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Pelvic fin walking and punting behaviour of *Raja radula* Delaroche, 1809 observed in the Sea of Marmara

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Abstract

During a scuba dive in the Sea of Marmara, a mature female rough ray (*Raja radula* Delaroche, 1809) was observed performing pelvic fin walking and punting, a previously unrecorded rajid behaviour from the Mediterranean Sea. The underwater video footage was analyzed; the average distance travelled per punt was 0.40 disc length (DL) at an average speed of 0.26DL per second.

Keywords: Benthic locomotion, Rajiidae, crura, punting.

Introduction

The batoid fishes are a diverse group of cartilaginous fishes that inhabit a wide range of environments - from pelagic rays in the open ocean to benthic rays in freshwater rivers (Ebert & Compagno, 2007). To accommodate such variety in habitat, a range of locomotor modes are employed. A continuum of pectoral fin swimming has been described by Rosenberger (2001), which demonstrates that many of the pelagic rays employ an oscillatory motion whereas the more benthic rays employ undulatory motion. The most commonly observed swimming mode is the rajiform locomotion, where the thrust generation involves the passing of undulatory waves (from anterior to posterior) along the enlarged pectoral fins (Sfakiotakis *et al*., 1999; Rosenberger, 2001).

In addition to these forms of swimming locomotion, benthic locomotion has been described, which is performed primarily by the small pelvic fins. Initially, this form of locomotion was described in skates (Rajiformes: Rajoidei). This family of batoids exhibits pelvic fins that appear to be specialized for walking − alternating one fin at a time (Holst & Bone, 1993, Lucifora & Vassallo, 2002) – and punting − employing both fins synchronously to locomote along the seabed (Koester & Spirito, 2003). The rajid pelvic fin is bilobed; the anterior lobe is composed of a large cartilaginous skeletal element and robust musculature. However, since the initial discovery of pelvic fin locomotion, non-rajid batoids that do not possess specialized pelvic fins have been described walking and punting (Macesic & Kajiura, 2010), suggesting that pelvic fin locomotion is actually widespread.

Our knowledge to date about pelvic fin locomotion is primarily based on laboratory studies (Holst & Bone, 1993, Lucifora & Vassallo, 2002, Macesic & Kajiura, 2010), with the exception of one study that reported the use of punting by the little skate, *Leucoraja erinacea*, in the wild (Koester & Spirito, 2003). In order to understand how batoids employ this locomotion in the wild, more field observations are needed. In this study, we describe field observations and video recordings of pelvic fin locomotion in the rough ray, *Raja radula*, from the Sea of Marmara. This is a *sensu lato* endemic species of the Mediterranean Sea, which does not occur in the Black Sea, but possibly penetrates to the northern Moroccan coast of the Atlantic Ocean (Stehmann & Bürkel, 1984). The species was recently reported from the Sea of Marmara (Yaka & Yüce, 2006). Despite the single and recent record of *R. radula* in the Marmara region, it is more likely to be an overlooked species, since relatively abundant populations were observed during scuba dives and several local fishermen were able to confirm the existence of the rough ray in their catch within the last couple of decades. Biological information regarding the species is quite scarce and the IUCN categorizes *R. radula* as data deficient, both in global and local red lists (Abdul Malak *et al*., 2011).

Material and Methods

During a scuba dive at Büyükada island (north-eastern Sea of Marmara; 40°50’16”N–29°07’08”E) on 05 July 2011, a single female rough ray individual with a disc width of ca. 30 cm and 45 cm TL was observed and filmed (using a Sony Z-1 camera; 30 frames/sec) at a depth of 12–15 m. Rough rays mature at 33–36 cm TL (Capapé, 1974), indicating the observed specimen to be sexually mature. Habitat at the site consisted mainly of coarse sand with fragments of dead bivalve shells (i.e. *Mytilus galloprovincialis*), including abundant algae species such as *Ulva lactuca* (Chlorophyta) and *Ceramium rubrum* (Rhodophyta). The rough ray was lying motionless over the sandy bottom at first encounter, and then started walking and punting slowly over the substrate by the initial thrust of crura. Digital video recordings of this behaviour was taken for two minutes and frame by frame examination of the footage clearly revealed the propulsion and recovery phases of typical batoid pelvic fin walking and punting, as described by Lucifora & Vassallo (2002) and Koester & Spirito (2003), respectively.

