Fachtagung "Lasermethoden in der Strömungsmesstechnik"
9. – 11. September 2008, Karlsruhe

FLOW MEASUREMENTS DURING THE MULTIMODAL COMMUNICATION IN HAWAIIAN BUTTERFLYFISH

STRÖMUNGSMESSUNG WÄHREND DER MULITMODALEN KOMMUNIKATION BEI HAWAIIANISCHEN SCHMETTERLINGSFISCHEN

Wolf Hanke[1], Kelly Boyle[2] & Timothy C. Tricas[2]
[1]Marine Science Center und Institut für Biowissenschaften der Universität Rostock, Albert-Einstein-Strasse 3, 18159 Rostock
[2]Hawai'i Institute of Marine Biology, Coconut Island, 46-007 Lilipuna Road, Kaneohe, HI 96744, USA
wolf.hanke@uni-rostock.de

Zusammenfassung

Schmetterlingsfische (*Chaetodontidae*) sind auffällige, farbenfrohe Bewohner tropischer und subtropischer Korallenriffe. Es gibt rund 120 Arten, von denen die meisten territorial sind und paarweise Reviere verteidigen. An den Reviergrenzen kommt es zu Droh- und Abwehrverhalten gegenüber den Nachbarn. Dieses Kommunikationsverhalten scheint multimodal zu sein, also mehrere Sinnessysteme zu integrieren. Die verschiedenen Verhaltensweisen, die von Art zu Art variieren, beinhalten meist ritualiserte Schwimmbewegungen, zum Beispiel schnelles auf den Gegner Zuschwimmen, Davonschwimmen, Schütteln des Kopfes oder Körpers und gezielte Flossenschläge in einigem Abstand vom Gegner. Neben der optischen Komponente der meisten dieser Verhaltensweisen vermuten wir, dass auch die Wahrnehmung von Wasserströmungen eine Rolle spielt.
Einige Arten von Schmetterlingsfischen besitzen eine anatomische Verbindung zwischen der Schwimmblase und dem Seitenlinienorgan (die laterophyse Verbindung), was für Fische höchst ungewöhnlich ist und einer Erklärung bedarf. Andere Vertreter der gleichen Familie besitzen diese Verbindung nicht.
In dieser vorläufigen Studie haben wir die Wasserbewegungen, die bei der Kommunikation bei zwei Arten von Schmetterlingsfischen (*Chaetodon multicinctus* mit und *Forcipiger flavissimus* ohne laterophyse Verbindung) auftreten, mittels kontinuierlicher Hochgeschwindigkeits-PIV gemessen. Vier bis acht Diodenlaser (150 mW) beleuchteten eine Lichtschnittebene in einem Aquarium (80*40*40 cm). Die Partikelbilder wurden mit einer Hochgeschwindigkeitskamera IDT X-Stream XS3 (www.idtpiv.com) mit 500 Bildern pro Sekunde aufgenommen.
Die vorläufigen Ergebnisse zeigen deutliche Unterschiede zwischen den beiden Arten. Während bei *Chaetodon multicinctus* mehrfach Strömungen mit gezielten Flossenbewegungen erzeugt wurden und auf das Seitenlinienorgan eingewirkt haben, war dies bei *Forgipiger flavissimus* nicht der Fall. Während bei beiden Arten natuerlich ein Anteil visueller und akustischer Informationen an der Kommunikation anzunehmen ist, waren die produzierten Wasserströmungen zweifellos wahrnehmbar und zumindest bei *Chaetodon multicinctus* so stark, dass sie zur Einschätzung des Gegners erheblich beitragen können. Mit der Schwanzflosse erzeugte Wasserbewegungen scheinen auch geeignet, zusätzlich olfaktorische Botschaften zu übermitteln.

Summary

Butterflyfishes (Chaetodontidae) are conspicuous, colorful inhabitants of tropical and subtropical coral reefs. There are approximately 120 species, most of which live in pairs and defend their territories against intruders. At the territorial borders, they display threatening and aggressive behavior towards their neighbors. This communication appears to be multimodal, i.e. integrate different sensory systems. The behavior, which differs between species, usually contains various ritualized swimming moves, e.g. fast swimming towards the opponent, swimming away, shaking of head or body, and tail flicks in some distance from the opponent. Besides the optical signal component of most of these behaviors, we assume that the perception of water flow also plays a role.

