Agricultural and Marine Sciences, 17:53-60 (2012)

Spatial-Temporal Distribution of the Palinurid and Scyllarid Phyllosoma Larvae in Oman Coastal Waters

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التوزيع المكاني والزماني ليرقات البالينوريد والإسكايلاريد فايلوسوما في المياه الساحلية العمانية

سيرجي خفوروف وسيرجي بيونتكوفسكي والينا بوبوفا

الخلاصة: تم جمع عينات بواسطة شباك البونغو بين الأعوام 2005 و 2008 من بحر عمان والجزء الشمالي الغربي من بحر العرب (بالقرب من جزيرة مصيرة)، وتم تحليلها كتقييم مبدئي للتوزيع الموسمي والمكاني ليرقات Phyllosoma. في العينات التي تم جمعها كانت نسبة 84٪ من المجموع الكلي ليرقات phyllosoma من عائلة *Palinuridae* بينما كان الباقي من عائِلة Scyllaridae. كانت يرقات ال *Panulirus homarus* في مرحلة التطور الأولى، وكان متوسط طول جسمها 1.30 ± 0.89 مليمتراً . وكانت يرقات Phyllosoma من عائلة *Scyllaridae* الأقل وفرة في مرحلة التطور الثانية والثالثة والرابعة، وكان متوسط طول جسمها 3.3 و2.3 و 4.63 مليمتراً على التوالي. من حيث التغيرات الموسمية كانت يرقات Phyllosoma تميل للظهور في المياه العمانية في شهر فبراير (شباط) لتصل أعدادها إلى الحد الأقصى في أبريل (نيسان). وكانت أقصى وفرة ل *P. homarus* phyllosoma أعلى بمرتين في بحر العرب بالمقارنة مع بحر عمان.

كلمات مفتاحية: بحر العرب، عوالق حيوانية ،يرقات

ABSTRACT: The Bongo Net samples collected between 2005 and 2008 in the Sea of Oman and in the north-western part of the Arabian Sea (near Massirah Island) were analyzed, for a pilot assessment of seasonal and spatial distribution of the phyllosoma larvae. In the samples collected, 84% of all phyllosoma larvae were from the family *Palinuridae*, while the others were contributed by family *Scyllaridae.* All larvae of *Panulirus homarus* were in the first development stage and had a mean body length of 1.30±0.89mm. The phyllosoma larvae of the less abundant family *Scyllaridae* were in the second, third, and fourth development stages, which had a mean length of 2.3mm, 3.3mm and 4.63mm, respectively. In terms of seasonal changes, the phyllosoma larvae tend to appear in Omani waters in February, reaching their maximum numbers in April. The abundance of phyllosoma *P. homarus* was as much as twofold higher in the Arabian Sea compared to the Sea of Oman.

Keywords: Arabian Sea, zooplankton, larvae.

Introduction

Lobsters (family *Palinuridae* and *Scyllaridae*) are a valuable fisheries resource in the coastal waters of Oman comprising primarily one species- *Panulirus homarus* (Linnaeus, 1878) (spiny lobster). Geographically, the species is distributed from the Dhofar region in the south of the country to the Sea of Oman waters, in the north. Landings of spiny lobster declined, from 2000t in 1980s to 407t in 2010 (Fishery Statistics Books 1999-2010; Fig.1). Overfishing, increased occurrence of harmful algal blooms and fish-kill incidents were all factors in this decline. All fit the same trend reported for the Omani coastal waters (Piontkovski *et al.,* 2012; Sheppard *et al.,* 2010), although the mechanisms of physical-biological coupling mediating these trends have yet to be evaluated.

To reach maturity, a spiny lobster has to pass through a number of development stages, starting from the phyllosoma larvae. In this regard, regular field surveys of the phyllosoma larvae number along the coast are of great importance if we are to understand the spatial-temporal characteristics of population recruitment. The larvae may be carried long distances by currents. This results in the settlement taking place far away from breeding grounds (Lewis, 1951).

In analyzing data of annual plankton surveys we aimed to initiate pilot assessment of seasonal and spatial distribution of the phyllosoma larvae along the Omani coast.

