Parasitol Res
DOI 10.1007/s00436-009-1423-z

ORIGINAL PAPER

A new approach to visualize ecosystem health by using parasites

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Received: 19 January 2009 / Accepted: 18 March 2009

Abstract A new approach is chosen to visualize ecosystem health by using parasite bioindicators in Segara Anakan Lagoon, a brackish water ecosystem at the southern Java coast, Indonesia. Three fish species (*Mugil cephalus*, *Scatophagus argus*, *Epinephelus coioides*) were collected in two different years and sampling sites and studied for ecto- and endoparasites. Additional data were taken for *E. coioides* from two further sites in Lampung Bay, Sumatra, and for *E. fucoguttatus* out of floating cages from a mariculture facility in the Thousand Islands, Jakarta Bay, North Java. The parasite fauna of fishes inside the lagoon was characterized by a high number of ecto- and a low number of endoparasites, the endoparasite diversity was relatively low and the prevalence of ectocommensalistic trichodinid ciliates was high. These parameters were chosen to indicate the biological conditions inside the lagoon. In *E. coioides* during rainy season, the prevalence of trichodinid ciliates was highest inside the lagoon (55%) compared with 27% in an open-net-cage mariculture and 5.7% in free-living specimens in Lampung Bay. The endoparasite diversity (Shannon-Wiener) was lowest in fish from Segara Anakan lagoon (0.66) compared with fish from an open-net-cage mariculture (0.71) and free-living specimens (1.39). Results for *E. fuscoguttatus* from the mariculture site in the Thousand Islands, a relatively undisturbed marine environment, demonstrated high parasite diversity (1.58) in the cultivated fish, a high number of endoparasites, and no trichodinids. A star graph is used to visualize the parasite composition for the different fishes, sampling sites, and conditions, using (1) the prevalence of trichodinid ciliates, (2) the ecto/endoparasite ratio and (3) the endoparasite diversity as bioindicators. The application of the star graph is suggested to be a suitable tool to visualize and monitor environmental health under high parasite biodiversity conditions within tropical ecosystems. It can also support a better communication to stake holders and decision makers in order to monitor environmental impact and change.

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Introduction

Aquatic tropical ecosystems underlie high anthropogenic stress in terms of pollution and environmental degradation. About 2.75 billion people are expected to live within 60 miles of a coastline in 2025, and the search for alternative income for local communities necessitates the sustainable use of coastal ecosystems. Finfish mariculture has high potential to provide valuable food products as export commodities and can increase employment opportunities. However, it also negatively effects the coastal environment and contributes to environmental degradation. Because of missing methodological standards, regulation, and governmental control, the expansion of finfish mariculture in many tropical countries is uncontrolled, and regular monitoring programs to document environmental change in the benefit of local people and finfish farmers are almost non-existing.

Published online: 01 April 2009

The status of a marine environment and environmental change can either be studied directly by using water quality parameters such as phosphate, nitrate, and DOC, or indirectly by using bioindicators. Indicator organisms react sensibly to specific environmental conditions and their occurrence or abundance can describe the situation of the environment. They have already successfully been applied to indicate, e.g., trace metals, organochlorines, and radionucleides (*Dreissena polymorpha*, Mersch et al. 1992) or heavy metals (*Corbicula fluminea*, Graney et al. 1983). Also, fish parasites can be used as biological indicators (e.g., Lafferty 1997; Marcogliese and Cone 1997; Overstreet 1997; Marcogliese 2005), e.g., for the host's ecology (feeding, Palm 1999; migration and recruitment, Moser 1991; Palm and Schröder 2001; Williams et al. 1992) or for environmental conditions (water quality, MacKenzie et al. 1995; Galli et al. 2001; pollution, Sures and Reimann 2003; environmental stress Khan and Thulin 1991; Landsberg et al. 1998). In particular, ectocommensals with direct life cycles such as trichodinid ciliates favor polluted waters, and can indicate a high bacterial load (Palm and Dobberstein 1999; Ogut and Palm 2005). Endoparasites with complex life cycles favor stable and non-polluted waters, where the full range of their required hosts is present (Khan and Thulin 1991; Yeomans et al. 1997; Diamant et al. 1999). Consequently, a combination of different fish parasites or parasitological parameters can enable an analysis of the health status of any aquatic environment, including finfish mariculture.

Because of over-fishing and as an alternative source of income, finfish mariculture is a steadily growing business worldwide and especially in tropical countries. In Indonesia, though being the largest archipelago in the world with more than 17,500 islands, the coastline in many regions has already been widely exploited and underlies a variety of anthropogenic influences, such as overexploiting fisheries, environmental degradation and pollution. The identification of suitable regions and sites that might be utilized for future finfish mariculture further increases the anthropogenic pressure onto the coastal zones. The Segara Anakan Lagoon is the last remaining extensive mangrove ecosystem on Java, and the Thousand Islands belong to a national park northwest of the Indonesian capital Jakarta. Both regions are under consideration for grouper (*Epinephelus* spp.) mariculture. However, the suitability and possible effects on the environment have not yet been explored.

Following the intensification of finfish mariculture, two major problems occur. An increasing number of fish farms is often followed by an increasing degradation of the surrounding environment due to the application of food and drugs (Shuanglin et al. 2000), resulting in cases of parasite and disease outbreaks within the mariculture facilities (Leong 1997). To protect the cultivated fishes and the private investment, a better parasite and disease control while monitoring the health status of the environment is the prerequisite for a sustainable and environmental friendly mariculture. Fish parasitological studies in Indonesia are scarce, and mainly restricted to faunistic studies on parasites of fisheries importance (e.g., Palm 2000, 2004; Palm et al. 2008; Rückert et al. 2008, 2009a; Kuchta et al. 2009). The present study was carried out in order to compare the fish parasite fauna of commercial fish species from different sampling sites in Indonesia (two sites inside Segara Anakan lagoon, see Yuniar et al. 2007), using selected fish parasitological parameters as biological indicators (see Rückert et al. 2009b). Fish from a commercial mariculture site in the Thousand Islands, from the National Seafarming Development Center and free-living fish in Lampung Bay were studied for comparison by using the same parameters. For the first time, a star graph is applied to visualize habitat quality using different parasite metrics together on a single figure. This method was developed for indicator integration to provide a 'holistic view in sustainable development' (Bell and Morse 2003), and can be a method of choice to communicate fish parasites as bioindicators to the wider audience.

Materials and methods

Samples were taken within the framework of the project "Science for the Protection of Indonesian Coastal Ecosystems" during dry and into the rainy season 2004 (August to November 2004) and during the dry season 2006 at two different localities (Motean and Klaces/Area 2 and Donan/Area 3) in Segara Anakan Lagoon (southern coast of Java, Indonesia; Fig. 1). Both sites can be distinguished by their environmental characteristics. Area 2 is located at the center of the lagoon and is influenced by several rivers that carry regular freshwater runoff and sedimentation, especially during rainy season (freshwater influenced lagoon ecosystem, LF). The salinity is variable and can be low (19.7–28.0). Area 3 is located nearby an outlet into the Indian Ocean with a higher salinity (29.3–31.2), and characterized by tidal exchange with the Indian Ocean and little freshwater input. The site is close to the oil industry and the city Cilacap, and can be considered being an anthropogenic highly influenced environment (seawater-influenced lagoon ecosystem, LS). Detailed information on the hydrodynamics and spatio-temporal variation of dissolved inorganic nutrients in both habitats are given by Holtermann et al. (2009) and Jennerjahn et al. (2009). Three fish species were sampled inside the lagoon, *Epinephelus coioides* (Hamilton) (n=41), *Mugil cephalus* (L.) (110) and *Scatophagus argus* (L.) (110), and obtained directly from local fishermen (Table 1) that fished in either of the two sampling sites.

