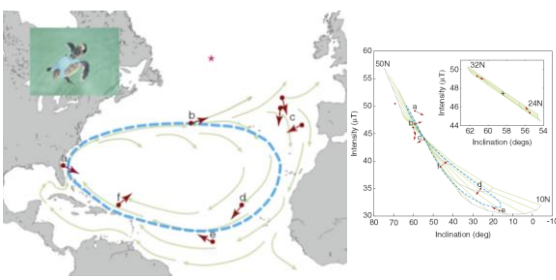
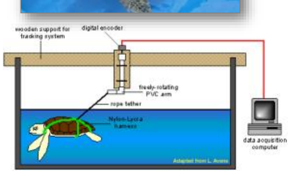
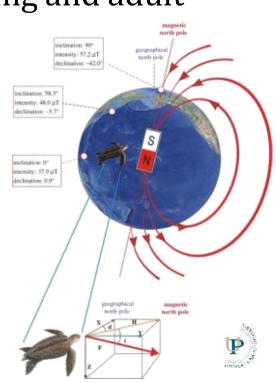


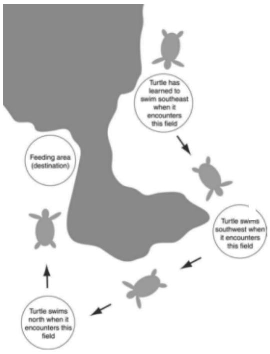
Figure 1. Use of magnetic cues in turtle migration.

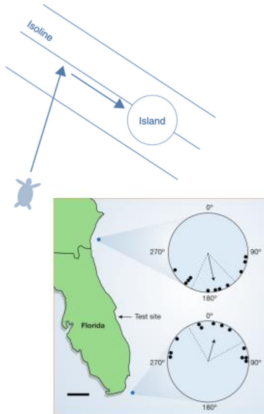
(A) Map of the North Atlantic showing currents in green and a possible loggerhead turtle migration route in blue. The magnetically simulate geographical locations in [7–9] are indicated by red dots, and the red arrows show the mean swimming directions relative to magnetic nort (up) of the loggerhead hatchlings. Asterisk shows the simulated point distant from the gyre where the hatchlings showed no consistent directio Inset: hatchling loggerhead turtle (*Caretta caretta*) in a harness (copyright K.J. Lohmann). (B) The blue migratory path and the positions c directional arrows from A are plotted in magnetic coordinates. Letters labelling arrows correspond to those in A and directions are show geographically (north up). Lines of latitude (grey) are shown in steps of 10 from 10 N at bottom right to 50 N at top left. Longitude (greer also steps in 10 from 10 W to 80 W. The inset shows a map in magnetic coordinates of the directions of juvenile green turtles when displace N and S of their feeding grounds. The convention is as for the main graph, except that lines of latitude (grey) and longitude (green) are bot shown in steps of 2 .

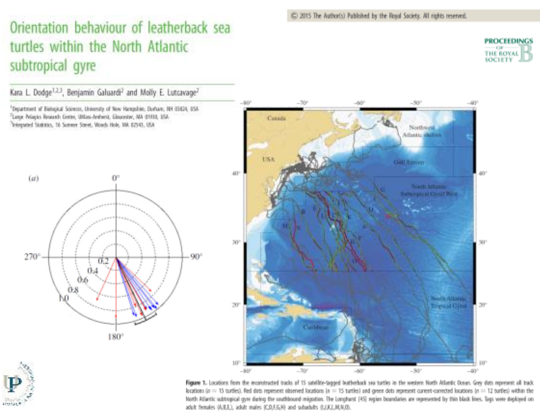
Natal beach homing and adult navigation











PROCEEDINGS OF THE ROYAL SOCIETY B

Orientation behaviour of leatherback sea turtles within the North Atlantic subtropical gyre

Kara L. Dodge[1,2,3], Benjamin Galuardi[2] and Molly E. Lutcavage[2]

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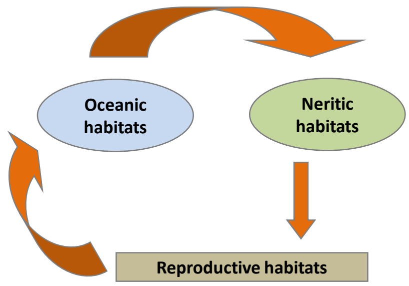
[2]Large Pelagics Research Centre, UMass-Amherst, Gloucester, MA 01930, USA
[3]Integrated Statistics, 16 Sumner Street, Woods Hole, MA 02543, USA

Figure 1. Locations from the reconstructed tracks of 15 satellite-tagged leatherback sea turtles in the western North Atlantic Ocean. Grey dots represent all track locations ($n = 15$ turtles). Red dots represent observed locations ($n = 15$ turtles) and green dots represent current-corrected locations ($n = 12$ turtles) within the North Atlantic subtropical gyre during the southbound migration. The Longhurst [45] region boundaries are represented by thin black lines. Tags were deployed on adult females (A,B,E,), adult males (C,D,F,G,H) and subadults (I,J,K,L,M,N,O).

Life history patterns

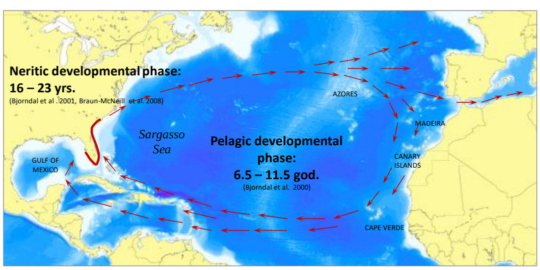
- the neritic developmental pattern
  - *Natator depressus*
- the oceanic developmental pattern
  - *Dermochelys coriacea*
  - *Lepidochelys olivacea* (E Pacific populations)
- the oceanic-neritic developmental pattern
  - all other sea turtle species

Oceanic-neritic developmental pattern

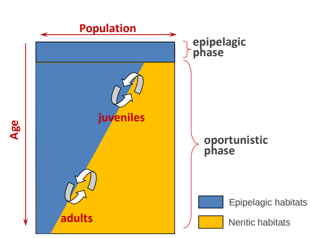


Trans-Atlantic developmental migrations

(Carr 1987. Conserv. Biol.)