Materials and Methods

Coastal survey has resulted in 118 samples collected between 2005 and 2008 in two regions (Fig. 2). The first one was

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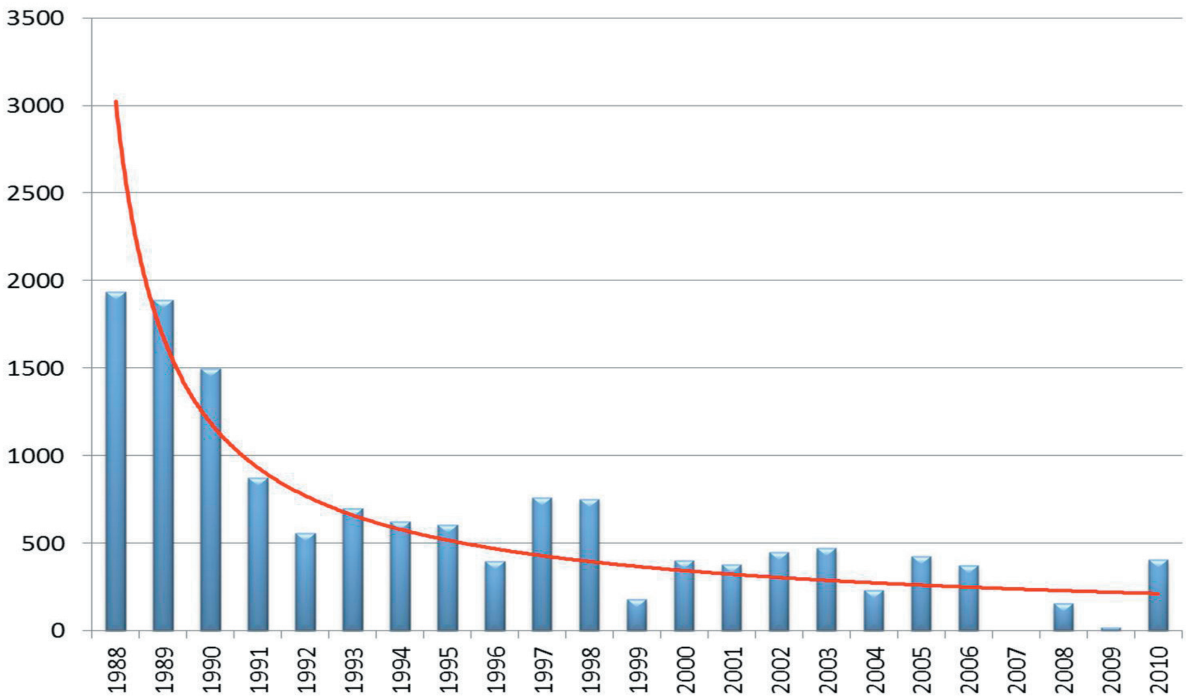

Figure 1. Reported catches of *Panulirus homarus* in Omani waters from 1988 to 2010 (metric tons).

