Context-dependent individual behavioral consistency in Daphnia

The understanding of consistent individual differences in behavior, often termed "personality," for adapting and coping with threats and novel environmental conditions has advanced considerably during the last decade. However, advancements are almost exclusively associated with higher-order animals, whereas studies focusing on smaller aquatic organisms are still rare. Here, we show individual differences in the swimming behavior of Daphnia magna, a clonal freshwater invertebrate, before, during, and after being exposed to a lethal threat, ultraviolet radiation (UVR). We show consistency in swimming velocity among both mothers and daughters of D. magna in a neutral environment, whereas this pattern breaks down when exposed to UVR. Our study also, for the first time, illustrates how the ontogenetic development in swimming and refuge-seeking behavior of young individuals eventually approaches that of adults. Overall, we show that aquatic invertebrates are far from being identical robots, but instead they show considerable individual differences in behavior that can be attributed to both ontogenetic development and individual consistency. Our study also demonstrates, for the first time, that behavioral consistency and repeatability, that is, something resembling "personality," is context and state dependent in this zooplankter taxa.
Hydrodynamic properties and distribution of bait downstream of a zooplankton trap

The flow regime around a chemically baited trap is crucial for the trapping process and distribution of bait downstream of traps. We measured the flow field downstream of a trap prototype in flume experiments and mapped the distribution of bait using laser induced fluorescence. The trap produced a downstream wake, where flow recirculated towards the trap, allowing organisms slower than the free stream flow to interact with the trap. The chemical tracer revealed an average gradient with increasing concentrations towards the trap. Finally, we evaluated trap performance in field experiments. Traps with internal light caught on average 3.4 times more zooplankton than traps without light in short-term deployments (1 h). Trapping efficiency could be manipulated by chemical stimuli; A piece of fish (Salmo salar) inside traps deterred 75% of the zooplankton compared to traps without fish. We conclude that the flow regime around a cylindrical trap may facilitate trapping and that combined stimuli modalities may allow higher selectivity. The effective radius of the trap will depend on the surrounding flow and will likely be small when flow-rate exceeds swimming speed of targeted organisms. Finally, we propose applications for selective traps in aquaculture and pest management.

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Adult and offspring size in the ocean: a database of size metrics and conversion factors

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Characteristic sizes of life in the oceans - from bacteria to whales

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Selective silicate-directed motility in diatoms
Diatoms are highly abundant unicellular algae that often dominate pelagic as well as benthic primary production in the oceans and inland waters. Being strictly dependent on silica to build their biomineralized cell walls, marine diatoms precipitate $240 \times 10^{12}$ mol Si per year, which makes them the major sink in the global Si cycle. Dissolved silicic acid (dSi) availability frequently limits diatom productivity and influences species composition of communities. We show that benthic diatoms selectively perceive and behaviourally react to gradients of dSi. Cell speed increases under dSi-limited conditions in a chemokinetic response and, if gradients of this resource are present, increased directionality of cell movement promotes chemotaxis. The ability to exploit local and short-lived dSi hotspots using a specific search behaviour likely contributes to micro-scale patch dynamics in biofilm communities. On a global scale this behaviour might affect sediment-water dSi fluxes and biogeochemical cycling.

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Solid phase extraction and metabolic profiling of exudates from living copepods

Copepods are ubiquitous in aquatic habitats. They exude bioactive compounds that mediate mate finding or induce defensive traits in prey organisms. However, little is known about the chemical nature of the copepod exometabolome that contributes to the chemical landscape in pelagic habitats. Here we describe the development of a closed loop solid phase extraction setup that allows for extraction of exuded metabolites from live copepods. We captured exudates from male and female Temora longicornis and analyzed the content with high resolution LC-MS. Chemometric methods revealed 87 compounds that constitute a specific chemical pattern either qualitatively or quantitatively indicating copepod presence. The majority of the compounds were present in both female and male exudates, but nine compounds were mainly or exclusively present in female exudates and hence potential pheromone candidates. Copepodamide G, known to induce defensive responses in phytoplankton, was among the ten compounds of highest relative abundance in both male and female extracts. The presence of copepodamide G shows that the method can be used to capture and analyze chemical signals from living source organisms. We conclude that solid phase extraction in combination with metabolic profiling of exudates is a useful tool to develop our understanding of the chemical interplay between pelagic organisms.