Using ImageJ (NIH), we extracted the average distance travelled per punt (in disc length (DL)), speed per punt (DLs^{-1}), and frequency of punts during a continuous period of pelvic fin locomotion, following Macesic & Kajiura (2010).

Results

The pelvic fin cycle consists of a recovery phase and a propulsive phase: alternating the left and right fins when walking and in synchrony when punting. During walking, one of the pelvic fin lifts off the bottom and swiftly protrudes anteriorly (recovery phase, Figure 1A); the other fin firmly touches the bottom (propulsion phase, Figure 1B–I) as a complementary of the cyclic continuum. No vertical undulations of pectoral fins occurred during asynchronous movements of the pelvic fins and the species held its body parallel to the bottom. The ray performed a general form of punting: although the fins were not entirely synchronous, the offset was minimal, and therefore, still considered punting. However, the ray also performed a couple of forceful, completely synchronous punts especially when it confronted an obstacle, each followed by gliding for a short distance in which the pelvics were repositioned for the next thrust. The observed punting activity is not clearly visible in the recordings, where only the distal tips of the pelvic fins were visible since main crural motion occurs under the large pectoral fins. The rough ray eventually pushed off the bottom by a rapid powerful punt followed by the pectoral fin undulations.

Although the left and right pelvic fin movements were often slightly offset, the movements were generally considered synchronous punts. Because the pectoral disc prevents observation of the pelvic fins, only events that occurred continuously, and not at the start or end of locomotion were included. A cycle was assigned as from the full posterior extension of the pelvic fins to the next. Thirteen events were counted and analyzed from the film. Average distance travelled per punt was 0.40DL ± 0.036SE, at an average speed of 0.26DLs^{-1} ± 0.026SE. Overall, the skate travelled at a frequency of approximately 0.72 punts per second.