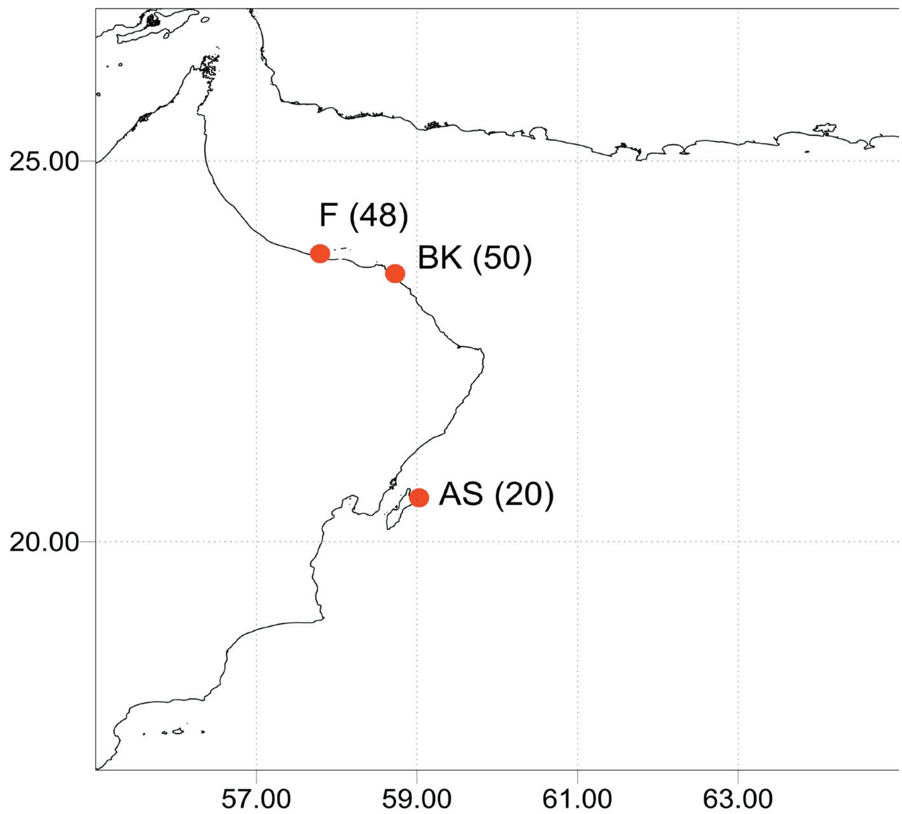

Figure 2. Sampling sites, with the total number of zooplankton samples collected (in brackets).

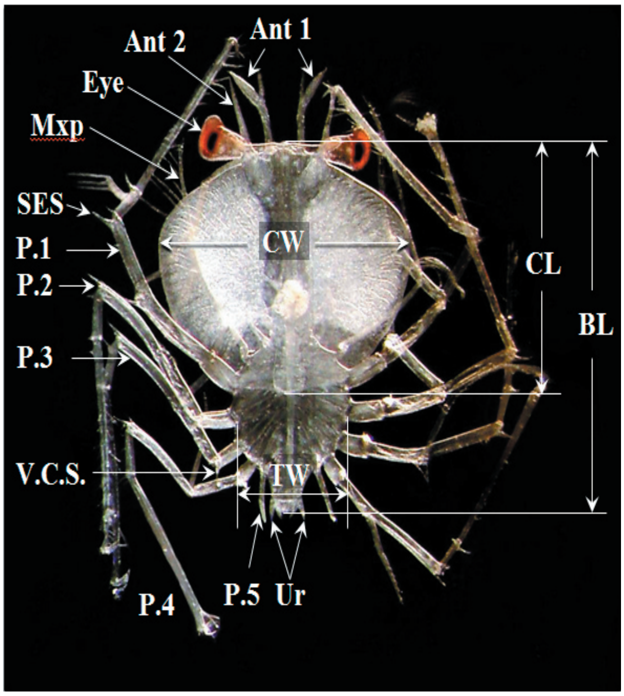

Figure 3. Morphometric characteristics of phyllosoma larvae. Morphology: Ant.1 – antennule; Ant.2 – antenna; Mxp – maxilliped 3; P.1 – P.5 – 1st – 5th pereiopods; Uro – uropod, V.C.S – ventral coxal spine; S.E.S. – sub–exopodal spine. Measurements: BL – body length; CL - cephalic length; CW – cephalic width; TW –thorax width.

located in the Sea of Oman near Muscat, with a sampling site in Bandar Al Khayran Bay (BK) and near Fakhal Island (F). The second one was located in the north-western part of the Arabian Sea, near Massirah Island (stations AS).

A Bongo net (with 150 µm mesh size and 0.4m diameter) was equipped with the water flow ("Hydrobios") counter. Samples were preserved with 4% formalin. In the lab, these samples were sub-sampled by a Motoda or Folsom box splitter and sorted out into taxonomic groups identified to the lowest taxon possible.

Taxonomical identification of the phyllosoma larvae was based on a number of manuals (Berry, 1974; Sekiguchi, 1986b; Johnson, Allen, 2005; Chow *et al.,* 2006; Coutures, 2001, Barnett *et al.,* 1984). The morphometric characteristics used were the length of the cephalic shield, the total body length, the width of cephalon and thorax (Fig. 3). Furthermore, the ratios of length to width for body parts and appropriate morphometric coefficients (Robertson, 1969; Sekiguchi, 1986b) were calculated (Table 1). Identification of the developmental stage has incorporated examination of eyes, antenna, and abdomen shape (Berry, 1974; Braine *et al.,* 1979; Minami *et al*., 2001).