Some species of butterflyfish have an anatomical connection between the swim bladder and the lateral line system (the laterophysic connection), which is totally unusual for fish and requires an explanation. Other species of the same family do not possess this connection.

In this preliminary study, we measured the water flow during the communication in two species of butterflyfish (*Chaetodon multicinctus* with and *Forcipiger flavissimus* without the laterophysic connection) using continuous high-speed PIV. Four to eight diode lasers (150 mW) illuminated the measurement plane in a glass tank (80 cm * 40 cm * 40 cm, L*W*H). Images were recorded with a high-speed camera IDT X-Stream XS3 (www.idtpiv.com) at 500 frames per second.

The preliminary results show distinctive differences between the two species. While *Chaetodon multicinctus* repeatedly produced vortex rings that hit the opponent, this was not observed in *Forcipiger flavissimus*. In both species, visual and acoustic stimuli must naturally be assumed to play a significant role in communication. But flow signals were undoubtedly perceivable in both species and in *Chaetodon multicinctus* were so strong that they should significantly contribute to the assessment of the strength of the opponent. In *Chaetodon multicinctus*, flow produced by the tail fin is also suitable to transport chemical signals.

Introduction

In butterflyfish (cf. Summary), recent experiments have founded a database of naturally occurring multimodal communication behavior in the wild, during which the optical and acoustical components have been recorded using video camcorders and hydrophones (Tricas et al., 2006). However, there have been no measurements of water flow so far, while both the communication behavior of the fish and their endorsement with sensory systems make a role of water flow in this context likely.

Figure 1 shows the two species investigated in this study, the multibanded butterflyfish *Chaetodon multicinctus* (left), and the longnose butterflyfish *Forcipiger flavissimus* (right). *Chaetodon* possesses a laterophysic connection, i.e. an anatomical connection between the swimbladder and the lateral line system (Webb and Smith, 1998), while *Forcipiger* does not.

In this study we used continuous high-speed PIV during the territorial behavior of these two species, providing the first flow measurements during communication behavior in fish.

Figure 1: Multibanded Butterflyfish *Chaetodon multicinctus* (left), and Longnose Butterflyfish *Forcipiger flavissimus* (right)

Material and methods

Fish were obtained from local dealers and mostly tested in pairs of one “resident fish” and one “intruder”, i.e. one fish was more accustomed to the experimental tank and/or was more confident and played the role of the owner of the territory (resident), while the other fish was introduced later and thus provoked an aggressive behavior.

In order to let the action take place within the PIV measurement area, the intruder was confined in a cage made of netting, and the resident was kept from swimming too close to the ground by a netting plateau (Figure 2). Four to eight continuous wave laser diodes (150 mW each, 650 nm) generated a light sheet in front of the cage and above the plateau (Fig. 2). A high-speed megapixel camera (IDT X-Stream XS3) with a Nikon 50 mm lens (f=1.2) filmed the light sheet from above through a glass plate that flattened the water surface. The camera was set to 500 frames per second, and to automated gain control. Seeding particles were Vestosint (Degussa Corporation, now Evonik Degussa Corporation, Parsippany, New Jersey) with a mean diameter of 45 µm. The field of view measured 140 mm * 112 mm.

A hydrophone (Reson) with a Cambridge Electronic Devices AD-Converter box was used to record acoustic events during the behavior using Spike2 software. A Sony camcorder (60 half frames per second) at the side of the tank, along with an additional Redlake MotionScope high speed camera (250 frames per second, not shown in Fig. 2), was used to capture the fish behavior and was fed a synchronization pulse from the IDT camera.

The behavior of interest can usually only be elicited a few times in each fish, after which a new acclimatization period of several hours can be necessary. The IDT camera with the given amount of memory can at 500 fps capture two seconds of behavior, after which several minutes are taken to transfer the data to the computer. The resident was therefore separated in the half of the tank far from the intruder’s cage using a sliding door before each trial. After admitting the resident to the intruder, it was crucial to closely monitor the behavior from behind a curtain using the camcorder signal, and end-trigger the IDT and Redlake cameras at the respective time. Trigger signals were additionally recorded on the acoustic hydrophone tracks.