In addition, 30 *E. coioides* from an open-water net cage at BBL Lampung (Balai Budidaya Laut, National Seafarm-

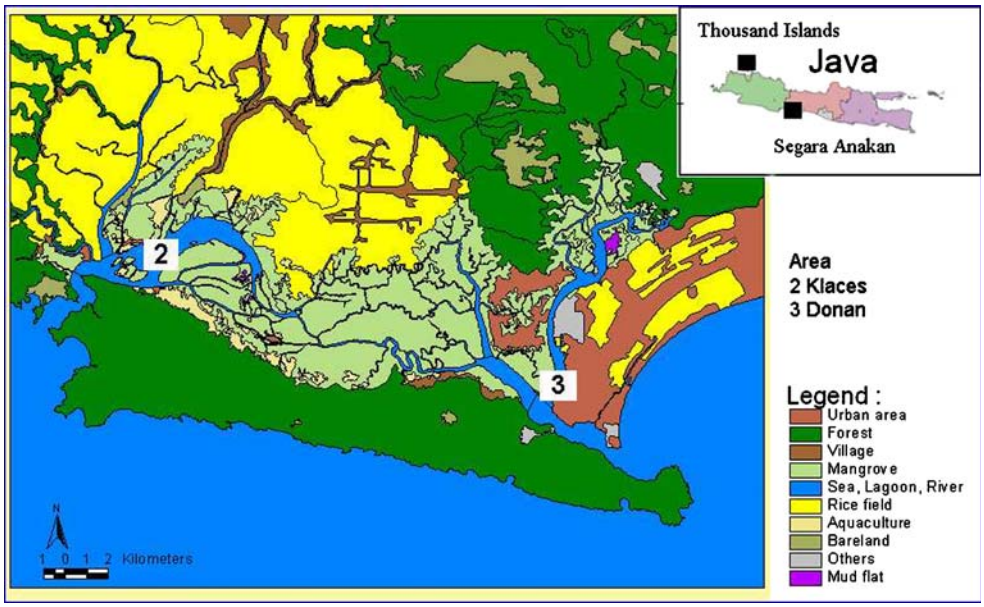

Fig. 1 Areas of investigation on Java Island, Indonesia

ing Development Center), L_T [cm]=27.4 (23–35), M_T [g]= 343.2 (187–698), in Hurun Bay (coastal mariculture, CM) and 35 specimens taken from the wild in Ringgung (coastal environment, CE), L_T [cm]=30.7 (20-39), M_T [g]=400.5 (103–746), both Lampung Bay, were studied for fish parasites during the rainy season 2002/2003, at a stable salinity of about 32. Lampung Bay is located at the southern tip of Sumatra, northwest of Java Island. It covers an area of approximately 600 km, with a mean depth of 22 m (maximum depth 75 m) and a coastline of about 160 km (Wiryawan et al. 1999). *Epinephelus fuscoguttatus* (Hamilton) (n=35, L_T [cm]=26.9 (24–33), M_T [g]=429.9 (272–743)) was studied from a mariculture facility on the Thousand Islands (Pulau Seribu, Jakarta Bay, northern coast of Java), a marine national park (Table 1; island mariculture, MM), during the rainy season in January 2005, with a salinity of around 32.

The fishes from the mariculture sites and the free-living specimens from Lampung Bay were examined directly after catching. Smears were taken from the gills and the inner opercula of the living fish. Specimens from Segara Anakan Lagoon were then deep-frozen for further examinations in the laboratory. During examination, the following measurements were taken: total fish length (L_T, to the nearest 1.0 cm) and total mass (M_T, to the nearest 1.0 g; Table 1). The skin, fins, eyes, gills, mouth- and gill cavity were studied for ectoparasites. The inner organs such as the digestive tract, liver, gall bladder, spleen, kidneys, gonads, heart, and swim bladder were separated and transferred into saline solution. While the internal organs were examined under a stereomicroscope, the gall bladder was removed and studied by using a phase-contrast microscope. Belly flaps and musculature were examined on a candling table.

Isolated parasites were fixed in 4% formalin and preserved in 70% ethanol. The smears from the gills and opercula were stained by using silver nitrate impregnation after Klein (1926, 1958). The slides were rinsed and covered with 5% silver nitrate solution and impregnated for 30 min in the dark. The $AgNO_3$ was removed and the slides were covered with distilled water and exposed to ultraviolet light for 40–50 min. The smears were dried after exposure. Acanthocephala were transferred to freshwater until the proboscis everted prior to fixation. For identification purposes, Nematoda and Acanthocephala were dehydrated in a gradated ethanol series and

Table 1 Fish species, number (n) of dissected specimens, mean length and mean weight (range in parentheses) of the studied fish species. *n* number, *Rs* rainy season, *Ds* dry season, L_T=total length, W_T=total mass

Fish species and location	*n* Rs/Ds	Rainy season 04/05		Dry season 06	
		L_T [cm]	M_T [g]	L_T [cm]	M_T [g]
Mugil cephalus; Segara Anakan, Area 2	35/20	16.7 (12–20)	57.7 (20–125)	21.8 (19–26)	109.5 (60–163)
M. cephalus; Segara Anakan, Area 3	35/20	14.3 (11–24)	40.2 (11–175)	18.0 (16–24)	65.3 (49–118)
Scatophagus argus; Segara Anakan, Area 2	35/20	9.5 (7–14)	29.5 (10–100)	11.7 (9–16)	59.6 (23–129)
S. argus; Segara Anakan, Area 3	35/20	11.1 (8–20)	54.1 (11–230)	14.1 (12–17)	92.4 (54–181)
Epinephelus coioides; Segara Anakan, Area 3	21/20	17.3 (10–28)	83.2 (13–250)	22.6 (17–28)	172.4 (71–306)

transferred to 100% glycerine (Riemann 1988). Digenea, Monogenea, and Cestoda were stained with acetic carmine, dehydrated, cleared with Eugenol and mounted in Canada balsam. Parasite identification followed standard parasite literature and original descriptions. Within the results *Pseudorhabdosynochus* spp. represents a combination of the two species *P. epinepheli* and *P. lantauensis*.

The parasitological terms (prevalence, intensity, and mean intensity) follow Bush et al. (1997), where the prevalence (*P*) is the number of fish with one or more individuals of a particular parasite species (or taxonomic group) divided by the number of hosts examined (expressed as a percentage) [prevalence (*P*)=no. of hosts infested/no. of hosts examined×100].

Intensity (of infection, *I*) is the number of individuals of a particular parasite species in a single host (expressed as a numerical range); and mean intensity (of infection, I_m) is the average intensity, in other words, it is the total number of parasites of a particular species found in a sample divided by the number of infected hosts [mean intensity (I_m)=total no. of a particular parasite / no. of infected hosts]

The diversity of the metazoan endoparasite fauna of each fish species was determined by using the Shannon–Wiener diversity index (H') and the evenness index (E) of Pielou (Magurran 1988) [Shannon–Wiener Index (H')=$\sum P_i \ln P_i$, evenness (E)=$H'/\ln S$, with H' being the diversity index, P_i the proportion of the individual (ith) species to the total and S is the total number of species in the community (species richness)]. The evenness was not considered a separate bioindicator within the present study. Myxozoan and microsporean parasites were not considered because it was not possible to calculate the intensity.