The ICES Zooplankton Methodology Manual was used, to estimate the abundance of phyllosoma larvae in samples (Harris *et al*., 2000). The abundance is calculated by N= $(nk)/m^3$, where n is the abundance of organisms in a sub-sample k of the collected sample.

Table 1. Morphometric characteristics of developmental stages.

Taxon	Stage	Instar	Specimen ID	Measurements				Ratios	
				BL	CW	CL	TW	CL/CW	CT
Panulirus homarus	Stage 1	1	AS/I/1.3	1,13	0,78	0,60	0,45	0.77	0.58
			AS/I/2a.2	1,13	0,70	0,60	0,40	0.86	0.57
		2	BK/I/6	1,18	0,78	0,75	0,43	0.96	0.55
			AS/I/2b	1,20	0,88	0,78	0,45	0.89	0.51
		3	AS/I/2c	1,27	0,75	0,75	0,38	1.0	0.51
			AS/I/3	1,28	0,63	0,68	0,45	1.08	0.71
			AS/I/9.4	1,28	0,60	0,70	0,48	1.17	0.8
		4	AS/I/8.1	1,33	0,70	0,75	0,45	1.07	0.64
			AS/I/9.2	1,33	0,75	0,78	0,50	1.04	0.67
			BK/I/7b	1,35	0,70	0,75	0,50	1.07	0.71
		5	AS/I/9.1	1,35	0,78	0,65	0,45	0.83	0.58
			AS/I/9.3	1,35	0,75	0,68	0,50	0.91	0.67
			AS/I/2a.1	1,38	0,73	0,75	0,50	1.03	0.68
		6	AS/I/4	1,38	0,70	0,73	0,48	1.04	0.69
			AS/I/8.2	1,38	0,70	0,83	0,45	1.19	0.64
		7	AS/I/1.1	1.48	0.78	0.83	0.55	1.06	0.71
Scyllaridae	Stage II		AS/II/5	2,3	1,55	1,58	0,80	1.02	0.52
	Stage III		AS/III/7a	3,3	2,38	2,25	1,23	0.95	0.52
	Stage IV		AS/IV/1.2	4,63	3,75	2,88	1,88	0.77	0.50

BL – body length (mm); CW – cephalic width; CL – cephalic length; TW – thorax width; CT – ratio between CW and TW.