In *Forcipiger*, this routine had to be altered in many cases, because the caged fish was too submissive to elicit aggression. In these cases, both fish were admitted to swim freely in the half of the tank with the PIV setup.

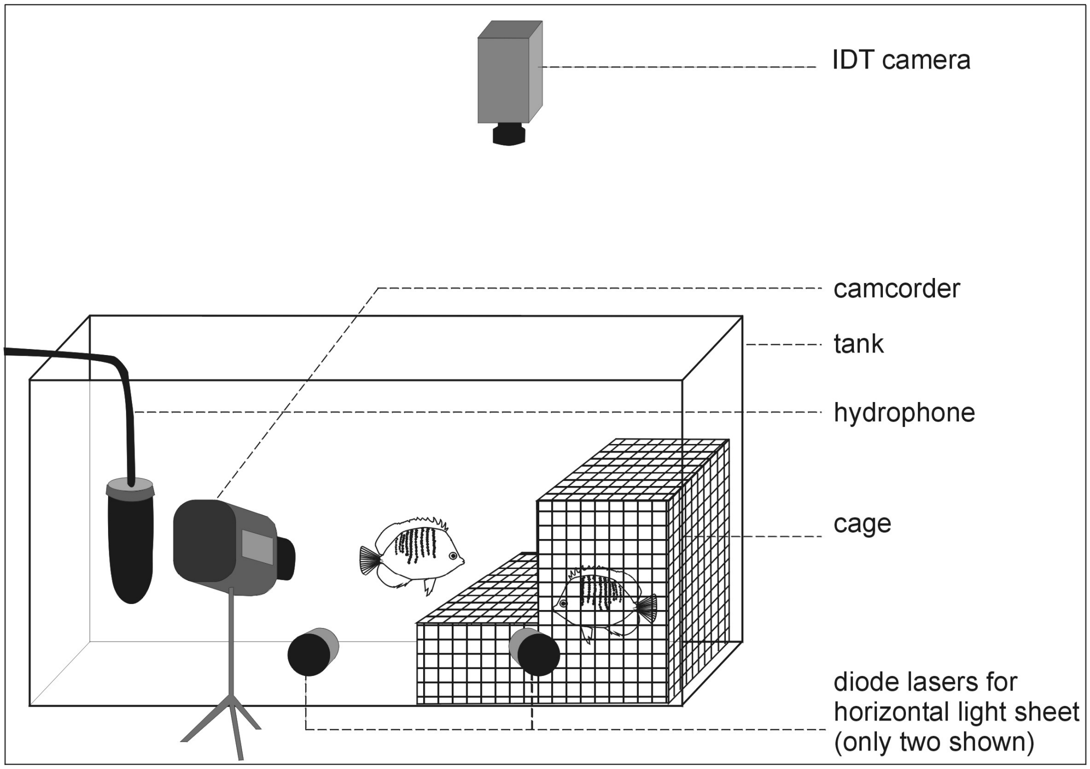

Figure 2: Experimental setup. Fish were filmed in a tank of 80cm*40cm*40cm (l*w*h). One fish, usually more confident from an extended period of acclimatization to the tank, played the role of the resident territory owner. The other one, the intruder, was inserted in a wide-meshed netting cage to confine the behavior to the area of the PIV measurements.

Results

Twenty-five sequences of *Chaetodon multicinctus* and ten sequences of *Forcipiger flavissimus* were recorded. Here we present examples from one measurement with *Chaetodon*, and one measurement with *Forcipiger*.

Figure 3 shows selected frames from a sequence with *Chaetodon multicinctus*. Images were taken with the IDT camera from above the tank, the light sheet was horizontal. Original data are presented along with the evaluated vector fields. Color code refers to vorticity. The resident swam by the cage with the intruder and stopped with the help of its pectoral fins (A), then performed a tail flick that sent a pressure wave and water flow towards the opponent (B to D). This high-amplitude tail flick (peak-to-peak equaling 40% of total body length) took only 126 ms and clearly had no locomotory purpose. The caged fish did not produce significant flow, it turned toward the opponent as it approached and went into lateral display then. The water moving from the resident's tail to the intruder, suitable to transport chemical messengers, took a comparatively long time of 0.6 seconds to reach the other fish. The water displacement that propagates with sound speed had a displacement amplitude several orders of magnitude below the body amplitude of the resident at the position of the intruder.