Additionally, the ratio of ecto- to endoparasites was calculated [E/E ratio (R)=no. of ectoparasite species/no. of endoparasite species], with trichodinid ciliates treated as present or absent. Species groups (such as Nematoda indet.) that could not be further identified and might represent other recorded taxa were omitted from these calculations.

Results

A total of 43 different parasite species/taxa were collected from the three fish species from Segara Anakan Lagoon (Tables 2 and 3, Yuniar et al. 2007; Rückert et al. 2009b). In Area 2 (LF) within the lagoon, the parasite fauna of *M. cephalus* and *S. argus* comprised 11 and 15 (2004) as well as 15 and 14 parasite species (2006), respectively. In Area 3 (LS), a total of 12 and 21 parasite species were recorded for *M. cephalus* and 12 and 20 species for *S. argus* in 2004 and 2006, respectively. *E. coioides* from Area 3 (LS) was infested with ten different parasite species in 2004 and 11 species in 2006. With a total of 27 parasite species/taxa, most parasite species were recorded for *E. coioides* from Lampung Bay. At the National Seafarming Development Center in Lampung Bay (CM) *E. coioides* from the net cage was infested with 18 parasite species. More species were detected from free-living (CE) *E. coioides* (19) in Ringgung. Seventeen parasite species were isolated from *E. fuscoguttatus* from the mariculture facility in the Thousand Islands (MM). Information on prevalence, abundance, and intensity of the collected parasite species is summarized in Tables 2, 3, 4 and 5. To analyze the parasite composition at the respective sampling sites, the ecological parameters (1) prevalence of trichodinid ciliates, (2) endo- and ectoparasite ratio, and (3) endoparasite diversity H' were considered as given below.

Trichodinid ciliates

In 2004, trichodinid ciliates were isolated from all studied fish species inside Segara Anakan Lagoon (Tables 2 and 3). Except for *M. cephalus* in Area 3 (LS), the prevalence of infestation was fairly high. Highest prevalence (83%) was observed for *Trichodina* spp. on *S. argus* collected from Area 2 (LF). Within the lagoon, the lowest infestation rate (8%) was found for *M. cephalus* in Area 3 (LS). The prevalence for *S. argus* and *M. cephalus* was higher in Area 2 (LF) compared with Area 3 (LS). It appeared that the fishes from the freshwater-influenced central lagoon had more trichodinids compared with those from the seawater-influenced lagoon ecosystem.

In 2006, *M. cephalus* in Area 2 (LF) was uninfected with trichodinid ciliates, whereas *S. argus* from Areas 2 (LF) and 3 had an observed prevalence of 70% (Tables 2 and 3). The infestation rate for *M. cephalus* in Area 3 (LS) was 55%. *E. coioides* reached a prevalence of infestation with *Trichodina* spp. of 55% in Area 3 (LS) during both sampled periods.

The infestation of *E. coioides* with *Trichodina* spp. was low at both sampling sites in Lampung Bay, with a prevalence of 27% at the coastal mariculture BBL Lampung and 5.7% in free-living fish from Ringgung (Table 4). No trichodinid ciliates were found on the grouper specimens (*E. fuscoguttatus*) from the mariculture facility in the marine national park, Thousand Islands (Table 5).

Ratio of ecto/endoparasites

The total number of parasites in/on the fishes from Segara Anakan Lagoon was similar within the lagoon (ten to 15 in 2004 vs. 11–21 in 2006) compared to the Thousand Islands (17) and Lampung Bay (18–19). However, the number of ecto- and endoparasite species was very different between these localities. In 2004, the number of ectoparasites in the lagoon was higher (five to ten) than the number of endoparasites (two to five). No significant difference was observed between the freshwater influenced Area 2 (LF) and the seawater influenced Area 3 (LS) within Segara

Table 2 Prevalence (*P*), intensity (*I*) and mean intensity (I_m) of the collected parasite species from the studied fish species (AREA 2)

Parasites (AREA 2)		*Mugil cephalus*				*Scatophagus argus*			
		Rainy season 04/05		Dry season 06		Rainy season 04/05		Dry season 06	
		P [%]	I_m (*I*)	*P* [%]	I_m (*I*)	*P* [%]	I_m (*I*)	*P* [%]	I_m (*I*)
Ectoparasites	*Trichodina* spp. (P)	50	3.5 (1–9)			83	2.7 (1–8)	70	12.1 (1–44)
	Transversotrema sp. (D)			20	6.8 (1–15)			5	1 (1)
	Metamicrocotyla sp. (Mo)			5	1(1)				
	Metahaliotrema scatophagi (Mo)					100	37.5 (5–114)	95	34.6 (6–60)
	Pseudorhabdosynochus sp. (Mo)								
	Diplectanidae gen. et sp. indet. (Mo)			100	20.4 (1–121)				
	Dactylogyridae gen. et sp. indet. (Mo)	74	9.6 (1–92)						
	Mazocreadiidae gen. et sp. indet. (Mo)			15	1 (1)				
	Monogenea indet. (Mo)	9	24.6 (1–48)						
	Zeylanicobdella arugamensis (H)			15	1.3 (1–2)	6	2 (1–3)		
	Nothobomolochus sp. (Cr)	9	1.3 (1–2)	15	2 (1–3)				
	Ergasilus sp. 1 (Cr)	63	6.7 (1–37)	25	4.4 (1–14)				
	Ergasilus sp. 2 (Cr)	3	3 (3)			6	51 (37–65)		
	Ergasilus sp. 3 (Cr)					83	16.6 (1–78)	90	26.8 (2–220)
	Ergasilidae gen. et sp. indet. (Cr)	20	5.3 (1–15)	25	1.8 (1–4)			5	21 (21)
	Caligus acanthopagri (Cr)			15	2.3 (1–5)	71	7 (1–22)	30	3.7 (1–7)
	Caligus epidemicus (Cr)			25	1 (1)	9	1.3 (1–2)	80	5.8 (1–16)
	Caligus rotundigenitalis (Cr)	37	1.5 (1–3)	20	2.5 (1–7)			10	1 (1)
	Pseudocaligus sp. (Cr)					11	1.8 (1–4)		
	Caligidae gen. et sp. indet. (Cr)	23	1.9 (1–4)	70	3.6 (1–1)	74	8.9 (1–44)	95	22.3 (4–56)
	Pennellidae gen. et sp. indet. (Cr)								
	Thysanote sp. (Cr)					66	1.8 (1–2)		
Endoparasites	Myxozoa gen. et sp. indet. (My)			15				15	
	Haploporidae gen. et sp. indet. (D)	29	4.1 (1–15)	20	1.5 (1–3)				
	Pseudohapladena cf. *scatophagi* (D)					9	10.6 (1–29)		
	Digenea indet. (D)			65	18.3 (1–145)			5	1 (1)
	Procamallanus sp. (N)					14	1.4 (1–2)		
	Cucullanus sp. (N)					29	3.2 (1–11)	100	12.5 (2–32)
	Capillaria sp. (N)					14	1.6 (1–3)	60	2.3 (1–9)
	Nematoda indet. (N)	9	2.3 (2–3)						
	Filisoma cf. *indicum* (Ac)					29	8.9 (1–21)	50	1.9 (1–3)

Anakan Lagoon. In 2006, the result was similar, with 12–17 ectoparasite species for *M. cephalus* and 9–12 ectoparasites for *S. argus* in Areas 2 (LF) and 3 (LS), respectively. The number of endoparasite species ranged from three to four to five to eight for the two fish species and areas of investigation (Tables 2 and 3).