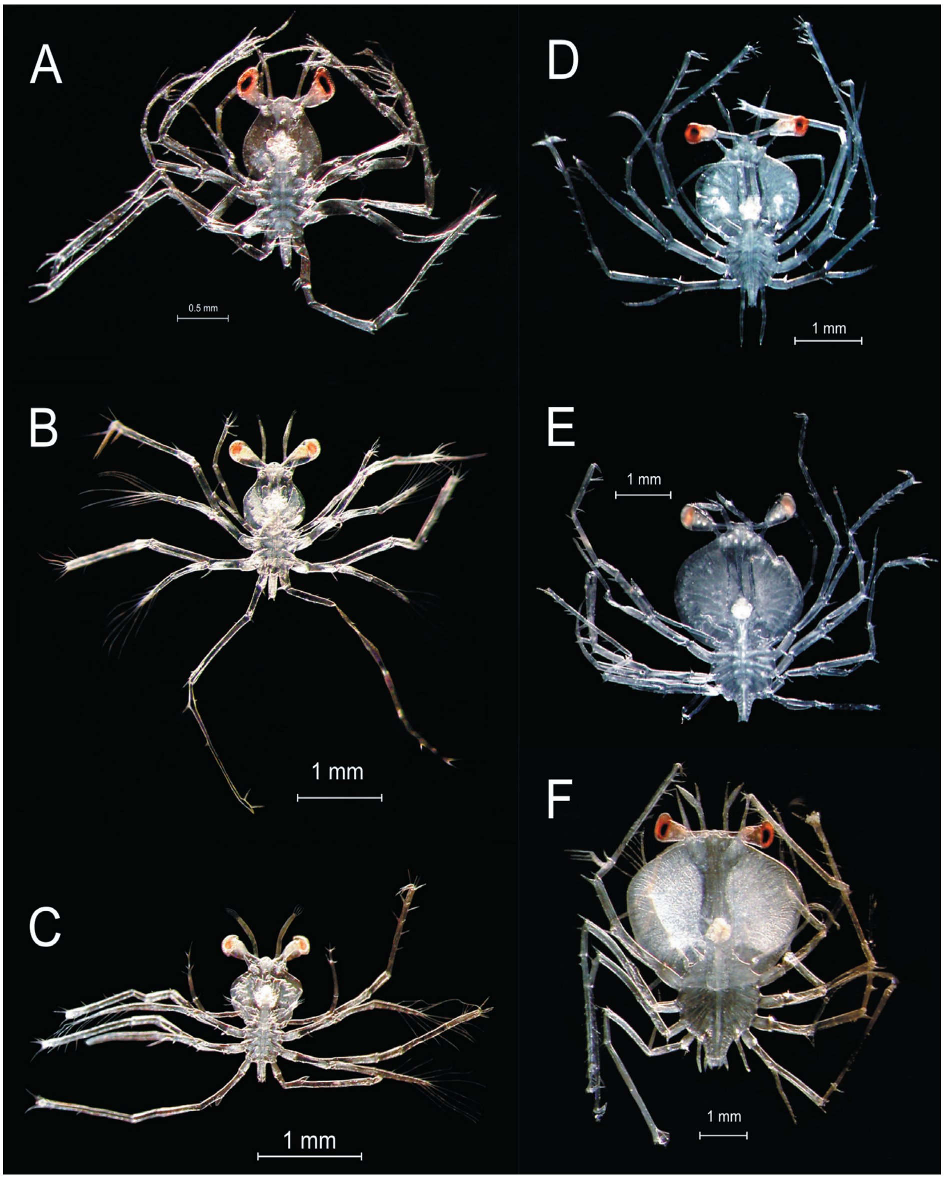

Figure 4. The phyllosoma larvae collected in Omani coastal waters. *Palinurus homarus*: A-A/S/I/1.1; B - AS/I/2a.1; C - AS/I/2a.2; *Scyllaridae:* D - AS/II/5; E - AS/III/7a; F - AS/IV/1.2.

Satellite derived (9-km spatial resolution SeaWIFS) Level-3 weekly data for chlorophyll *a* concentration were used to retrieve maps of chlorophyll a in 2007. Spatial distribution of chlorophyll "*a*" was acquired using the GES-DISC Interactive Online Visualization and Analysis Infrastructure software as part of the NASA's Goddard Earth Sciences Data and Information Services Center.

Results and Discussion

Omani coastal waters inhabited by phyllosoma larvae are subjected to gradual seasonal changes. The driving force of these changes is the monsoonal winds mediating the system of coastal currents. These currents experience dramatic changes resulting in total reversing of direction depending on the time and origin of monsoons. In summer (which is the time of the south-west monsoon), the Oman Coastal Current propagates northward, along the Omani coast. In winter, the winds of the north-east monsoon reverse the system of currents making the water mass transport oriented southward. The inter-monsoon periods (spanning the spring and fall), might be characterized as the time of reconstruction in the system of currents.

In the summer months of the south-west monsoon, productivity of the western Arabian Sea is at its maximum, due to Omani coastal upwelling. In winter, the north-east monsoon sets up the upwelling along the coast of Iran and Pakistan resulting in highly productive waters in the Sea of Oman and the northern Arabian Sea (Smith, 2005; Wiggert *et al.,* 2009).

In the zooplankton samples collected, 84% of all phyllosoma larvae were from the family *Palinuridae* (*Panulirus homarus*), while the others were contributed by the family *Scyllaridae* (Fig. 4). All phyllosomas of *P. homarus*