Figure 4 shows a frame from a measurement with *Forcipiger*. Left are the original data, right are the evaluated PIV vectors. In this case, the intruder performed an aggressive behavior known as the "head bob", an extremely fast vertical movement of the head. It is remarkable that very little flow is produced. Head bobs are frequently accompanied by acoustic signals; however, that was not the case in the recorded sequence.

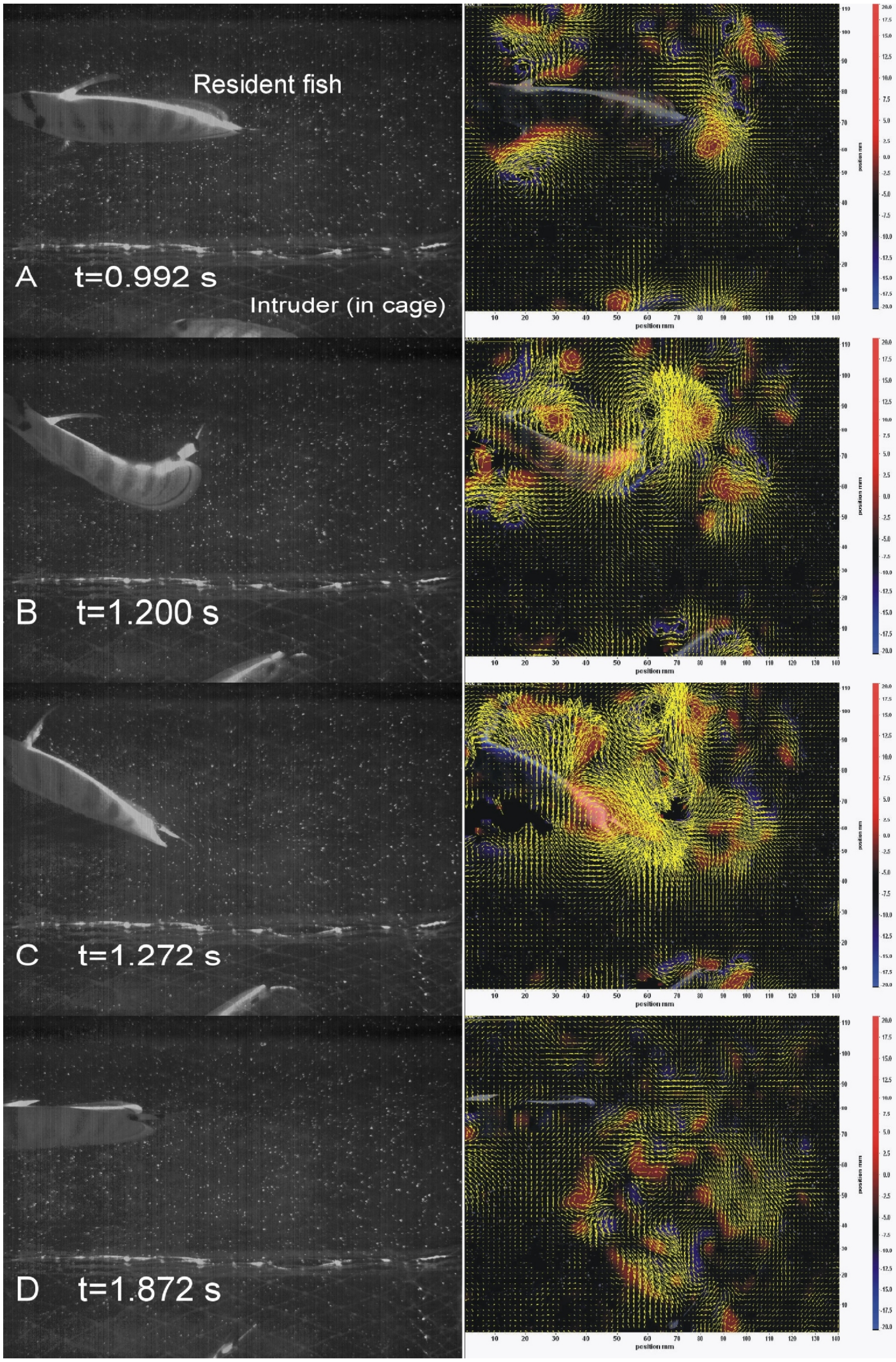

Figure 3: selected frames from a sequence with *Chaetodon*. Original data left, PIV evaluation right; time as indicated in the figure.