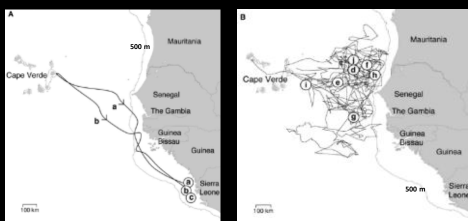
C. caretta: Relaxed life history model



- Casale et al. 2008. *Mar. Ecol. Prog. Ser.*

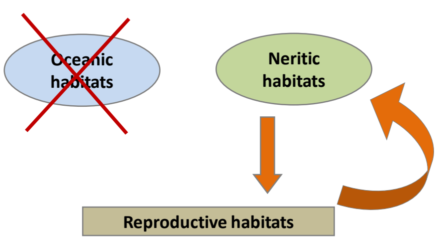
Loggerhead sea turtle

- satellite telemetry: high ecological plasticity in behavior and habitat use

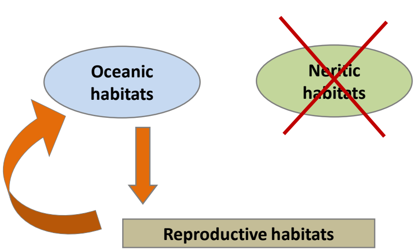


Hawkes et al. 2006. Curr. Biol. 16: 990-995.

Neritic developmental pattern



Oceanic developmental pattern



Nest site fidelity

- flipper tagging (ID code)
- filopatry (females)

→ isolated reproductive populations

- mtDNA haplotypes

Ecological Applications, 8(1), 1998, pp. 1-7
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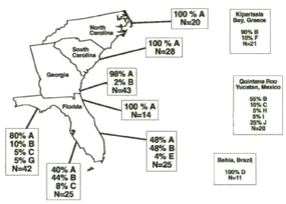
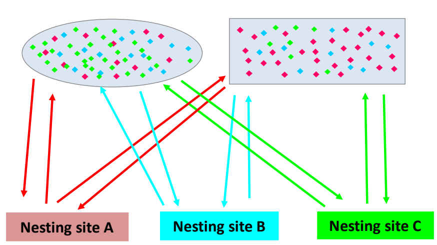
TRANSATLANTIC DEVELOPMENTAL MIGRATIONS OF LOGGERHEAD SEA TURTLES DEMONSTRATED BY mtDNA SEQUENCE ANALYSIS

ALAN B. BOLTEN,[1,2] KAREN A. BJORNDAL,[1,3] HELEN R. MARTINS,[3] THOMAS DELLINGER,[4] MANUEL J. BISCOITO,[7] SANDRA E. ENCALADA,[8] AND BRIAN W. BOWEN[1,2]



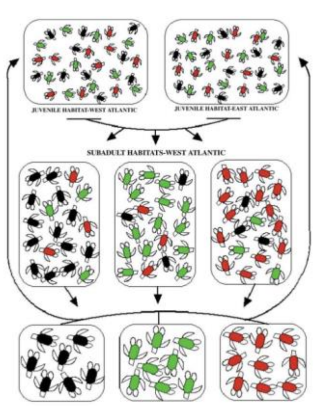
Population structure in marine habitats

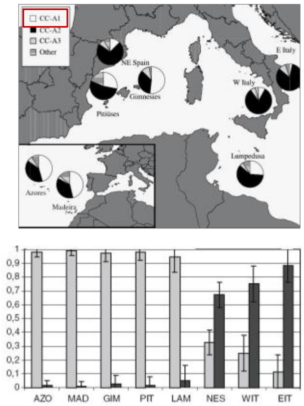


Conservation implications of complex population structure: lessons from the loggerhead turtle (*Caretta caretta*)

B. W. BOWEN,* A. L. BASS,† L. SOARES‡ and R. J. TOONEN*

Hawaii Institute of Marine Biology, University of Hawaii, P.O. Box 1346, Kaneohe, HI 96744, USA, †Department of Biology, University of South Florida, 4202 E. Fowler Ave, Tampa, FL 33620, USA, ‡Projeto TAMAR-IBAMA, Caixa Postal 2219, Rio Vermelho, Salvador, Bahia 40210-970, Brazil





Haplotype Frequency(%)

CC-A1:
- endemic for Atlantic

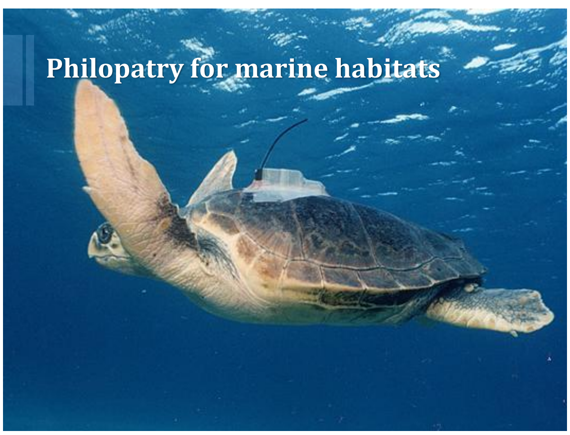
CC-A2, CC-A3:
- shared, Atlantic and Mediterranean