The sex specific metabolic footprint of Oithona davisae

In pelagic copepods, the group representing the highest animal abundances on earth, males and females have distinct morphological and behavioural differences. In several species female pheromones are known to facilitate the mate finding process, and copepod exudates induce changes in physiology and behaviour in several phytoplankton species. Here we tested whether the sexual dimorphism in morphology and behaviour is mirrored in the exudate composition of males and females. We find differences in the exudate composition, with females seemingly producing more compounds. While we were able to remove the sex pheromones from the water by filtration through reverse phase solid phase extraction.
columns, we were not able to recover the active pheromone from the solid phase.

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**Adult and offspring size in the ocean over 17 orders of magnitude follows two life history strategies**
Explaining variability in offspring vs. adult size among groups is a necessary step to determine the evolutionary and environmental constraints shaping variability in life history strategies. This is of particular interest for life in the ocean where a diversity of offspring development strategies is observed along with variability in physical and biological forcing factors in space and time. We compiled adult and offspring size for 407 pelagic marine species covering more than 17 orders of magnitude in body mass including Cephalopoda, Cnidaria, Crustaceans, Ctenophora, Elasmobranchii, Mammalia, Sagittoidea, and Teleost. We find marine life following one of two distinct strategies, with offspring size being either proportional to adult size (e.g., Crustaceans, Elasmobranchii, and Mammalia) or invariant with adult size (e.g., Cephalopoda, Cnidaria, Sagittoidea, Teleosts, and possibly Ctenophora). We discuss where these two strategies occur and how these patterns (along with the relative size of the offspring) may be shaped by physical and biological constraints in the organism’s environment. This adaptive environment along with the evolutionary history of the different groups shape observed life history strategies and possible group-specific responses to changing environmental conditions (e.g., production and distribution).

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Inter- and intra-specific diurnal habitat selection of zooplankton during the spring bloom observed by Video Plankton Recorder

Diel vertical migration (DVM) is a common behavior adopted by zooplankton species. DVM is a prominent adaptation for avoiding visual predation during daylight hours and still being able to feed on surface phytoplankton blooms during night. Here, we report on a DVM study using a Video Plankton Recorder (VPR), a tool that allows mapping of vertical zooplankton distributions with a far greater spatial resolution than conventional zooplankton nets. The study took place over a full day–night cycle in Disko Bay, Greenland, during the peak of the phytoplankton spring bloom. The sampling revealed a large abundance of copepods performing DVM (up during night and down during day). Migration behavior was expressed differently among the abundant groups with either a strong DVM (euphausiids), an absence of DVM (i.e., permanently deep; ostracods) or a marked DVM, driven by strong surface avoidance during the day and more variable depth preferences at night (Calanus spp.). The precise individual depth position provided by the VPR allowed us to conclude that the escape from surface waters during daytime reduces feeding opportunities but also lowers the risk of predation (by reducing the light exposure) and thereby is likely to influence both state (hunger, weight and stage) and survival. The results suggest that the copepods select day and night time habitats with similar light levels (~10–9 μmol photon s−1 m−2). Furthermore, Calanus spp. displayed state-dependent behavior, with DVM most apparent for smaller individuals, and a deeper residence depth for the larger individuals.

Low fertilization rates in a pelagic copepod caused by sexual selection?

We studied female fertilization status in North Sea summer populations and laboratory cultures of the marine copepod Temora longicornis and found fractions of fertilized females in both field and laboratory populations that were much smaller (<50%) than predicted by a theoretical model that assumes random mating. Such low fertilization rates are normally related to environmental factors such as poor food or low densities, which we could not confirm in our experiment. Male density was negatively related to fertilization rate, and a large fraction of males did not mate in laboratory incubations. We therefore suggest that sexual selection, through mate choice or male–male competition could account for low fertilization rates of females in populations of pelagic copepods during some periods of the year.
Non-consumptive effects of predator presence on copepod reproduction: insights from a mesocosm experiment

