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Tracking the behaviour of large fish in the open ocean. Matt Hansen, Alicia Burns and Jens Krause describe 10 years of billfish research

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Ten years ago, 2012, in Cancun Mexico, a collaborative effort involving members of three different research groups set out to address a number of basic questions regarding billfish biology. Our team consisted of researchers from three different research groups in animal behaviour (Jens Krause, Humboldt University Berlin, Germany), biomechanics (Paolo Domenici, Italian National Research Council) and fish physiology (John Steffensen, University of Copenhagen). Billfishes have long fascinated fishermen and members of the general public alike, and the fact that they could suddenly be observed at close quarters in the wild created an opportunity to address long-standing questions, such as "What do they use the bill for?", "Are they really the fastest fishes in the oceans" and "What, if any, function does the sailfish sail serve?"

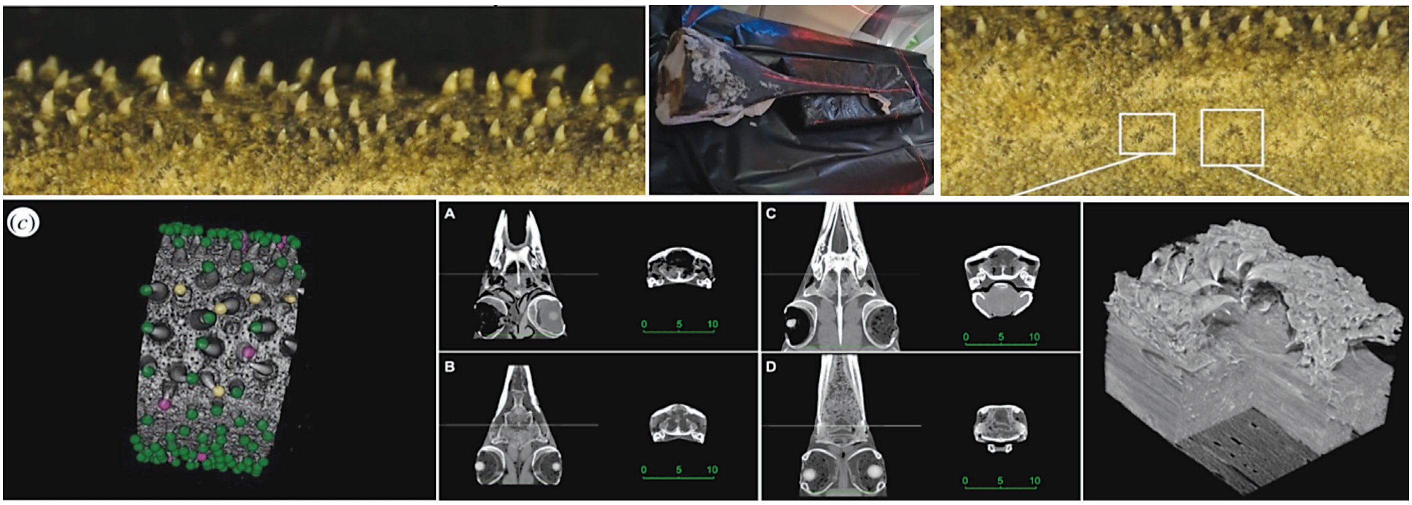
For the members of the Domenici and Steffensen labs it was normal to work offshore. However, for those of us more accustomed to shallow rivers and temperature-controlled labs working on guppies and sticklebacks, it was a major re-adjustment to film large predators while snorkeling in the open ocean for long periods. Sea-sickness, bad weather, periods of extreme heat and cold, were just some of the daily challenges. But these were quickly forgotten when we were able to make the first high-speed recordings of billfish attacking fish schools in the wild.

Immediately one of our first questions was answered – sailfish, *Istiophorus platypterus*, use their bill during attacks on fish schools to slash and tap at fish (Domenici *et al.* 2014). This behaviour had the combined effect of helping catch prey for themselves, whilst also injuring prey to facilitate capture by their groupmates (Herbert-Read *et al.* 2016; Krause *et al.* 2017). Then, using a combination of accelerometers, high-resolution sonar and physiological measurements, we established that sailfish are unlikely to exceed swimming speeds of 40 km/hr (Marras *et al.* 2015) – debunking the long-held myth that they are the fastest fish in ocean at 100 km/hr. However, much like goldfish and their 3 second memory, this claim about being the fastest fish turned out to be one of those zombie-claims which repeatedly comes back to life after being debunked. To this day we are continually asked by journalists whether it is true that sailfish are the fastest fish in the sea. In addition to observing the use of the bill, we were also able to record high resolution video showing very clearly the sail of sailfish being deployed only immediately before the sailfish attacked a school, suggesting ➤