Epinephelus coioides inside the seawater-influenced Segara Anakan lagoon harbored five ecto- (including two *Pseudorhabdosynochus* species) and five endoparasites during both the rainy and dry seasons. The cultivated *E. coioides* at BBL Lampung harbored more endoparasites (12) than ectoparasites (six, including two *Pseudorhabdosynochus* species). No significant difference was observed for the number of endoparasites (ten) and ectoparasites (nine, including two *Pseudorhabdosynochus* species) in the free-living fish from Ringgung (Table 4). The number of endoparasite species (13) was much higher compared with the number of ectoparasites (four, including two *Pseudorhabdosynochus* species) in the cultivated *E. fuscoguttatus* from the Thousand Islands (Table 5).

The lowest ratio from the numbers of ectoparasite species vs. the numbers of endoparasite species was calculated for cultivated *E. fuscoguttatus* in the Thousand Islands (0.3), compared with free-living (0.9) and cultivated (0.5) *E. coioides* from Lampung Bay. *E. coioides* from Area 3 (LS) in Segara Anakan Lagoon had a ratio of 1.0 during

Table 3 Prevalence (*P*), intensity (*I*) and mean intensity (I_m) of the collected parasite species from the studied fish species (AREA 3)

Parasites (AREA 3)		*Mugil cephalus*				*Sactophagus argus*				*Epinephelus coioides*			
		Rainy season 04/05		Dry season 06		Rainy season 04/05		Dry season 06		Rainy season 04/05		Dry season 06	
		P [%]	I_m (*I*)	*P* [%]	I_m (*I*)	*P* [%]	I_m (*I*)	*P* [%]	I_m (*I*)	*P* [%]	I_m (*I*)	*P* [%]	I_m (*I*)
Ectoparasites	*Trichodina* spp. (P)	8	1 (1)	55	17.2 (1-73)	56	2.4 (1-6)	70	15.2 (1-56)	55	2.5 (1-20)	55	64.9 (1-347)
	Transversotrema sp. (D)			80	18 (1-111)			5	5 (5)				
	Metahaliotrema scatophagi (Mo)			5	36 (36)	87	14.1 (1-44)	95	61.9 (15-342)				
	Haliotrema cf. *mugilis* (Mo)			20	11.6 (3-33)								
	Pseudorhabdosynochus sp. (Mo)							5	29 (29)	95	75.3 (6-212)	95	451.2 (5-1238)
	Dactylogyridae gen. et sp. indet. (Mo)	49	6.1 (1-31)										
	Mazocreadiidae gen. et sp. indet. (Mo)			10	1 (1)								
	Metamicrocotyla sp. (Mo)	6	2 (2)	5	1 (1)								
	Diplectanidae gen. et sp. indet. (Mo)			75	11.6 (12-312)								
	Monogenea indet. (Mo)	29	7.1 (1-29)										
	Zeylanicobdella arugamensis (H)	3	1 (1)	5	1 (1)	11	1 (1)			10	1 (1)		
	Nothobomolochus sp. (Cr)	26	1.8 (1-5)	15	2.3 (1-5)								
	Ergasilus sp. 1 (Cr)	40	4.1 (1-30)	75	13.7 (1-89)								
	Ergasilus sp. 2 (Cr)					9	2.3 (1-4)						
	Ergasilus sp. 3 (Cr)					74	19 (1-233)	55	11.2 (1-41)				
	Ergasilidae gen. et sp. indet. (Cr)	29	3.2 (1-8)	10	2 (1-3)								
	Caligus acanthopagri (Cr)			15	2 (1-3)	86	3.2 (1-16)	65	3.4 (1-8)				
	Caligus epidemicus (Cr)							50	2.5 (1-7)				
	Caligus cf. *epinepheli* (Cr)			30	1.8 (1-6)			5	1 (1)	5	1 (1)		
	Caligus rotundigenitalis (Cr)	11	4.5 (1-15)	10	2 (1-3)								
	Caligus sp. (Cr)			5	1 (1)			10	1 (1)				
	Caligidae gen. et sp. indet. (Cr)	26	2.6 (1-8)	25	2.2 (1-4)	80	3.5 (1-23)	85	8.8 (1-24)				
	Thysanote sp. (Cr)					66	1.7 (1-2)						
	Cymothoa sp. (Cr)					29	1.4 (1-2)	65	2.2 (1-5)				
	Alcirona sp. (Cr)											20	1.3 (1-2)
	Corallanidae gen. et sp. indet. (Cr)											5	1 (1)
	Pennellidae gen. et sp. indet. (Cr)			10	1.5 (1-2)			5	2 (2)	71.4	30.1 (1-233)	95	44.5 (1-109)
	Gnathiidae gen. et sp. indet. (Cr)					5.7	1 (1)						
Endoparasites	Myxozoa gen. et sp. indet. (My)			45				40				15	
	Bucephalidae gen. et sp. indet. (D)							10	1.5 (1-2)	5	1 (1)		
	Didymodiclinus sp. (D)									81	11.5 (1-31)	60	2.5 (1-8)
	Lecithobotrys sp. (D)	3	1 (1)	20	28.5 (10-47)								

Haploporidae gen. et sp. indet. (D)	26	5.4 (2-11)	5	1 (1)								
Pseudohapladena cf. *scatophagi* (D)					6	1 (1)	25	5.4 (1-18)				
Digenea indet. (D)			55	3.6 (1-8)			35	5.1 (2-10)				
Bothriocephalus sp. (Ce)									24	1.2 (1-2)	45	2.6 (1-5)
Cucullanus sp. (N)							75	7 (1-54)				
Philometra sp. (N)									10	1.5 (1-2)	15	1.3 (1-2)
Philometroides sp. (N)									67	3.1 (1-12)	50	2.1 (1-4)
Capillaria sp. (N)							50	5.1 (1-4)				
Nematoda indet. (N)							10	2.5 (1-4)			5	1 (1)
Filisoma cf. *indicum* (Ac)					46	3.9 (1-22)	55	3.5 (1-13)				

both samples, in the rainy season 2004/5 and the dry season 2006. Highest ectoparasite/endoparasite ratios were calculated for *M. cephalus* in Area 2 (LF) (8.0 and 6.0 during rainy and dry seasons, respectively) and Area 3 (4.5 and 5.7); with values for *S. argus* in Area 2 ranging from 2.0 to 2.3 and in Area 3 from 5.0 to 2.0 during both sampled seasons.

Metazoan endoparasite diversity (Shannon–Wiener index)

The highest endoparasite diversity (1.58) was recorded for *E. fuscoguttatus* from the Thousand Islands (MM), followed by free-living *E. coioides* (1.39) in Ringgung (CE) and cultivated specimens (0.71) at BBL Lampung (CM), both Lampung Bay. The endoparasite diversity for *E. coioides* from Area 3 (LS) in Segara Anakan lagoon ranged from 0.66-1.23 in the rainy season 2004 and the dry season 2006 respectively. The endoparasite diversity for *S. argus* within Segara Anakan Lagoon was higher in Area 2 (LF) compared to Area 3 (LS; 1.18 vs. 0.14) in 2004 and lower (0.54 vs. 1.31) in 2006. The endoparasite diversity for *M. cephalus* was low during both sampled years and seasons, but higher in Area 3 (LS) compared with Area 2 (LF; Table 6).