↓

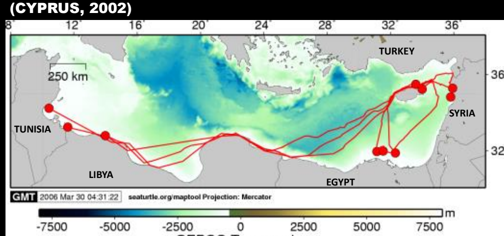
Mixed Stock Analysis

ATLANTIC ORIGIN

MEDITERRANEAN ORIGIN



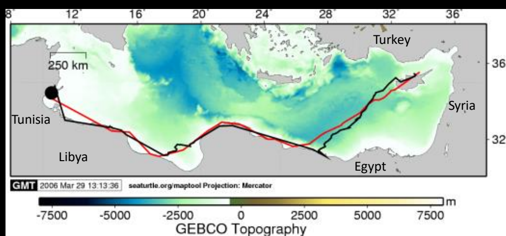
LOGGERHEAD TURTLES – POST-REPRODUCTIVE MIGRATIONS (CYPRUS, 2002)



Broderick et al. 2007. Proc. R. Soc. B 274: 1533-1538.

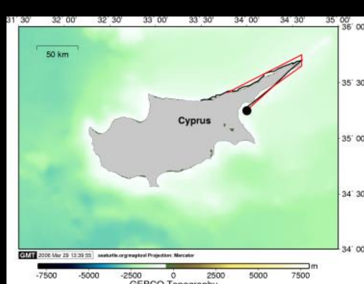
60-90 days

LOGGERHEAD TURTLE 1 – 2002 and 2005

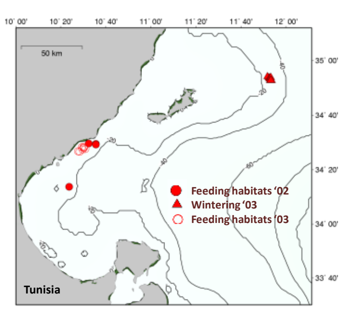


Broderick et al. 2007. Proc. R. Soc. B 274: 1533-1538.

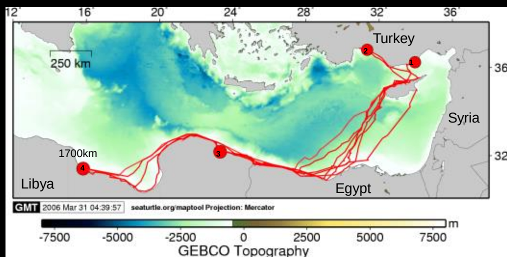
LOGGERHEAD TURTLE 2 – 2001 and 2003



Fidelity for marine habitats



GREEN TURTLES – CYPRUS, 1998, 1999

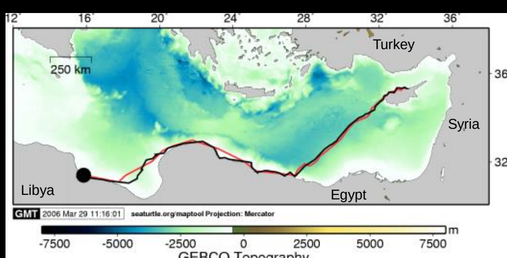


LC 1,2,3,A, <5km/hr

40-60 days

Broderick et al. 2007. Proc. R. Soc. B 274: 1533-1538.

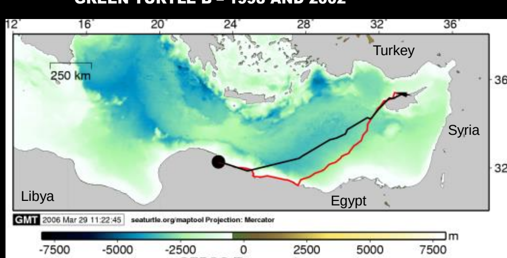
GREEN TURTLE A – 1999 AND 2004



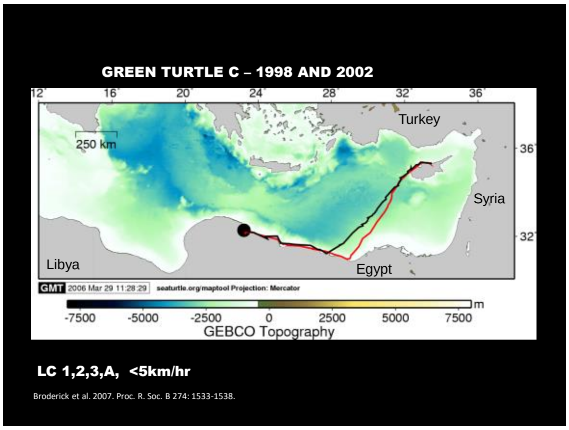
LC 1,2,3,A, <5km/hr

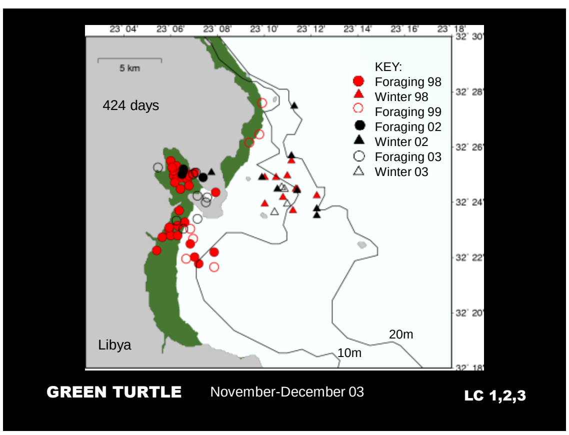
Broderick et al. 2007. Proc. R. Soc. B 274: 1533-1538.