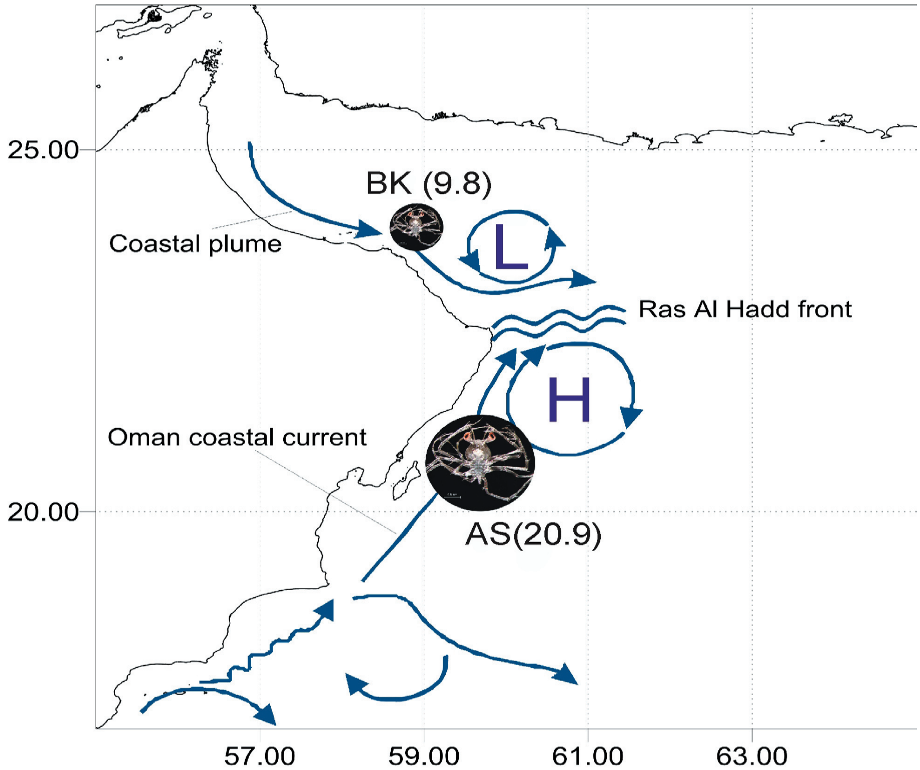

Figure 5. The abundance of phyllosoma larvae *Palinurus homarus* over sampling sites and a scheme of coastal currents.

The diameter of circles with larvae image is proportional to the total abundance (ind m^{-3}) given in red, for stations BK and AS.

Schematic diagram of coastal circulation during the southwest monsoon is a courtesy of the Rosenstiel School of Marine and Atmospheric Science, University of Miami (http://disc.sci.gsfc.nasa. gov/oceancolor/additional/science-focus/ocean-color/ras_al_hadd_jet.shtml).

L-cyclonic eddy, H-anticyclonic eddy.

have had the first development stage. The body length varied between 1.13 and 1.48mm and had a mean length of 1.30±0.89mm.

The phyllosoma larvae of the less abundant family *Scyllaridae* were at the second, third, and fourth development stage, which had a mean length of 2.3mm, 3.3mm, and 4.63 mm, respectively.

At station AS in the Arabian Sea, the abundance of the *P. homarus* larvae (20 ind m^{-3}) was twofold higher that at station BK in the Sea of Oman (Fig. 5). Larvae of family *Scyllaridae* were found at station AS only, in relatively small numbers (1.6 ind. m^{-3}).

In terms of seasonal changes, the phyllosoma larvae exhibited minimal abundance in winter (from December to February) and maximal values in May (Fig. 6). At that time, the peak is formed by the first development stage of *P. homarus.*

As far as the interannual changes are concerned, the variability of abundance over the years was quite high. The phyllosoma larvae were not found in the samples collected in 2005 and 2008. The most productive (in terms of larvae abundance) was in 2007 (Fig. 6).

In using the Bongo nets to catch the phyllosoma larvae, we rested on a previous successful application of this type of nets to sample macroplanktonic crustaceans (Pepin and Shears, 1997). The phyllosoma larvae caught - all had the non-segmented antennula, antenna, and eyes. These features allow larvae to be attributed to the first development stage. The body length of this stage varied, from 1.13 to 1.48mm (Table 1). This means that organisms could belong to different species or, the same development stage might have a broad size range, due to intensive growth rate but long development period.