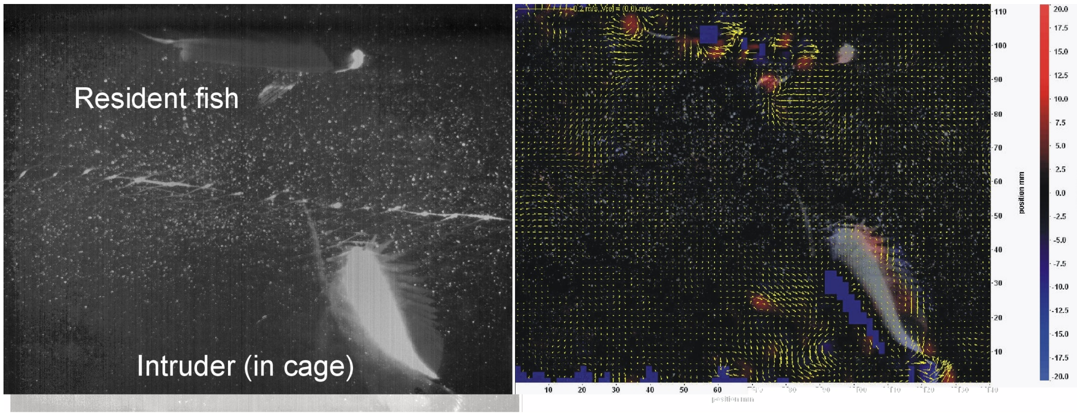

Figure 4: selected frame from a sequence with *Forcipiger*. Original data left, PIV evaluation right; color code indicates vorticity.

Discussion

This preliminary study successfully established a PIV setup that is suitable for observing natural behavior in fish, with no indication that the laser light might disturb the behavioral patterns or influence the fishes' motivation. Red laser light around 650 nm is much less visible to fish than other wavelengths (cf. also Hanke and Bleckmann, 2004), but it was here proven to work well with a CMOS camera at 500 fps even at low intensities. Higher intensity would be desirable to improve the depth of field. While communication in coral reef fish generally also contains visual and acoustic elements (Maruska et al., 2007), we found a production of water flow that can aid in the assessment of the properties of a territorial rival in several cases. The huge variability of this complex behavior requires further extensive measurements, preferably including Laser Doppler Anemometry.

Acknowledgements

We thank Dr. John Allen for supplying the high speed camera. This work was supported by a grant of the German Research Foundation (DFG) to WH, and by the Department of Zoology, University of Hawai'i at Manoa.

References

Hanke, W. and Bleckmann, H. (2004). The hydrodynamic trails of Lepomis gibbosus (Centrarchidae), Colomesus psittacus (Tetraodontidae) and Thysochromis ansorgii (Cichlidae) measured with Scanning Particle Image Velocimetry. *Journal of Experimental Biology* 207, 1585-1596.

Maruska, K. P., Boyle, K. S., Dewan, L. R. and Tricas, T. (2007). Sound production and spectral hearing sensitivity in the Hawaiian sergeant damselfish, *Abudefduf abdominalis*. *Journal of Experimental Biology* 210, 3990-4004.

Tricas, T. C., Kajiura, S. M. and Kosaki, R. K. (2006). Acoustic communication in territorial butterflyfish: test of the sound production hypothesis. *Journal of Experimental Biology* 209, 4994-5004.

Webb, J. F. and Smith, W. L. (1998). The laterophysic connection in chaetodontid butterflyfish: morphological variation and speculations on sensory function *Philosophical Transactions of the Royal Society B-Biological Sciences* 355, 1125-1129.