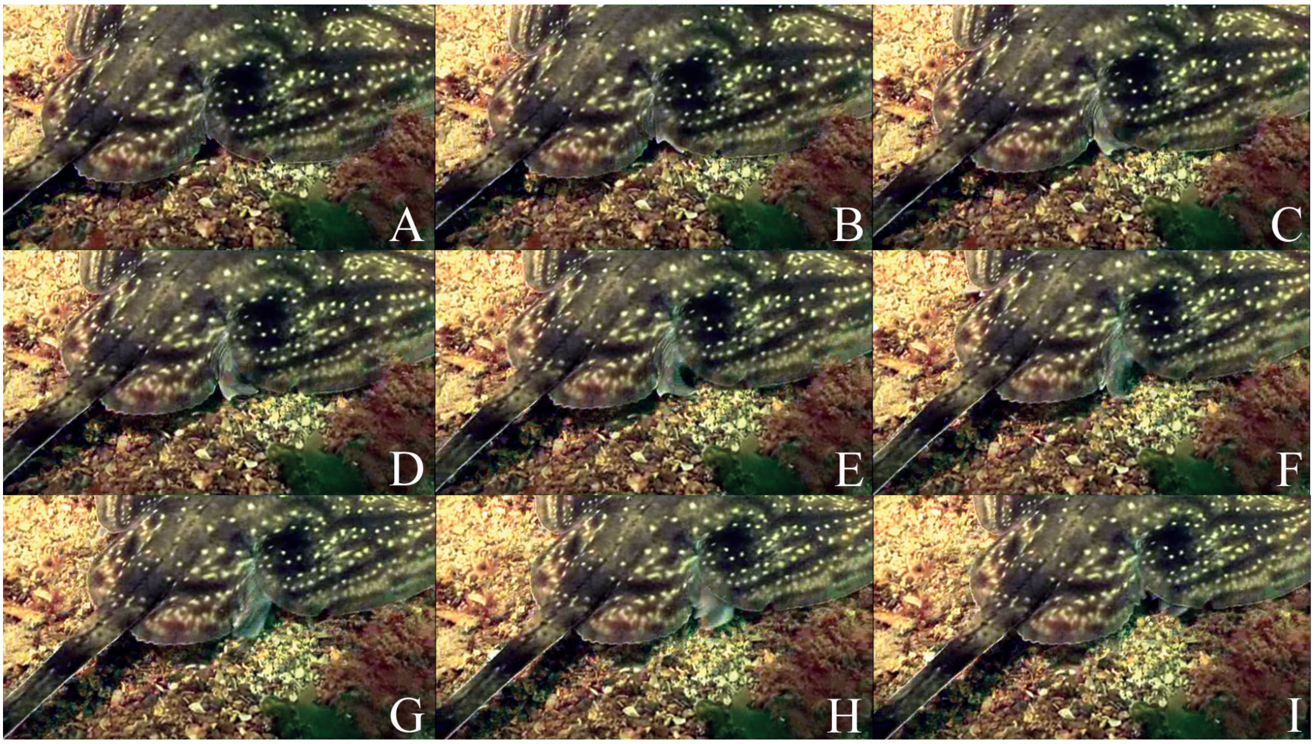

Fig. 1: Close-up view of the successive right pelvic fin steps of *Raja radula* from the Sea of Marmara. Each frame represents locomotion within 0.3 seconds of interval. (A: recovery phase; B – I: propulsion phase).

Discussion

Previous studies have pointed out the numerous advantages of pelvic fin walking and punting locomotion, which mostly relate to predator–prey interactions and swimming energetics. Since the pectoral fins remain motionless during these specialized movements, batoids create minimal mechanical disturbance in the water thus allowing undistorted electrosensing of potential preys, and facilitating localization of epifaunal and infaunal organisms (Koester & Spirito, 2003; Macesic & Kajiura, 2010). Moreover, pelvic fin locomotion provides a stealth mode for skates, due to the reduced water movements that increase the probability of an individual remaining undetected for long periods of time (Lucifora & Vassallo, 2002). Alternate actions of pelvics at low cruising speeds also enable the skates to conduct rapid manoeuvres, such as rotating the body to bring prey to their mouth (Holst & Bone, 1993). As regards energetics, it was theoretically shown that fish can swim more efficiently by alternating periods of accelerated swimming and powerless gliding (Weihs, 1974), and such intermittent swimming appears to be cheaper than steady locomotion (Videler & Weihs, 1982). The pelvic fin locomotion of *R. radula* observed in this study is probably not associated with prey detection, but more likely to be due to an avoidance behaviour where limb-like pelvics were first used to walk and then punt over the sandy substrate in order to move away from the source of disturbance – divers, in this case. A similar field observation was mentioned by Koester & Spirito (2003), where *Leucoraja erinacea* simultaneously punt and swim when followed by divers for a prolonged period of time or when divers approached the skate too closely.

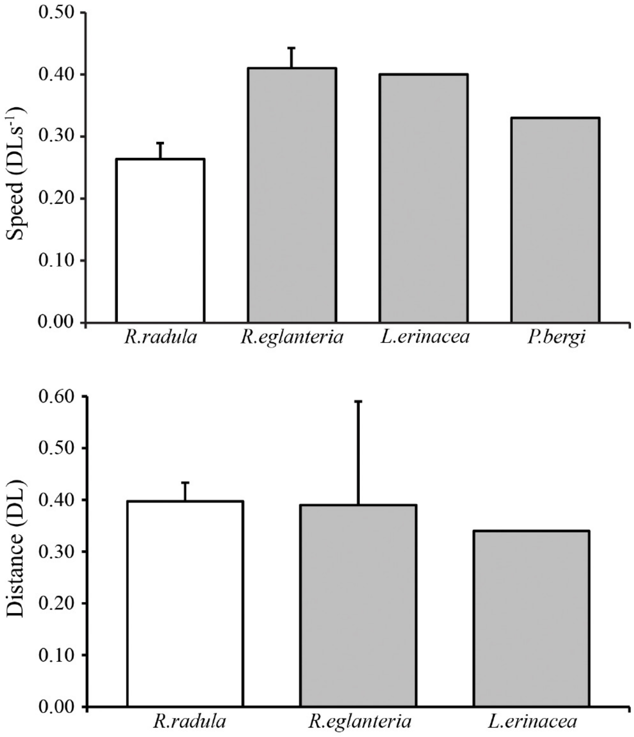

Fig. 2: Comparison of punting kinematic variables (distance: DL, speed: DL s^{-1}) for different batoid species (mean±SE). Sources of data: *Raja radula* (present study), *Raja eglanteria* (Macesic & Kajiura, 2010), *Leucoraja erinacea* (Koester & Spirito, 2003), *Psammobatis bergi* (Lucifora & Vassallo, 2002).