Visual integration

To visualize the three utilized parasite bioindicators, the values obtained for the different fishes and sampling localities were transferred onto a positive–negative axis as given in Figs. 2 and 3. Theoretical threshold values are introduced to distinguish between positive, suitable conditions and negative, non-suitable conditions. A 50% prevalence of trichodinid ciliates was chosen as a threshold for unfavorable conditions, ranging from a possible 0–100% and indicating an increasing bacterial load within the surrounding water body. The threshold value 1.0 for the ecto/endoparasite ratio represents an equal number of ecto- and endoparasites, where lower numbers of endoparasites indicate unnatural parasite composition within the studied fish species. The endoparasite diversity threshold of 1.25 is in the middle of its range (0–2.5), and low endoparasite diversity refers to unnatural environmental (tropical) conditions. The choice of the threshold for each metric so far is arbitrary, and not yet allows justified judgment for decision makers. These values will be altered in the future, when currently taken time series for the parasite infections from the selected fish species and localities become available.

The three bioindicators are visualized according to Bell and Morse (2003) and arranged in a triangular orientation, with the negative values oriented towards the center of the triangle. The resulting star graphs are given in Figs. 4, 5, 6 and 7, for *M. cephalus* (Fig. 4) and *S. argus* (Fig. 5) in Segara Anakan Lagoon as well as for *E. coioides* from the

Table 4 Prevalence (*P*), intensity (*I*) and mean intensity (I_m) of the collected parasite species from *E. coioides* (LAMPUNG BAY)

		Epinephelus coioides Rainy season 02/03			
		Mariculture (BBL)		Free-living (Ringgung)	
		P [%]	I_m (*I*)	*P* [%]	I_m (*I*)
Ectoparasites	*Trichodina* spp. (P)	27	6 (1-20)	5.7	1 (1)
	Benedenia epinepheli (M)	46.7	1.8 (1-4)		
	Neobenedenia melleni (M)	3.3	1 (1)		
	Capsalidae gen. et sp. indet. (M)	66.7	2.7 (1-7)	25.7	4.7 (1-20)
	Pseudorhabdosynochus spp. (M)	100	65.2 (17-156)	100	104.4 (2-547)
	Sagum epinepheli (CR)			2.9	1 (1)
	Alcirona sp. (CR)			74.3	10.3 (1-34)
	Argathona rhinoceros (CR)			11.4	1.3 (1-2)
	Pennellidae gen. et sp. indet. (CR)			85.7	31.1 (1-208)
	Gnathiidae gen et sp. indet. (CR)			2.9	1 (1)
Endoparasites	Microsporea gen. et sp. indet. (MI)	50		5.7	
	Myxozoa gen. et sp. indet. (MY)	40		100	
	Prosorhynchus australis (D)	3.3	1 (1)		
	Prosorhynchus luzonicus (D)	80	8.4 (1-26)	14.3	9.8 (1-43)
	Allopodocotyle epinepheli (D)			68.6	5.7 (1-18)
	Parotobothrium balli (C)	20	2 (1-5)		
	Scolex pleuronectis (C)	10	1.3 (1-2)	11.4	4.3 (1-10)
	Hysterothylacium sp. I (N)	6.7	1 (1)		
	Terranova sp. (N)	16.7	1.2 (1-2)	2.9	1 (1)
	Raphidascaris sp. I (N)	6.7	1 (1)	2.9	1 (1)
	Camallanus carangis (N)	6.7	1.5 (1-2)		
	Philometra ocularis (N)			14.3	2.2 (1-4)
	Philometra sp. (N)			45.7	2.1 (1-4)
	Philometroides sp. (N)			11	2.3 (2-3)
	Serrasentis sagittifer (A)	6.7	1 (1)		
	Gorgorhynchoides sp. (A)	10	1 (1)		

anthropogenic influenced Area 3 (LS) in Segara Anakan Lagoon in comparison with *E. fuscuguttatus* from a mariculture facility in the Thousand Islands (MM, Fig. 6), and with free-living *E. coioides* (CE) and specimens from an open-water net cage in Lampung Bay (CM, Fig. 7).

Discussion

Fish parasites as biological indicators have already been utilized to indicate various kinds of pollutants or environmental situations, such as bacterial biomass (Palm and Dobberstein 1999), heavy metals (Sures and Siddall 2003) or environmental stress (Landsberg et al. 1998; for reviews of parasitological bioindicators, see Lafferty 1997; Marcogliese and Cone 1997; Overstreet 1997; Williams and MacKenzie 2003; Marcogliese 2005). In most of these cases, specific parasite species or ecological parameters such as the prevalence and intensity of infection with different parasites have been applied to demonstrate faunistic differences between polluted (influenced) and non-polluted sampling sites. Most recently, Sasal et al. (2007) utilized the entire parasite community of apogonid fish to detect anthropogenic influences (urban and industrial pollution) on two coral reef lagoons in New Caledonia. The parasite community (restricted to the higher taxa, e.g., larval Cestoda, adult Crustacea, larval and adult Digenea, larval Nematoda) was not the same in the two bays, and some parasite taxa were found to be significant indicators of specific environmental conditions. The difficulty in utilizing these organisms as bioindicators for environmental health is that all parasites, and if applicable, their life cycle stages, can react differently and also contradictory to environmental change. For example, ectoparasitic trichodinids can favor polluted or bacteria-enriched waters (Yeomans et al. 1997; Palm and Dobberstein 1999; Ogut and Palm 2005) while endoparasitic helminths can disappear due to the effect of the pollutant on the intermediate stages and hosts. Other parasites can be quite tolerant to environmental stressors, such as the acanthocephalans that even accumulate heavy metals in the host's intestine (Sures 2003).

Table 5 Prevalence (*P*), intensity (*I*) and mean intensity (I_m) of the collected parasite species from *E. fuscoguttatus* (THOUSAND ISLANDS)

Parasites		Rainy season 04/05	
		P [%]	I_m (*I*)
Ectoparasites	*Benedenia epinepheli* (Mo)	87	5.2 (1-14)
	Capsalidae gen. et sp. indet. (Mo)	90	6 (1-35)
	Pseudorhabdosynochus spp. (Mo)	100	344.4 (116-1006)
Endoparasites	Myxozoa gen. et sp. indet. (My)	69	
	Prosorhynchus australis (D)	3	1 (1)
	Prosorhynchus cf. *crucibulum* (D)	3	1 (1)
	Enenteridae gen. et sp. indet. (D)	3	2 (2)
	Lecithochirium magnaporum (D)	23	1.1 (1-2)
	Allopodocotyle epinepheli (D)	3	1 (1)
	Parotobothrium balli (C)	23	1 (1)
	Scolex pleuronectis (C)	40	3.9 (1-18)
	Hysterothylacium sp. (N)	6	1(1)
	Terranova sp. (N)	26	1.7 (1-4)
	Raphidascaris sp. I (N)	63	3 (1-6)
	Raphidascaris sp. II (N)	3	1 (1)
	Camallanus carangis (N)	11	1 (1)

To provide a 'holistic view in sustainable development', Bell and Morse (2003) used a visual integration method to utilize different indicators. Merging a variety of indicators into a single one can provide the bigger picture to, e.g., decision makers that often do not need to know all details. The authors attempted to get around two major problems by using this method: (1) complexity. Indicators may be sensible from a technical perspective, but one can lose sight of the bigger picture and become enmeshed in details; (2) compromise. An indicator framework may not allow an immediately apparent analysis of trade-offs between some indicators and others. Artificial thresholds separate tolerable from non-tolerable values and enable a generalized situation overview by using independent markers. Within the present study, we applied this method by using three parasitological indicators to visualize the parasitation of four different fish species in different sampling sites and seasons: (1) the prevalence of trichodinid ciliates was used to indicate bacterial load at the sampled localities, according to Palm and Dobberstein (1999) and Ogut and Palm (2005); (2) the ratio of ecto- versus endoparasites is used to indicate the natural parasite composition in a tropical marine habitat, where the number of endoparasites in predatory fish is often higher than the number of ectoparasites (Vidal-Martínez et al. 1998; Jakob and Palm 2006; Rückert et al. 2009b); and (3) the endohelminth parasite diversity, which is used to indicate the exclusion of some species from a natural or non-natural (open-water net cage mariculture) environment (see Rückert 2006; Rückert et al. 2009b).