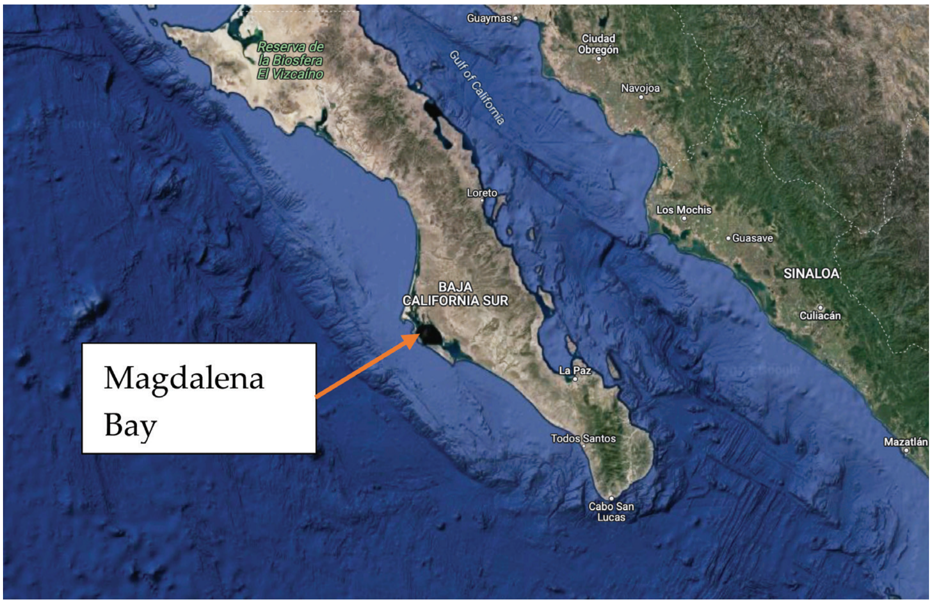
Sailfish (copyright Rodrigo Fryscione Wyssman)

it too plays a role in hunting and attack behaviour. Indeed, once the sail goes up the swinging motion of the head (and bill) is greatly reduced – a highly adaptive trait – because the sailfish often inserts its bill into the fish school where it goes unnoticed until it starts slashing at the fish (Svendsen *et al.* 2016). Finally, given that sailfish usually carry out a single horizontal slash to the right or left to capture fish, we investigated potential handedness and found that indeed some individuals showed strong preferences for one side and that this is correlated with capture success (Kurvers *et al.* 2017). These initial 3yrs of fieldwork were highly rewarding and were made possible by Rodrigo Fryscione Wyssman and his company (Solo Buceo) under whose captaincy and guidance we conducted these trips and we extend our gratitude to him.

After 2015, sailfish sightings became less frequent around Cancun, but we fortunately found a new location off Magdalena Bay, Baja California Sur where similarly to the sailfish, striped marlin (*Kajikia audax*) were reliably found at the surface hunting fish schools. Here we started a collaboration with our Mexican colleagues at CICIMAR in La Paz to study the mechanisms used by marlin to herd and attack schools of Pacific sardines. This time, two additional teams from theoretical biology (Romanczuk and Krause S labs) joined the collaboration to model the billfish attacks and identify mechanisms underlying



Billfish bill morphology (copyright Breuker, Zaslansky, Müller, Hansen and Hildebrandt)



Drone shot of striped marlin group pursuit (copyright Alicia Burns)

the predator-prey interactions. We also received support from colleagues (Zaslansky, Müller and Hildebrandt labs) who have access to scanning facilities involving computed tomography and micro-computed tomography to study various aspects of the structure of the bills. These multi-disciplinary efforts made it possible to integrate billfish behaviour and morphology which showed that striped marlin primarily dash through fish schools unlike sailfish which swim at the same speed as their prey and carefully insert their bill for aimed slashes (Hansen *et al.* 2020). The bills turn out to be covered in micro-teeth which in sailfish are regularly replaced and particularly long laterally whereas in marlin - which show less bill use in fish captures – they are mostly broken. Other insights concerned the existence of an oil gland at the base of the bill which was first discovered by John Videler *et al.* (2016) in swordfish, *Xiphias gladius*, and which we showed also to be present in sailfish, striped marlin and blue marlin, *Makaira nigricans* (Dhellemmes *et al.* 2020). Its function has been discussed in connection with reduced drag and antibacterial properties. We also found a completely new structure on the bill of sailfish – tiny pits filled with even tinier teeth - which we called "lacunae rostralis" (Häge *et al.* 2021). The function of these pits is unknown, and so our detective work continues, but we speculate that they may contain sensory organs and relate to the unique way the sailfish can insert their bill into the prey school. Most recently, our behavioural work with striped marlin quantified for the first time how a group of pelagic predators divides a school of prey fish between themselves (Hansen *et al.* 2022) and we have also started to explore the nature of striped marlin's relationship with other top predators, such as California sea lions (*Zalophus californianus*) (Hansen *et al.* 2023).

Our main project for the future is focused on the group-hunting of the striped marlin and the way they collectively chase fish schools in the open ocean. The use of drones makes it possible to obtain the trajectories of the fish schools and the marlin that surround them, and we hope to make some novel contributions to the literature on group-hunting in this context. First efforts show that an intermediate group size of about 10 billfish at a fish school seems to provide the highest capture efficiency for these predators (Herbert-Read *et al.* 2016). Further, working with our new colleagues at CICIMAR La Paz, whose work covers everything ➤

from plankton to ocean currents, has already provided invaluable context and local knowledge to this fascinating system.

References (many names omitted to save space)
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Above, flying the drone from the boat – Matthew Hansen, Captain Carlos, Alicia Burns and Korbinian Pacher. Below, CICIMAR La Paz