Average punting speed of *R. radula* was slightly lower than for other batoids such as *R. eglanteria* (0.41DLs^{-1} ± 0.024SE; Macesic & Kajiura, 2010), *L. erinacea* (0.33DLs^{-1}; Koester & Spirito, 2003) and *Psammobatis bergi* (0.40DLs^{-1}; Lucifora & Vassallo, 2002). In terms of average distance travelled per punt during each cycle, *R. radula* was quite consistent with the compared batoids (Fig. 2).

Behavioural studies on batoid locomotion both in the field and in captivity are scarce; existing information was obtained from a few species inhabiting certain ecosystems. Despite the absence of relevant data from the Mediterranean Sea, this study provides the first *in situ* observation of pelvic fin locomotion for the endemic *R. radula*, which advances our knowledge on specialized crural activity i.e. it is not restricted to definite geographical boundaries. The observed kinematics of synchronous and alternate movements of pelvic fins of the rough ray are in agreement with previous locomotory descriptions for different rajid species (Holst & Bone, 1993; Lucifora & Vassallo, 2002), thus supporting the hypothesis that punting and pelvic fin walking are a basal form of batoid locomotion (Macesic & Kajiura, 2010).

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References

Abdul-Malak, D., Livingstone, S.R., Pollard, D., Collette, B.B., Cuttelod, A. *et al.,* 2011. *Overview of the Conservation Status of the Marine Fishes of the Mediterranean Sea.* IUCN Publications, Spain, 61 pp.

Capapé, C., 1974. Contribution à la biologie des Rajidae des côtes tunisiennes. II. *Raja radula* Delaroche, 1809: répartition géographique et bathymétrique, sexualité, reproduction. *Archives de l'Institut Pasteur de Tunis*, 51, 211-228.

Ebert, D.A., Compagno, L.J.V., 2007. Biodiversity and systematics of skates (Chondrichthyes: Rajiformes: Rajoidei). *Environmental Biology of Fishes*, 80 (2-3), 111-124.

Holst, R.J., Bone, Q., 1993. On bipedalism in skates and rays. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 339, 105-108.

Koester, D.M., Spirito, C.P., 2003. Punting: An unusual mode of locomotion in the little skate, *Leucoraja erinacea* (Chondrichthyes: Rajidae). *Copeia*, 3, 553-561.

Lucifora, L.O., Vassallo, A.I., 2002. Walking in skates (Chondrichthyes, Rajidae): anatomy, behaviour and analogies to tetrapod locomotion. *Biological Journal of the Linnean Society*, 77, 35-41.

Macesic, L.J., Kajiura, S.M., 2010. Comparative punting kinematics and pelvic fin musculature of benthic batoids. *Journal of Morphology*, 271 (10), 1219-1228.

Rosenberger, L.J., 2001. Pectoral fin locomotion in batoid fishes: undulation versus oscillation. *The Journal of Experimental Biology*, 204 (2), 379-394.

Sfakiotakis, M., Lane, D.M., Davies, J.B.C., 1999. Review of fish swimming modes for aquatic locomotion. *IEEE Journal of Oceanic Engineering*, 24 (2), 237-252.

Stehmann, M., Bürkel, D.L., 1984. Rajidae. p. 163-196. In: *Fishes of the north-eastern Atlantic and Mediterranean, Vol. 1*. Whitehead, P.J.P., Bauchot, M.-L., Hureau, J.-C., Nielsen, J., Tortonese, E. (Eds). UNESCO, Paris.

Videler, J.J., Weihs, D., 1982. Energetic advantages of burst-and coast swimming of fish at high speeds. *The Journal of Experimental Biology*, 97, 169-178.

Weihs, D., 1974. Energetic advantages of burst swimming of fish. *Journal of Theoretical Biology*, 48 (1), 215-229.

Yaka, U., Yüce, R., 2006. The rough ray, *Raja radula* Delaroche, 1809 (Rajidae) new to the Sea of Marmara, Turkey. *Zoology in the Middle East*, 39, 112-114.