The high biodiversity of fish parasites at the studied tropical localities and the study of different fish species make a direct comparison of single ecological parameters such as prevalence and intensity of infection problematic (compare Tables 2, 3, 4 and 5). For example, for the record of a rare parasite species, it is difficult to connect the occurrence of a specific rare species to favorable or non-favorable environmental conditions. However, the occurrence of a high number of rare species increases species richness, resulting in a parasite-rich infection that is typical for many tropical marine fishes under natural conditions. Visual integration of the three selected parasite

Table 6 Shannon–Wiener index and evenness (in brackets) for the endoparasites of the studied fish species during different seasons

Fish species and location	Rainy season	Dry season 2006
Mugil cephalus Area 2 (04/05)	0 (0)[a]	0 (0)[a]
M. cephalus Area 3 (04/05)	0.37 (0.15)	0.05 (0.05)
Scatophagus argus Area 2 (04/05)	1.25 (0.47)	0.54 (0.45)
S. argus Area 3 (04/05)	0.14 (0.06)	1.31 (0.81)
Epinephelus coioides Area 3 (04/05)	0.66 (0.41)	1.23 (0.89)
E. coioides BBL, Lampung Bay (02/03)	0.71 (0.31)	–
E. coioides Ringgung, Lampung Bay (02/03)	1.39 (0,70)	–
E. fuscoguttatus, Thousand Islands (04/05)	1.58 (0.64)	–

[a] Calculation was not possible for *Mugil cephalus* based on a single endoparasite species

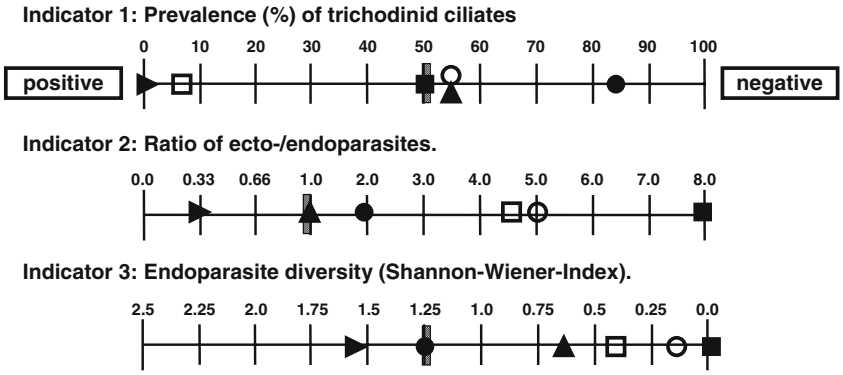

Fig. 2 Indicator transfer onto a positive-negative axis. The markings give the data points for the studied fishes and habitats in 2004 from Segara Anakan Lagoon and for 2005 from the Thousand Islands. The *bars* show theoretical thresholds for suitable conditions. *filled upright triangle Epinephelus coioides* Area 3, *filled right-facing triangle E. fuscoguttatus* Thousand Islands (January 2005), *filled square Mugil cephalus* Area 2, *open square M. cephalus* Area 3, *filled circle Scatophagus argus* Area 2, *open circle S. argus* Area 3

bioindicators resulted in star graphs with most values from Segara Anakan Lagoon oriented towards the center of the triangle. *S. argus*, *M. cephalus*, and *E. coioides* had significant infestations with trichodinid ciliates, a high number of ectoparasites compared to endoparasites, and the endohelminth diversity was relatively low. Within the lagoon, the differences between the two sampled locations and seasons were not so obvious. It appeared however, that the freshwater influenced central lagoon had more trichodinids compared with those from the seawater influenced lagoon ecosystem. For all sampled fishes and both seasons, the resulting star graph demonstrated the same trend (Figs. 4 and 5). This is remarkable because the three studied fish species from the lagoon are known for different feeding ecologies and ecological needs.

Another picture can be seen if comparing the sampled *E. coioides* from Segara Anakan Lagoon during 2004 and 2006 with free-living specimens and those from an open-water net cage in Lampung Bay (Fig. 7). Free-living *E. coioides* had lowest values for trichodinid ciliates and highest endoparasite diversity, with intermediate values for the specimens from the mariculture farm. Similarly, even cultured groupers *E. fuscoguttatus* from net cages in a non-polluted marine environment in the Thousand Islands had much better values compared to *E. coioides* from Segara Anakan. While both resulting triangles for *E. coioides* from Segara Anakan were still under the given threshold, with better values for the dry season 2006 compared to the rainy season 2004, the data from the mariculture (*E. coioides* and *E. fuscoguttatus*) and free-living *E. coioides* from a clean environment were beyond the threshold. A low number of trichodind ciliates were found, the ecto/endoparasite ratio was low and the endohelminth diversity was high. However, in the latter, it must be kept in mind that anti-parasite treatment inside the mariculture facilities might influence the observed ecto/endoparasite composition.

The visual integration of the three chosen parasite bio-indicators allows comment on the environmental status at the sampled localities, especially if comparing 'natural' or stable (free-living *E. coioides*) with 'non-natural', influenced or altered tropical environments (*E. coioides* in Lampung Bay and Segara Anakan). According to the chosen parasite bioindicators, Segara Anakan Lagoon is a distinctive habitat,

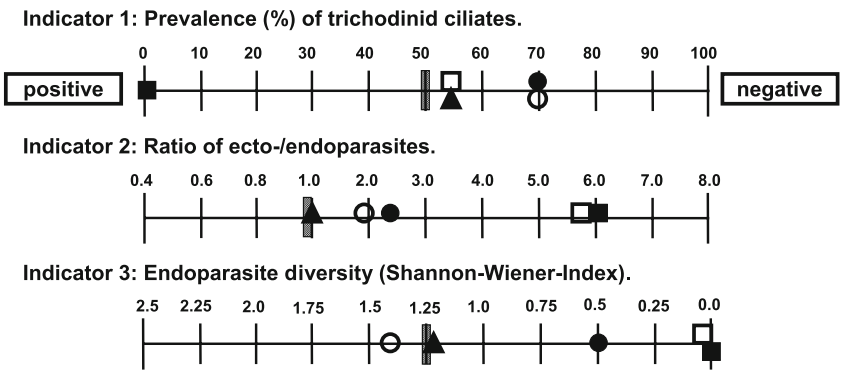

Fig. 3 Indicator transfer onto a positive–negative axis. The markings give the data points for the studied fishes and habitats in 2006. The *bars* show theoretical thresholds for suitable conditions. *filled upright triangle Epinephelus coioides* Area 3, *filled square Mugil cephalus* Area 2, *open square M. cephalus* Area 3, *filled circle Scatophagus argus* Area 2, *open circle S. argus* Area 3

