Comparative/Ecological Biomechanics

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Biomechanics is the study of the structure, function and systems of biological organisms using the methods of mechanics. When people talk about biomechanics as a general term, it often refers to kinesiology, ergonomy, and is closely related to sports science and medical science. Animal locomotion is another classical and popular topic in Biomechanics, which is often linked to biomimetics. However, biomechanics has a much broader realm, from the mechanical aspects of tiny cell organelles, to tissues/organs, to living organisms, and to certain ecosystems. The most interesting topics in biomechanics for me are comparative biomechanics and ecological biomechanics.

Comparative biomechanics and ecological biomechanics are two different but very closely related areas. They both mostly study non-human organisms, investigate the adaptations of the organisms and gain insights into evolution. The comparative biomechanics emphasizes more on the comparison across different organisms or over evolutionary time, and the ecological biomechanics focuses more on the interactions between organisms (e.g., predator-prey interactions), or with the physical environment (e.g., wind, waves). A lot of researchers and laboratories combine both aspects, and they are treated as one subject in our later discussions.

1 What does it study?

Comparative/ecological biomechanics studies the physics of how organisms perform mechanical functions such as locomotion (including running, swimming, jumping, flying, etc.), feeding, interacting with each other, or withstanding environmental forces, as well as the interplay between mechanical design, neural control, and behavioral responses to other organisms and physically variable environments [1, 2]. Multiple levels of biological systems are investigated, including tissues, organs and organ systems (e.g., legs, wings, circulatory systems, olfactory organs), whole organisms, and their interactions with others and the environment. [1] The biomechanical adaptations across different taxa and over evolutionary time is also often considered.

Example questions are: How does a tree transport water? How does a fungus spread spores? How does an earthworm move? How does a mantis shrimp crack a shell? How does a bat spot prey? How does a shark feed by suction? How does a beaver build a dam? How does a moth withstand strong winds? How does the mechanical design of mussels shape the ecosystem on a wave-swept shore.

Intertidal biomechanics is one of the popular topics, and of my most interest (so far) in this area. The intertidal zone of wave-swept rocky shores are among the most dynamic, physically stressful environment with great biodiversity. Thus, it“has been (and will continue to be) a model system for the development and testing of ecological theories” [3]. Example researches are: fatigue in mollusc shells, swimming and feeding of microscopic organisms in turbulence, recruitment of larvae into benthic habitats; response to extreme events.

2 What techniques/knowledge does it use?

The main physics knowledge used in this area is solid and fluid mechanics, sometimes electromagnetism and material physics. Modern physics like relativity, or quantum theories are rarely needed. The main biological knowledge required are physiology, neurobiology, developmental biology, ecological and evolutionary theories, sometimes molecular biology and genetic information.

Experimental (laboratory and field) and computational techniques are both needed. As in most science studies, computational techniques like mathematical modeling, statistical analysis are always very important.

It is quite often that engineering skills are required during experimental works. For example, building a laboratory simulations of the turbulence, or a specific device for measuring some mechanical properties (e.g. the dynamometers designed by Denny Lad to measure wave forces [4]). Also, a wide range of imaging techniques are used in this area. For example, microcinematography, slow-motion capturing, digital particle image velocimetry (DPIV), X-ray reconstruction of moving morphology, and fluoromicrometry (tracking radio-opaque markers in soft tissues).

3 What are the applications?

The most direct application of comparative/ecological biomechanics is to"elucidate basic physical rules that can be applied to different kinds of organisms about how body structure affects mechanical function in nature" [2]. And we can better understand how evolution happens and how ecosystems develop. Thus we may be able to better predict how global climate change may affect organisms, how organisms will cope with it and find useful indicators of a certain physical aspects of the environment. Those indicators can be the population of a species, or one physiological 'parameter' of an organism, and so on.
Another important application is to inspire industrial design, e.g. biomimetics, biorobotics. The physical principles learned in organisms can provide"new solutions to basic engineering problems that nature has evolved" [3]. It can also help us better understand human body, as well as giving hints to the design of orthotics, prosthesis and other clinical/sports engineering.