In spite of numerous reports on phyllosoma biology and ecology (Phillips *et al.,* 1981; Sekiguchi, 1986a; Kathirvel, 1990; Yeung *et, al*., 1995; Inoue *et al.,* 2001; Minami *et al.,* 2001; Inoue *et al.,* 2004; Manzanilla-Dominguez and Gasca, 2004; Manzanilla-Dominguez and

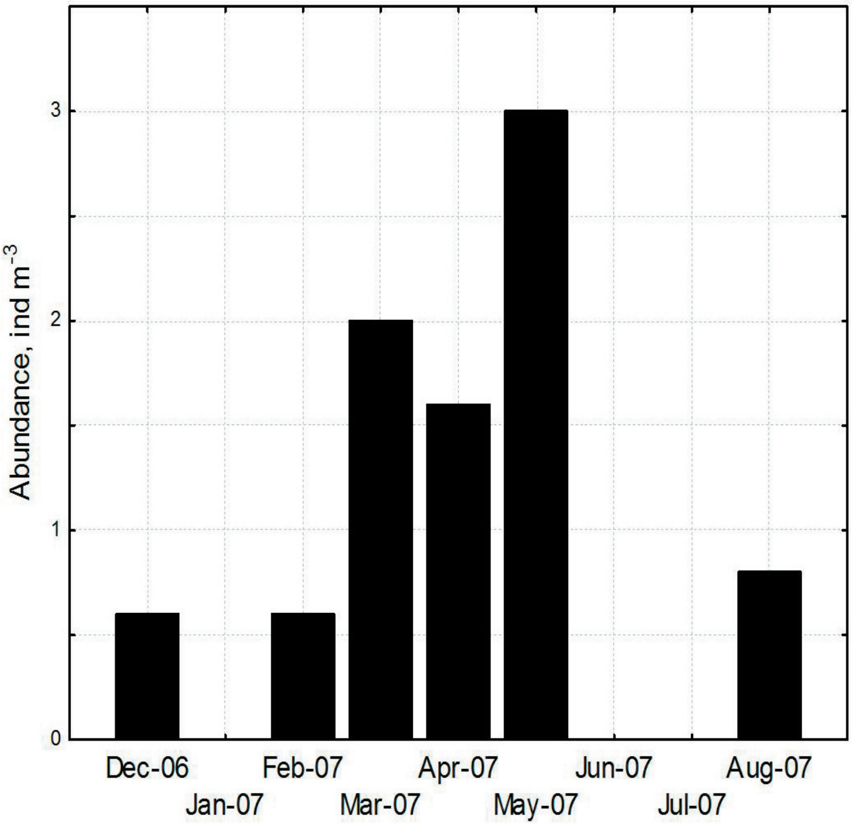

Figure 6. Seasonal changes of the abundance of phyllosoma larvae *Panulirus homarus* in the Arabian Sea (station AS).

Suárez-Morales,2005), there is still a lack of quantitative estimates of abundance. We did not find published data for the phyllosoma abundance in the Sea of Oman. The data available nearby dealt with the Kuwait region, in which the abundance of phyllosoma larvae *Thenus orientalis* was 0.7 ind. m^{-3} (Al-Yamani and Khvorov, 2007).

In terms of comparative approach, the abundance reported for the other geographical regions of the world's ocean was much less. For instance, in coastal waters of Juan Fernandez Archipelago (Chilean islands, 33° 40' S - 78° 50' W) and Desventuradas Islands (26° 20' S - 80° 05' W) in the south-east Pacific, the abundance of phyllosoma larvae was 0.6 ind. m^{-3} (Mujica, 2006). In the coastal waters of South Africa, the abundance of phyllosoma *P. homarus* was 3 orders of magnitude less - 0.6 ind. /1000 m^3 (Berry, 1974). Our estimates are consistent with earlier reports on high concentration of larvae contributed by Palinura in the western Indian Ocean (Prasad *et al.*, 1975).

As mentioned above the abundance of phyllosoma *P. homarus* was as much as twofold higher in the Arabian Sea compared to the Sea of Oman (Fig. 4). There might be a number of reasons for that. For instance, the productivity of the coastal waters of the western Arabian Sea in April and May 2007 was higher than the productivity of the coastal waters of the Sea of Oman (Fig. 7). This implies less favorable feeding grounds for the phyllosoma larvae in the Sea of Oman compared to the Arabian Sea.

In developing methods of the phyllosoma aquaculture, Igarashi and Kittaka (1994) stressed the importance of using microalgae. They reported that yearly-stage phyllosomas succeeded in prolonging their lives in culture water with microalgae, while the phyllosomas contained without microalgae survived for only few days.