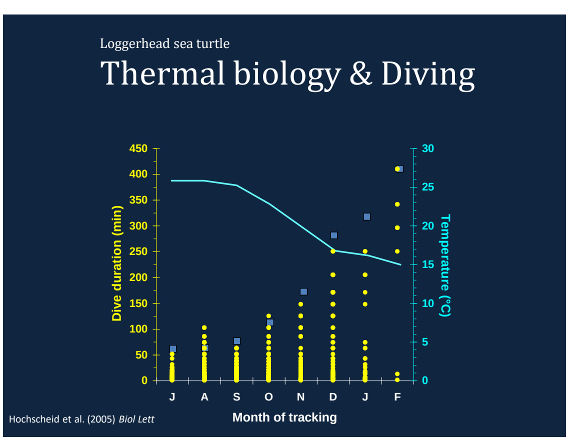
GREEN TURTLE B – 1998 AND 2002



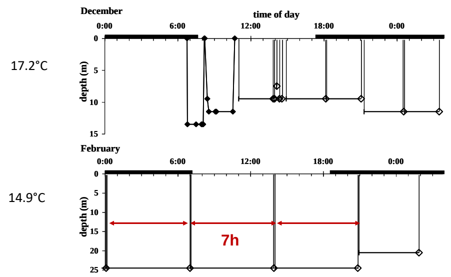
Broderick et al. 2007. Proc. R. Soc. B 274: 1533-1538.

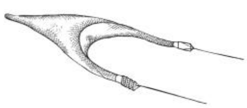

GREEN TURTLE C – 1998 AND 2002
Turkey
Syria
Libya
Egypt
250 km
GEBCO Topography
LC 1,2,3,A, <5km/hr
Broderick et al. 2007. Proc. R. Soc. B 274: 1533-1538.


5 km
424 days
KEY:
Foraging 98
Winter 98
Foraging 99
Foraging 02
Winter 02
Foraging 03
Winter 03
Libya
20m
10m
GREEN TURTLE
November-December 03
LC 1,2,3

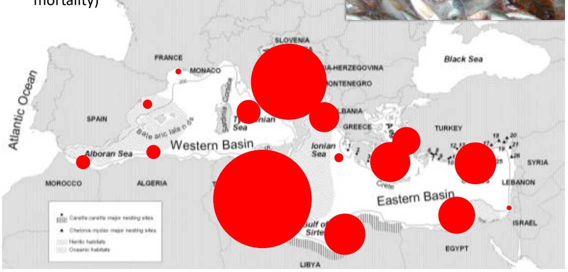

Loggerhead sea turtle
Thermal biology & Diving
Dive duration (min)
Temperature (°C)
J
A
S
O
N
D
J
F
Month of tracking
Hochscheid et al. (2005) Biol Lett

Diving profiles - winter





- Bottom-trawl bycath of sea turtles in the Mediterranean: < 30.000 captures/yr (≈ 20% mortality)

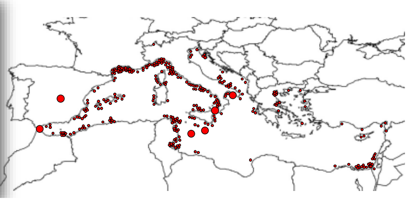


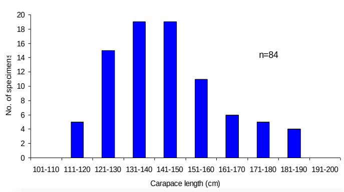
Sea turtles in the Mediterranean

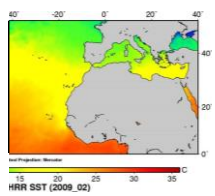
Family / Species regional	Regional IUCN status
fam. Cheloniidae (želve)	
loggerhead turtle/glavata kareta (*Caretta caretta*)	LC (2015)
green turtle/orjaška črepaha (*Chelonia mydas*)	n/a
hawksbill turtle/karetna želva (*Eretmochelys imbricata*)	(rare visitor)
kemps ridley (*Lepidochelys kempii*)	(rare visitor)
fam. Dermochelyidae (usnjače)	
leatherback turtle / usnjača (*Dermochelys coriacea*)	n/a (vagrant)

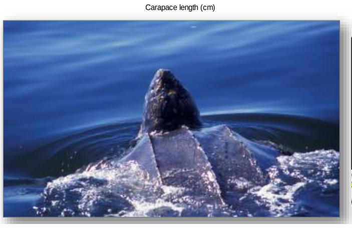
Dermochelys coriacea

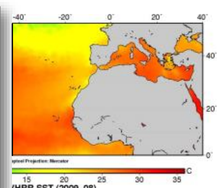
- 411 records btw. 1520-2001 (Casale et al. 2003. Herp J)
- Longline Catch Rate *Mediterranean* : *Atlantic* = 1:60 – 1:200 (Casale et al. 2003. Herp J; Watson et al. 2005. Can J Fish Aquat Sci)







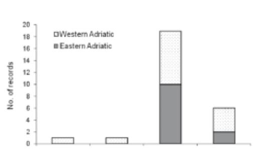




VIE ET MILIEU - LIFE AND ENVIRONMENT, 2008, 58 (3/4): 237-241

NEW DATA ON THE OCCURRENCE OF LEATHERBACK TURTLES *DERMOCHELYS CORIACEA* IN THE EASTERN ADRIATIC SEA

B. LAZAR[1,2*], L. LIPEJ[3], D. HOLCER[1,2], V. ONOFRI[4], V. ŽIŽA[5], P. TUTMAN[6], E. MARČELJA[7], N. TVRTKOVIĆ[1]



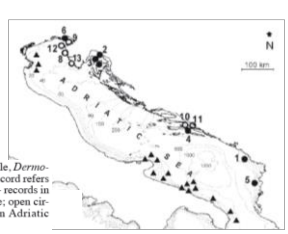
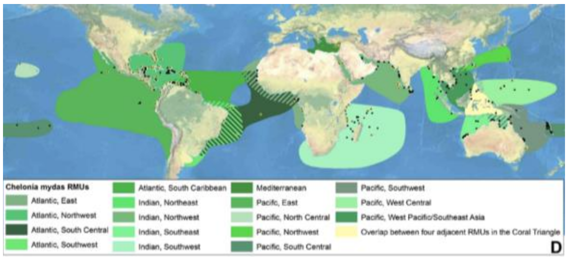


Fig. 1. – Distribution of recoveries of leatherback turtle, *Dermochelys coriacea*, in the Adriatic Sea. Number of the record refers to respective record numbers (N°) in Table I. (circles - records in the eastern Adriatic; filled circles-data from literature; open circles - new data; triangles - records in the western Adriatic according to Casale *et al*. 2003).