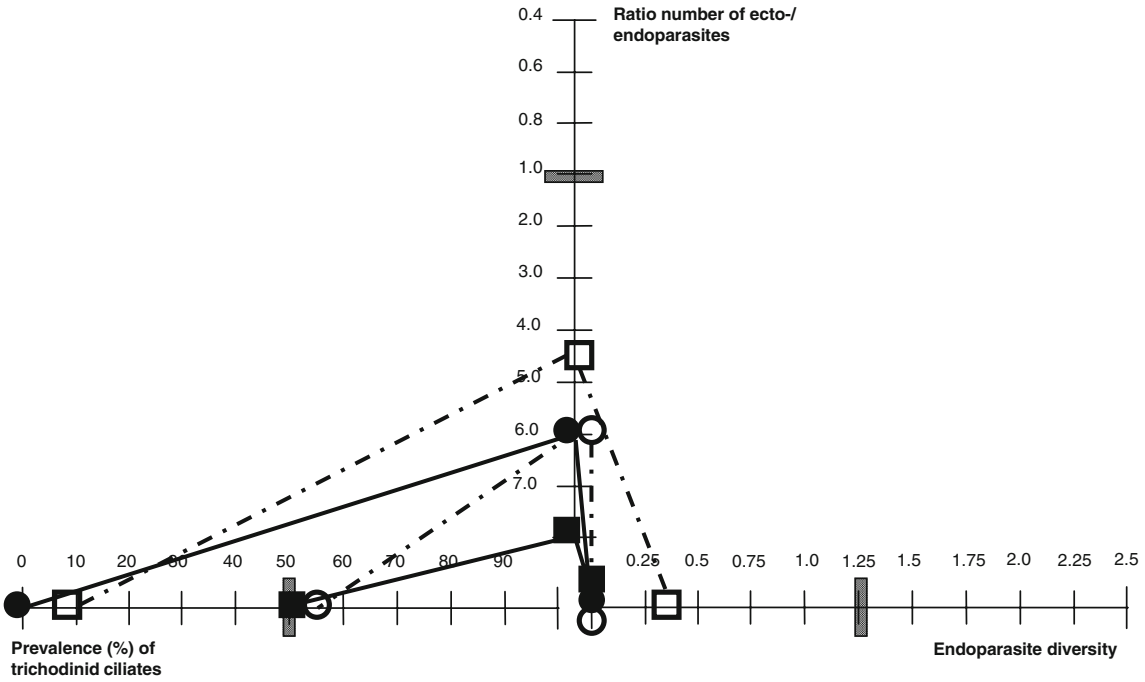

Fig. 4 Visual indicator integration for *Mugil cephalus* during different sampling periods and habitats. The *bars* show theoretical thresholds for suitable conditions. *filled square Mugil cephalus* 2004 Area 2, *open square M. cephalus* 2004 Area 3, *filled circle M. cephalus* 2006 Area 2, *open circle M. cephalus* 2006 Area 3

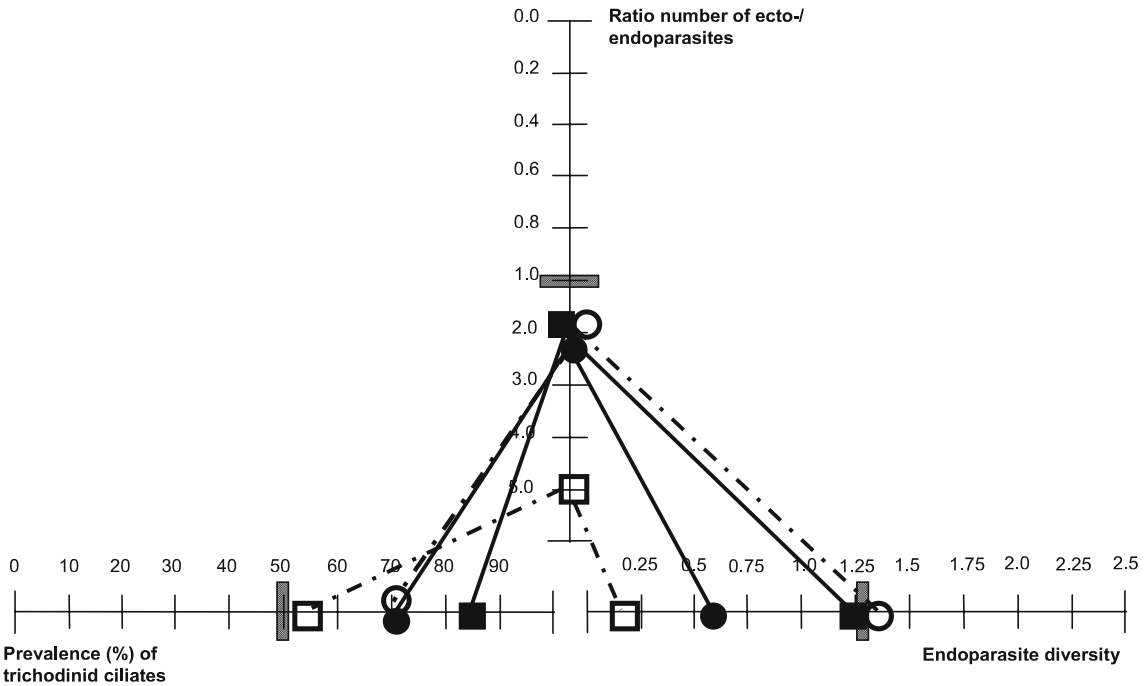

Fig. 5 Visual indicator integration for *Scatophagus argus* during the different sampling periods and habitats. The *bars* show theoretical thresholds for suitable conditions. *filled square Scatophagus argus* 2004 Area 2, *open square S. argus* 2004 Area 3, *filled circle S. argus* 2006 Area 2, *open circle S. argus* 2006 Area 3