4 Personal Comments

The attractive things in this area are:

- It can involve field/laboratory study and theoretical/computational work at the same time, indicating a good "work-work" balance and may not so easy to get boring :D
- Evolutionary theories are always very fascinating; ecological theories are sometimes also interesting :p
- It is not medical oriented, looking more into different non-human organisms, can appreciate the magic of nature in a broader view.

The concerns are:

- It requires quite comprehensive knowledge and skills, as it needs both field/laboratory and theoretical/computational techniques, and often engineering as well. (It may actually be my strength? Because I usually like to learn different stuff and exploring different areas, but quite bad at digging deep into just one thing and be persistent:(.)
- All the fancy, magical topics in physics are not so related anymore, like quantum mechanics, electromagnetisms, relativities, etc.. T-T Biomechanics basically only need classical mechanics.

5 Further Readings [1]

Books (sort by relevance):

- Denny, Mark. *Ecological Mechanics: Principles of Life's Physical Interactions.* Princeton University Press, 2017. (Available online from VUW library)
- Vogel, Steven. *Comparative biomechanics : life's physical world.* Princeton University Press, 2003. (Available in Kelburn library of VUW.)
- Koehl, Mimi, and Anne Rosenfeld. *Wave-Swept Shore: The Rigors of Life on a Rocky Coast.* University of California Press, 2006. (Available in VUW onilne library.)
- Denny, Mark. *Biology and the Mechanics of the Wave-Swept Environment.* Princeton University Press, 1988. (Available in VUW onilne library.)

Laboratories (sort by topics, intertidal - other marine - insect - bird or other flight - other):

- Denny Lab at Stanford University, USA, for intertidal biomechanics: https://dennylab.stanford.edu/.

[1] I only used English to search. There may be better books/labs in other languages/countries.

- Koehl Lab at University of California, Berkeley, USA, for intertidal and other ecological/evolutionary biomechanics: http://ib.berkeley.edu/labs/koehl/labresearch.html.
- Carrington Lab at University of Washington, USA, for intertidal biomechanics: https://depts.washington.edu/nucella/.
- Pepper Lab at University of Puget Sound, USA, for intertidal biomechanics and other biological fluid mechanics: https://drpepperlab.com.
- Patek Lab at Duke University, USA, for mechanics of movements in mantis shrimp and ants, and arthropod acoustic communication: https://pateklab.biology.duke.edu.
- Standen Lab at University of Ottawa, Canada, for marine vertebrate biomechanics: http://www.standenlab.com/research/.
- Mehta Lab at The University of California, Santa Cruz, USA, for biomechanics about marine elongate limbless/reduced-limbs vertebrates: http://mehta.eeb.ucsc.edu/.
- Lauder Lab at Harvard University, USA, for fish biomechanics and fish robotics: http://www.people.fas.harvard.edu/~glauder/.
- Mountcastle Lab at Bates College, USA, for insect flight: http://www.andrewmountcastle.org/.
- Sane Lab at National Center or Biological Science, India, for insect flight: https://www.ncbs.res.in/faculty/sane.
- Dickinson Lab at California Institute of Technology, USA, for fruit fly biomechanics: https://dickinsonlab.caltech.edu/.
- Federle Lab at University of Cambridge, UK, for insect biomechanics and surface attachment mechanisms in animals: https://www.zoo.cam.ac.uk/research/groups/insect-biomechanics
- Taylor & Thomas Lab at University of Oxford, UK, for flight biomechanics: https://flight.zoo.ox.ac.uk/.
- Altshuler Lab at University of British Columbia, Canada, for hummingbird biomechanics: http://altshuler.zoology.ubc.ca/index.html.
- Biewener Lab at Harvard University, USA, for avian and mammalian locomotion: https://biewenerlab.oeb.harvard.edu/.

References

[1] Comparative biomechanics. http://biophysics.berkeley.edu/comparative-biomechanics/. Accessed on Mar 11, 2018.

[2] Koehl lab - koehl research interests. http://ib.berkeley.edu/labs/koehl/resint.html. Accessed on Mar 12, 2018.

[3] Overview | denny lab. https://dennylab.stanford.edu/about/overview. Accessed on Mar 13, 2018.

[4] Dynamometers: Measuring wave forces | denny lab. https://dennylab.stanford.edu/dynamometers-measuring-wave-forces. Accessed on Mar 13, 2018.