Reproduction in planktonic animals depends on numerous biotic and abiotic factors. One of them is predation pressure, which can have both direct consumptive effects on population density and sex ratio, and non-consumptive effects, for example on mating and migration behaviour. In copepods, predator vulnerability depends on their sex, motility pattern and mating behaviour. Therefore, copepods can be affected at multiple stages during the mating process. We investigated the reproductive dynamics of the estuarine copepod Eurytemora affinis in the presence and absence of its predator the mysid Neomysis integer in a mesocosm experiment. We found that the proportion of ovigerous females decreased in the presence of predators. This shift was not caused by differential predation as the absolute number of females was unaffected by mysid presence. Presence of predators reduced the ratio of males to non-ovigerous females, but not by predation of males. Our combined results suggest that the shift from ovigerous to non-ovigerous females was unaffected by mysid presence. Presence of predators reduced the ratio of males to non-ovigerous females, but not by predation of males. Nauplii production was initially suppressed in the predation treatment, but increased towards the end of the experiment. The proportion of fertilized females was similar in both treatments, but constantly fell behind model predictions using a random mating model. Our results highlight the importance of non-consumptive effects of predators on copepod reproduction and hence on population dynamics.
The chemical ecology of copepods

An increasing number of studies show the importance of chemical interactions in the aquatic environment. Our understanding of the role of chemical cues and signals in larger crustaceans has advanced in the last decades. However, for copepods, the most abundant metazoan zooplankton and essential for the functioning of the marine food web, much is still unknown. We synthesize current knowledge about chemical ecology of copepods including foraging, survival and reproduction. We also compile information on the sensory apparatus and new analytical approaches that may facilitate the identification of signal molecules. The review illustrates the importance of chemical interactions in many aspects of copepod ecology and identifies gaps in our knowledge, such as the lack of identified infochemicals and electrophysiological studies to confirm the function of sensory structures. We suggest approaches that are likely to further our understanding of the role of chemical interactions in the pelagic ecosystem.

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Female choice in eutrophied waters - an individual based model of sticklebacks

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Optimal mate choice patterns in pelagic copepods

The importance of sexual selection for the evolution, dynamics and adaptation of organisms is well known for many species. However, the topic is rarely studied in marine plankton, the basis of the marine food web. Copepods show behaviors that suggest the existence of sexually selected traits, and recent laboratory experiments identified some selected morphological traits. Here, we use a ‘life history-based’ model of sex roles to determine the optimal choosiness behavior of male and female copepods for important copepod traits. Copepod females are predicted to be choosy at population densities typically occurring during the main breeding season, whereas males are not. The main drivers of this pattern are population density and the difference in non-receptive periods between males and females. This suggests that male reproductive traits have evolved mainly due to mate competition. The model can easily be parameterized for other planktonic organisms, and be used to plan experiments about sexual selection.
Habitat change influences mate search behaviour in three-spined sticklebacks

Mate choice is one of the main mechanisms of sexual selection, with profound implications for individual fitness. Changes in environmental conditions can cause individuals to alter their mate search behaviour, with consequences for mate choice. Human-induced eutrophication of water bodies is a global problem that alters habitat structure and visibility in aquatic ecosystems. We investigated whether changes in habitat complexity and male cue modality, visual or olfactory, influence mate search behaviour of female three-spined sticklebacks, Gasterosteus aculeatus. We allowed gravid females to search for mates in experimental pools that contained two nesting males and one social female, under low and high structural complexity (created from green Plexiglas sheets), with access to either visual or olfactory cues of the individuals. We found increased habitat complexity reduced the number of visits to nesting males, while a switch from visual to olfactory cues reduced the time spent searching for males, the number of visits to nesting males, the time spent evaluating males, and the relative time spent associating with males rather than females. Thus, females decreased mate searching and mate evaluation in the absence of visual stimulation. This reduced the rate of mate encounters and probably also the opportunity for choice. Our results show that changes in habitat structure and visibility can alter female mate searching, with potential consequences for the opportunity for sexual selection.

The smell of virgins: mating status of females affects male swimming behaviour in Oithona davissae

Many copepod species rely on pheromone cues to find partners. Some parasitic and benthic copepod males are able to distinguish between females of different reproductive states. Here, we demonstrate that the swimming activity and velocity of males of a pelagic copepod, Oithona davissae, increases in the presence of virgin when compared with mated females and that the cue is waterborne. The ability to distinguish between virgin and mated females may reduce male mortality during mate search and the cost related to mating behaviour (precopula) in both sexes. We estimate that at realistic population densities the ability of males to distinguish between virgin and mated females saves them several hours per day of dangerous and energetically expensive fast female tracking.