Green sea turtle (*Chelonia mydas*)

Regional Managemen Units (RMUs)

Wallace et al. 2010. PlosONE 5(12)

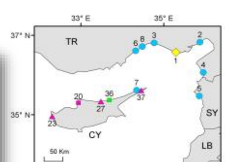


Green sea turtle (*Chelonia mydas*)

Reproductive populations

Casale et al. 2018. *Endang. Spec. Res.*

- Major green turtle rookeries: Turkey, Cyprus and Syria
  - 13 major nesting locations
- Mean nest number change since 2000: +47.1%
- Regional IUCN status: not existent
- *Conservation-dependent*



Major nesting sites in the Mediterranean (nests $yr^{-1} \geq 10$ and nests $km^{-1} \geq 2.5$).

Diversity and Distributions, (Diversity Distrib.) (2015) 1–10

BIODIVERSITY RESEARCH

Migratory corridors and foraging hotspots: critical habitats identified for Mediterranean green turtles

K. L. Stokes[1], A. C. Broderick[1], A. F. Canbolat[2], O. Candan[3], W. J. Fuller[1,4,5], F. Glen[6], Y. Levy[7,8], A. F. Rees[1,9], G. Rilov[7,10], R. T. Snape[1,5], I. Stott[11], D. Tchernov[7] and B. J. Godley[1*]

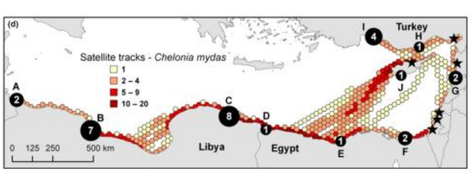
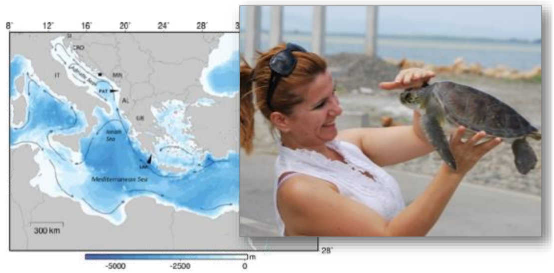


Figure 2 Post-nesting green turtle satellite tracks from (a) Cyprus (*n* = 22), (b) Turkey (*n* = 8), (c) Syria (*n* = 1) and Israel (*n* = 3), and (d) migratory corridor density map (conclusive tracks only; *n* = 29). Numbers indicate the number of individuals tracked conclusively to each foraging ground. In panel b, tracks in blue are from the first year of tracking (2004) and those in black are from the second year of tracking (2005). Colour in panel d is indicative of the number of satellite tracks that pass through each hexagonal grid cell. Movements to secondary foraging grounds after prolonged stays in initial foraging grounds are not included. Letters in (d) indicate the following foraging grounds: A – Libya/Tunisia border, B – Gulf of Sirte, C – Gulf of Bomba, D – Gulf of Salum, E – Gulf of Arab, F – Lake Bardawil, G – Tripoli, Lebanon, H – Erdemli, I – Gulf of Antalya, J – Episkopi Bay.

HERPETOLOGICAL JOURNAL, Vol. 14, pp. 143-147 (2004)

THE PRESENCE OF THE GREEN SEA TURTLE, *CHELONIA MYDAS*, IN THE ADRIATIC SEA

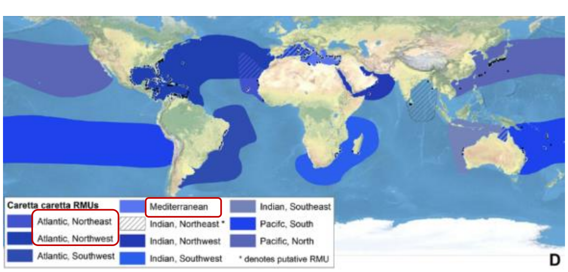
BOJAN LAZAR[1,2], PAOLO CASALE[3], NIKOLA TVRTKOVIC[1], VALTER KOZUL[4], PERO TUTMAN[4], AND NIKŠA GLAVIC[4]



Loggerhead sea turtle (*Caretta caretta*)

Regional Managemen Units (RMUs)

Wallace et al. 2010. PlosONE 5(12)

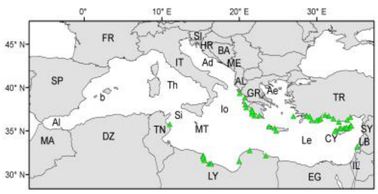


Loggerhead sea turtle (*Caretta caretta*)

Reproductive populations

Casale et al. 2018. *Endang. Spec. Res.*

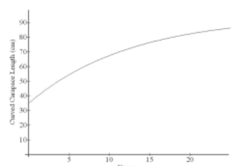
- 96% of clutches laid in Greece, Turkey, Libya and Cyprus
  - 52 major nesting sites
- The mean nest number change since 2000: +26.4%
- Regional IUCN status: LC, *conservation-dependent* (MTSG 2015)



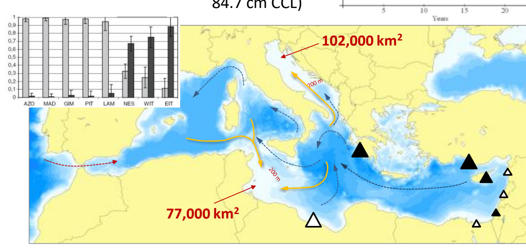
Major nesting sites in the Mediterranean (nests $yr^{-1} \geq 10$ and nests $km^{-1} \geq 2.5$).