Overall, the phyllosoma larvae are believed to be an opportunistic carnivore, whose diets correlate with the relative abundance of prey in the ambient water (Suzuki *et al.,* 2008). In our case, data on mesozooplankton groups in samples did also imply high concentration of abundant zooplankton species in April and May, during the phyllosoma abundance peak. For instance, the copepods comprise about 70% of the mesozooplankton abundance of which *Oithona brevicornis* was one of the dominant species. In BK and AS regions, maximal concentration of this species was in April-May (Table 2).

Interestingly, peaks of phyllosoma abundance in both regions in 2007 were associated with the inter-monsoon season (April-May). The intermonsoon period is the time of minimal productivity in the western Arabian Sea. The reasons and mechanisms mediating this peculiarity of the phyllosoma seasonal cycle are yet to be found. More detailed field surveys are required.

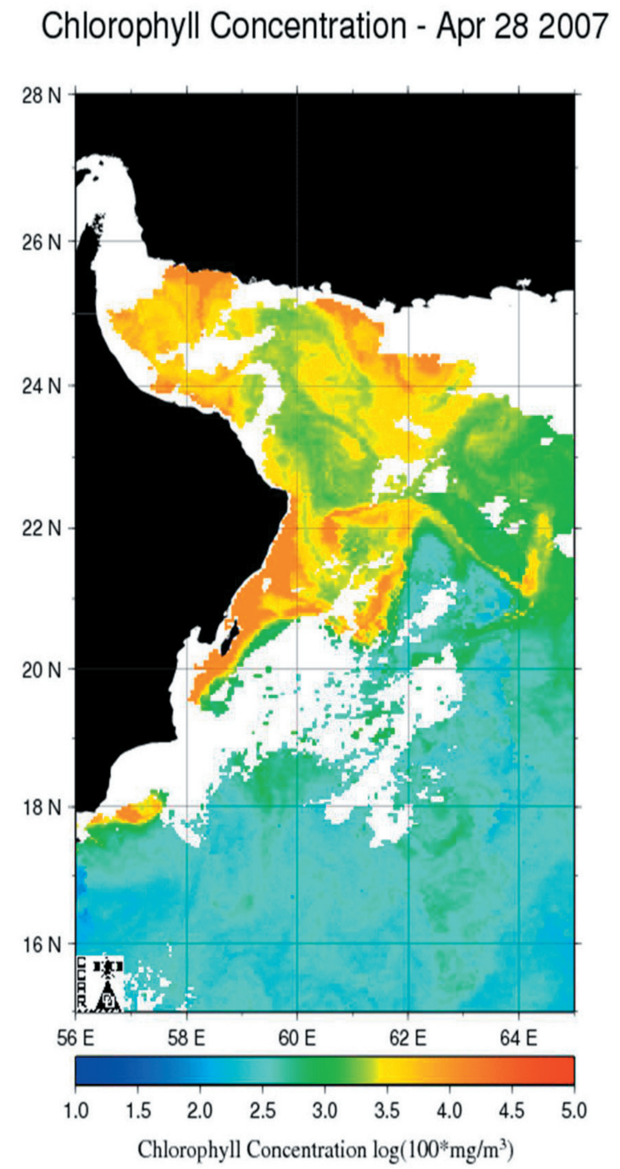

Figure 7. Remotely sensed distribution of chlorophyll *a* in April, 2007 (SeaFIWS scanner).

Acknowledgments

We appreciate S. Smith, I. Prusova, A.Al-Azri and K.Al-Khashmi for the samples provided to study the phyllosoma larvae.

This research was supported by the Research Council grant # ORG/EBR/09/004 (Sultanate of Oman).

Table 2. Monthly changes of *Oithona brevicornis* abundance (ind. m^{-3}) at BK and AS1 stations.

Date (mo./date/year)	BK	Date (mo./date/year)	AS1
3/5/2007	3,3	2/25/2007	1,5
3/20/2007	67,4	3/27/2007	1,5
4/16/2007	2,4	4/23/2007	1,6
4/2/2007	124,1	5/28/2007	78,000
5/6/2007	126,6	10/28/2007	14,6
5/20/2007	6,2	11/24/2007	26,000
6/17/2007	20,5		
7/1/2007	20,1		
8/25/2007	10,8		

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Received: February 12, 2012
Accepted: May 5, 2012