Mediterranean Sea:

Marine habitats

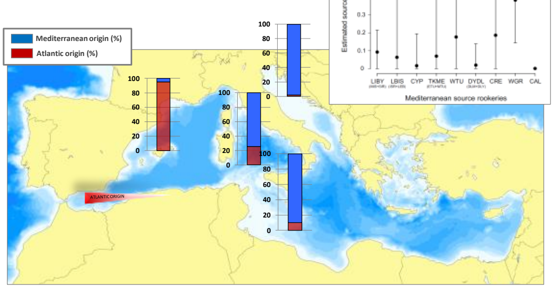


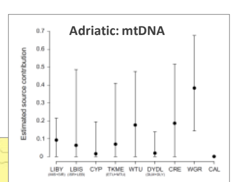
- Epipelaic phase: < 3 yrs (CCL < 30 cm)
- Neritic phase: 2.5 – 16/28 yrs (66.5-84.7 cm CCL)



Loggerhead sea turtle (*Caretta caretta*)

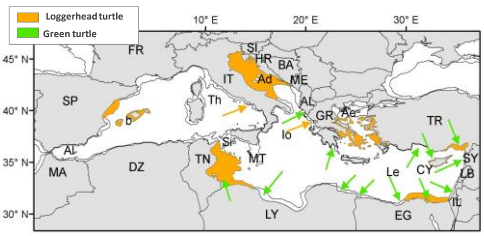
At-sea Biology





Neritic foraging and wintering sites

Casale et al. 2018. Endang. Spec. Res



Italian Journal of Zoology, 2014, 478–495
Vol. 81, No. 4, http://dx.doi.org/10.1080/11250003.2014.963714

Movement patterns of marine turtles in the Mediterranean Sea: a review

P. LUSCHI[1] & P. CASALE[2,3]

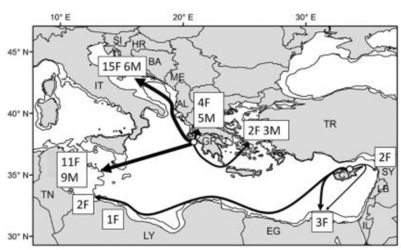
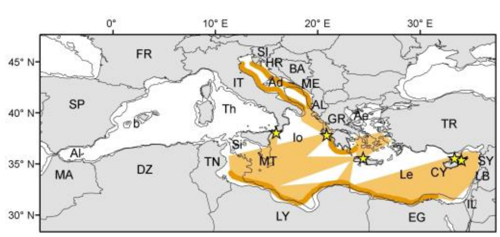


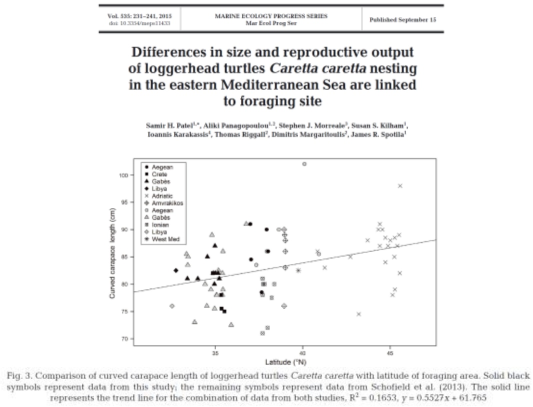
Figure 1. General migratory routes of the 63 adult loggerhead turtles satellite tracked in the Mediterranean (Table I) and showing type A movement pattern (Godley et al. 2008). Only groups of ≥ 10 animals released from the same site are considered, while releases of single individuals (Table I) are not shown. Arrows represent the approximate, general courses and do not show the actual reconstructed routes.

Loggerhead sea turtle (*Caretta caretta*)

Main known migratory corridors for adults

Casale et al. 2018. *Endang. Spec. Res*

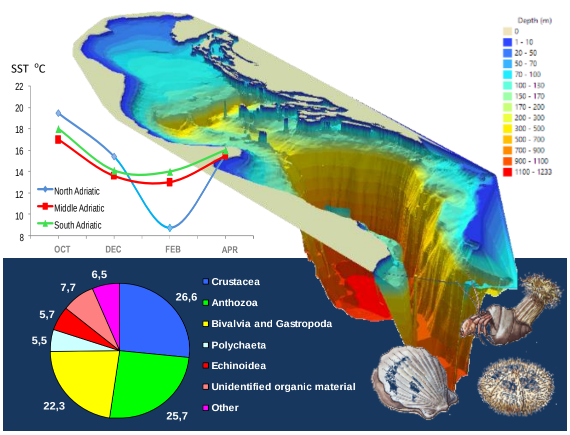



Vol. 535: 231–241, 2015
doi: 10.3354/meps11433
MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser
Published September 15

Differences in size and reproductive output of loggerhead turtles *Caretta caretta* nesting in the eastern Mediterranean Sea are linked to foraging site

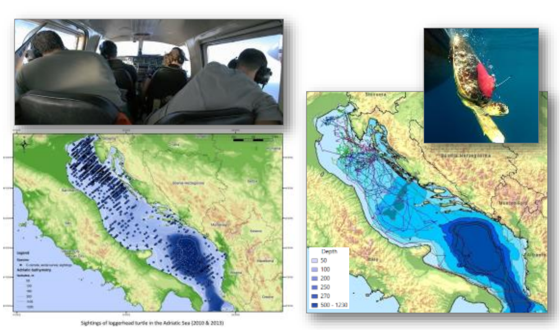
Samir H. Patel[1,*], Aliki Panagopoulou[1,2], Stephen J. Morreale[3], Susan S. Kilham[1], Ioannis Karakassis[4], Thomas Riggall[2], Dimitris Margaritoulis[2], James R. Spotila[1]

Fig. 3. Comparison of curved carapace length of loggerhead turtles *Caretta caretta* with latitude of foraging area. Solid black symbols represent data from this study; the remaining symbols represent data from Schofield et al. (2013). The solid line represents the trend line for the combination of data from both studies, $R^2 = 0.1653$, $y = 0.5527x + 61.765$



Caretta caretta

Summer distribution



Caretta caretta

Density and abundance

Abundance estimate

- *Not-corrected*: 27,000 (C.I. 24,000-31,000)
  - N Adriatic : 18,200 (C.I. 17,700-20,000)
- *Corrected* (13% *time-at-surface*): 213,000

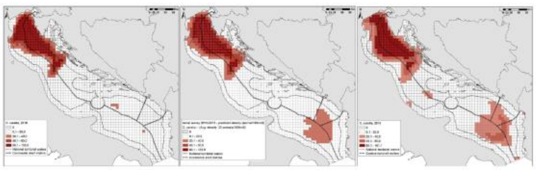
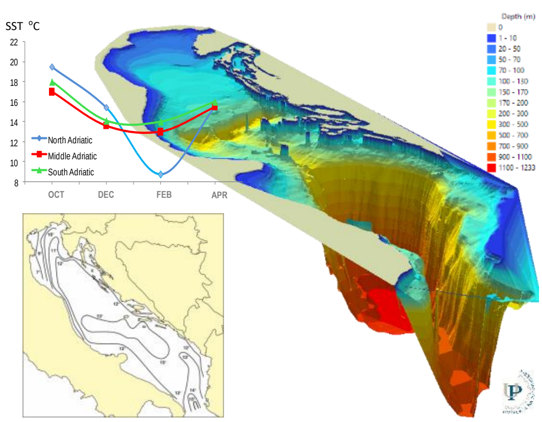
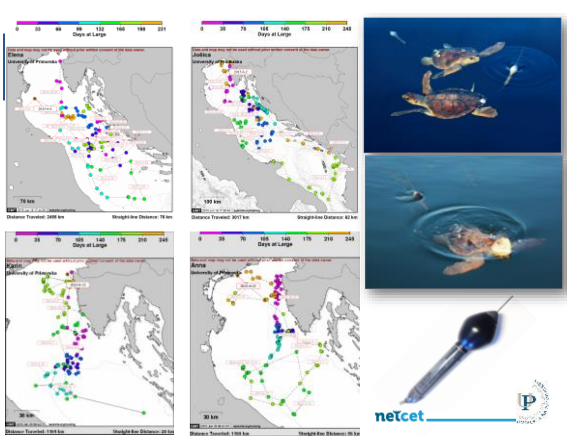


FIGURE 4 | Loggerhead turtle densities for the data from 2010 (left); 2010 + 13 (center), and 2013 (right). The scales represent below average and then twice, three times, and greater than three times average density (shades of dark red).

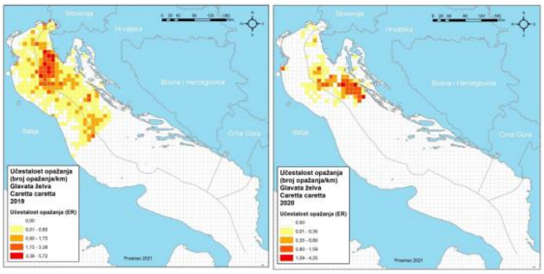




Aerial Surveys

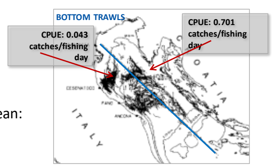
2019/2020

Summer 2019 Winter 2020



Adriatic Sea

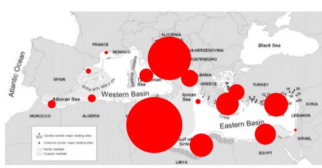
Trawl bycatch

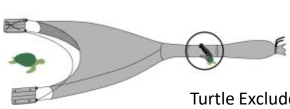


- Bottom-trawl bycath in the Mediterranean: < 30.000 captures/yr (≈ 20% mortality)
- Adriatic Sea: bycatch hot-spot
- peak during the "winter"

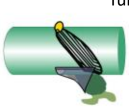
W Adriatic (Italy)
- 4,273 captures/year
- direct mortality: 9.4%
- potential mortality: 43.8%

E Adriatic (Croatia, Slovenia)
- 2,500 captures/year
- direct mortality: 7.5 – 12.5%
- potential mortality: 26.9%





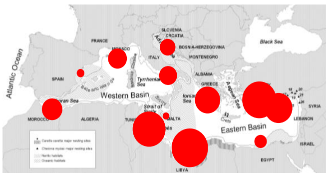
Turtle Excluder Device (TED)



Mediterranean Sea

Gill-net bycatch

- >20.000 captures/year
- Avg. mortality: 60%



Vol. 408: 241–250, 2010
doi: 10.3354/meps08577
MARINE ECOLOGY PROGRESS SERIES
Mar Ecol Prog Ser
Published June 3

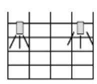
OPEN ACCESS

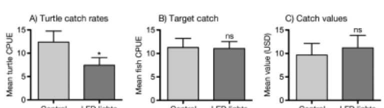
Developing visual deterrents to reduce sea turtle bycatch in gill net fisheries

John H. Wang[1,*], Shara Fisler[2], Yonat Swimmer[3]

[1]Joint Institute for Marine and Atmospheric Research, University of Hawaii at Manoa, 1125B Ala Moana Blvd., Honolulu, Hawaii 96814, USA
[2]Ocean Discovery Institute, 2211 Pacific Beach Drive, Suite A, San Diego, California 92109, USA
[3]NOAA Fisheries, Pacific Islands Fisheries Science Center, 501 W. Ocean Blvd., Suite 4200, Long Beach, California 90802, USA

Life EuroTurtles





FISH and FISHERIES

FISH and FISHERIES, 2011, 12, 299–316

Sea turtle by-catch in the Mediterranean

Paolo Casale[1,2]

[1]Department of Biology and Biotechnologies 'Charles Darwin', University of Rome 'La Sapienza', Viale dell'Università 32, 00185 Roma, Italy; [2]WWF Italy, Via Po 25c, 00198 Roma, Italy

Table 2 Sea turtle by-catch associated mortality estimates and turtle size by fishing gear. Small scale: capture or deaths ascribed to small-scale fisheries (boats <12 m). Captures per year from Table 1 rounded at the nearest thousand. See text for mortality rates (MRs) and sizes.

	Captures/year			Deaths/year		
	Total	Small scale	MR (%)	Total	Small scale	CCL cm mean (range)
Bottom trawl	39 000		20	7800	0	53.9 (22–87)
Pelagic longline	57 000	25 000	30	17 100	7500	50.5 (20.5–79.5)
Demersal longline	13 000	13 000	40	5200	5200	51.8 (27.1–72)
Set net	23 000	23 000	60	13 800	13 800	48.8 (21–80)
Total	132 000	61 000		43 900	26 500	

CCL, curved carapace length.

Intentional catch

- food, artifacts, antagonism...
- Algeria, Egypt, France, Greece, Morocco, Tunisia, Turkey, Cyprus, Syria

SCIENCE ADVANCES | RESEARCH ARTICLE Mazaris *et al., Sci. Adv.* 2017;**3**:e1600730 20 September 2017

MARINE CONSERVATION

Global sea turtle conservation successes

Antonios D. Mazaris,[1] Gail Schofield,[1,2] Chrysoula Gkazinou,[1] Vasiliki Almpanidou,[1] Graeme C. Hays[2*]

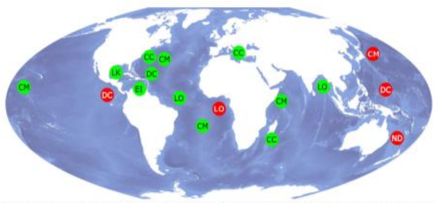
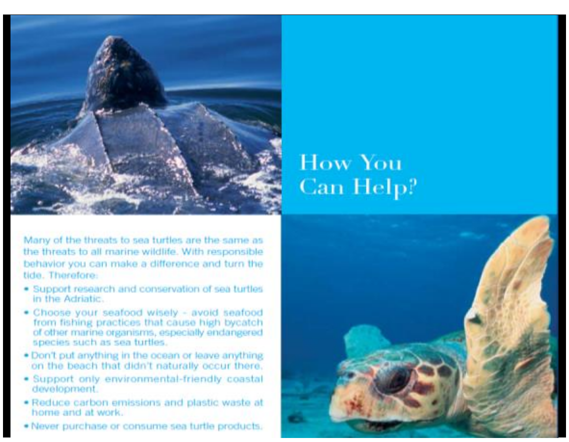


Fig. 2. Trends in the nesting abundance of sea turtles integrated within RMUs. Plot symbols reflect species, colors reflect upward (green) or downward (red) trends, and symbol size represents mean growth rate. CC, *C. caretta* (loggerhead turtle); CM, *C. mydas* (green turtle); DC, *D. coriacea* (leatherback sea turtle); EI, *E. imbricata* (hawksbill turtle); LK, *L. kempii* (Kemp's ridley); LO, *L. olivacea* (olive ridley); ND, *N. depressus* (flatback turtle).

Ecological roles of sea turtles

- problem: low populations (mostly)
  - ecological extinction?
- Habitat maintainance
  - green turtle grazing: increase in productivity of seagrass beds
  - hawksbils: "removing" sponges from coral reefs
- Energy transfer
  - from marine habitats → nesting beaches (input of nutrients, stabilization of dunes
  - food source for numerous predators
- Maintainance of trophic dynamic in marine food webs
  - Leatherbacks: top jellyfish predator (preventing further shift in species dominance from fish to jellyfish)
- Bioturbation – role in nutrient cycling
- Sea turtles: habitat for some species



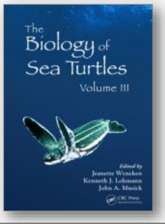
Readings

Vol. 36: 229–267, 2018 | ENDANGERED SPECIES RESEARCH Endang Species Res | Published August 1

REVIEW

Mediterranean sea turtles: current knowledge and priorities for conservation and research

Paolo Casale[1,*], Annette C. Broderick[2], Juan Antonio Camiñas[3,4], Luis Cardona[5], Carlos Carreras[6], Andreas Demetropoulos[7], Wayne J. Fuller[8], Brendan J. Godley[2], Sandra Hochscheid[9], Yakup Kaska[10], Bojan Lazar[11,12], Dimitris Margaritoulis[13], Aliki Panagopoulou[13,14], ALan F. Rees[2,13], Jesús Tomás[15], Oguz Türkozan[16]



10 Predators, Prey, and the Ecological Roles of Sea Turtles

Michael R. Heithaus

SCIENCE ADVANCES | RESEARCH ARTICLE

MARINE CONSERVATION

Global sea turtle conservation successes

Antonios D. Mazaris,[1] Gail Schofield,[1,2] Chrysoula Gkazinou,[1] Vasiliki Almpanidou,[1] Graeme C. Hays[2*]