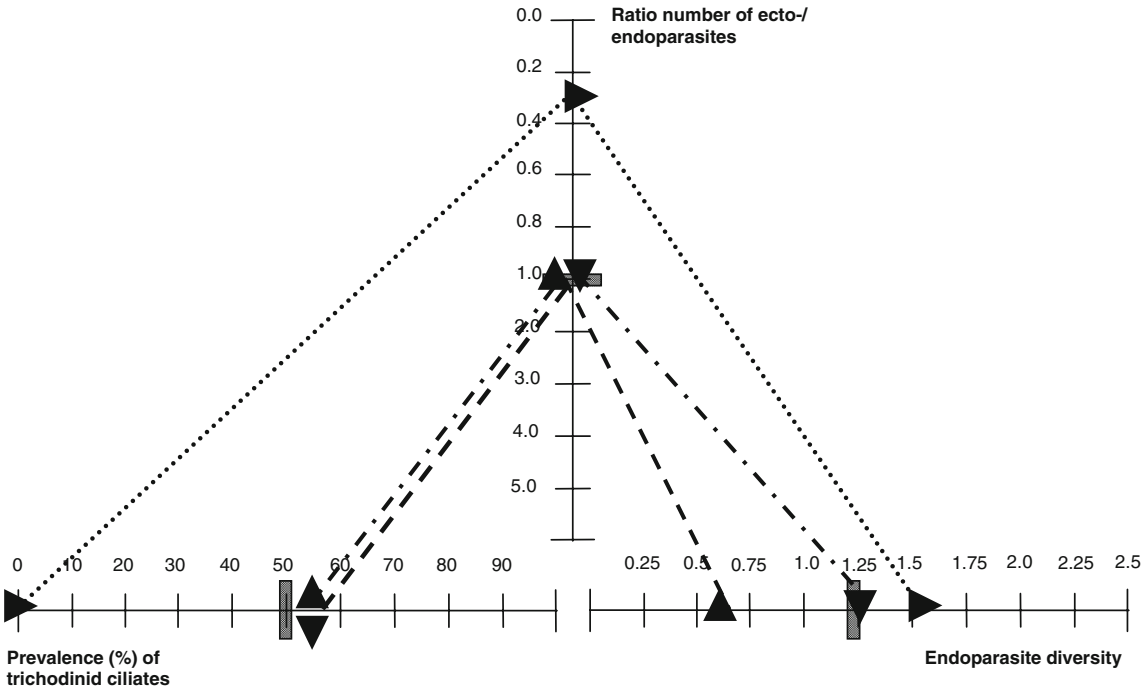

Fig. 6 Visual indicator integration for *Epinephelus coioides* and *E. fuscoguttatus* during different sampling periods and habitats. The *bars* show theoretical thresholds for suitable conditions. *filled upright triangle E. coioides* 2004 Area 3, *filled inverse triangle E. coioides* 2006 Area 3, *filled right-facing triangle E. fuscoguttatus* Thousand Islands (January 2005)

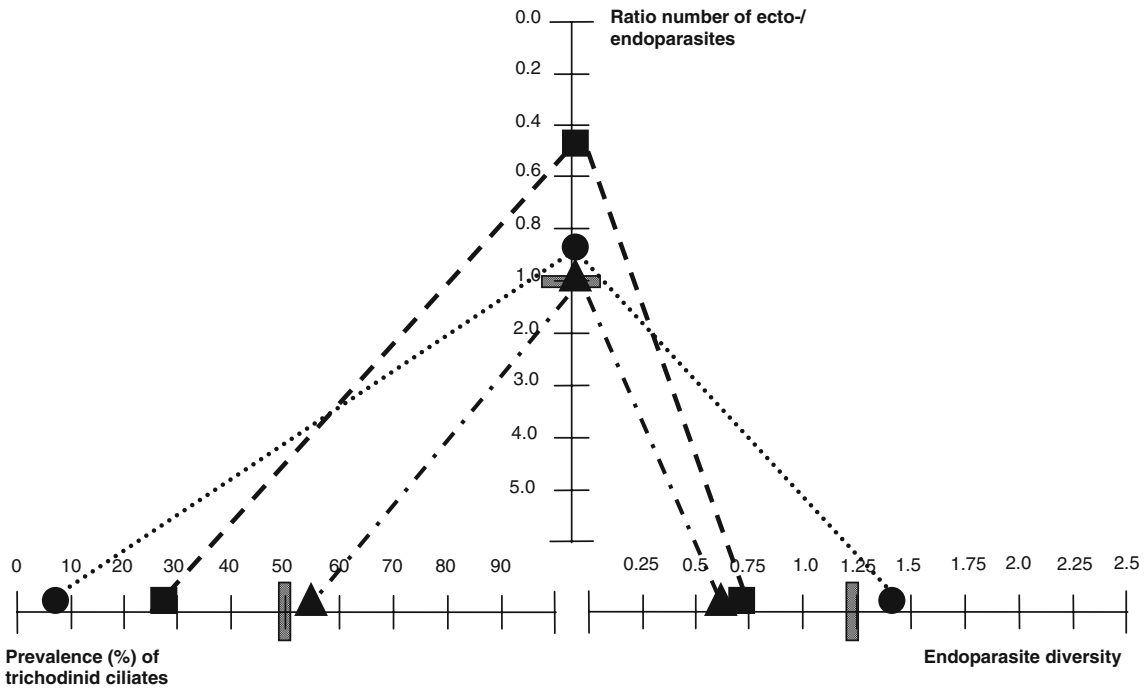

Fig. 7 Visual indicator integration for *Epinephelus coioides* from Segara Anakan compared with Lampung Bay during the rainy season. The *bars* show theoretical thresholds for suitable conditions. *filled upright triangle E. coioides* Segara Anakan, *filled square E. coioides* BBL Lampung Bay, *filled circle E. coioides* Lampung Bay

compared with a natural tropical marine environment such as Lampung Bay (Rückert 2006; Rückert et al. 2009a, see Fig. 7) or the Thousand Islands. This is not astonishing because within a typical mangrove ecosystem, which is underlying high anthropogenic and natural stressors such as changing environmental conditions (salinity, sedimentation), the represented marine fish species and parasites have to live and adapt to such conditions. According to Jennerjahn et al. (2009), despite an extremely high population density and intensive agriculture in the hinterland, nutrient pollution and eutrophication in the lagoon is low to moderate on a global scale (oligo- or slightly mesotrophic, data taken also from 2004–6). While probably a short residence time of water in the shallow central lagoon (Area 2, LF) rapidly exports a major part of the land-derived nutrients to the sea, natural processes (e.g., decompostation) exert major control on the nutrient inventory. According to Jennerjahn et al. (2009), the magnitude of nutrient inputs into the central lagoon may be generally lower during the dry season because of lower land-derived inputs. With increasing dryness the combined effects of tidal dynamics and recycling in mangroves gain importance for the nutrient budget of the central lagoon. Concentrations of nitrate and ammonium were much higher in mangrove pore water than in lagoon water, likely caused by microbial reworking of organic matter (Jennerjahn et al. 2009). The prevalence of trichodinid ciliates was highest in the central lagoon, though the available data for Segara Anakan hardly indicate any signs of nutrient pollution and eutrophication. Consequently, the occurrence of trichodind ciliates on the studied fishes is linked to microbial loading in the system, as earlier suggested for another marine habitat by Palm and Dobberstein (1999).

The lagoon might be considered as a risk habitat for parasitic infections (especially through pathogenic ectoparasitic monogeneans and crustaceans) in the case of finfish mariculture, as can be seen by a high diversity of ectoparasites on the sampled fishes (Yuniar et al. 2007). An interesting result is the positive evaluation of the mariculture sites for both, the groupers from BBL in Lampung Bay (*E. coioides*) and especially from the Thousand Islands (*E. fuscoguttatus*), as can be seen by positive indicator values for the sampled mariculture fish. In the former, trash fish feeding and floating net cages enable transmission of ecto- and endoparasites into the cultivated fish (Rückert 2006; Rückert et al. 2009a). In the latter, good indicator values might be explained by the novelty of the mariculture site (founded in 2001) and the use of a low number of open water floating net cages with low stocking densities. The Thousand Islands is one of the marine national parks and can be seen as a relatively non-polluted and clean habitat. This is favorable even for fish that is kept under non-natural conditions within a mariculture facility.

Finfish mariculture is a rapidly developing industry in Indonesia (Harris 2001) and other maritime nations in the tropics, such as, e.g., the Philippines and Thailand. To date, only 0.03 % of the potential area for mariculture is used in Indonesia (FIRI 2006) and new mariculture facilities are still developed on a trial and error bases to match the rising demand and to increase the benefit to the coastal communities. However, not all chosen locations are equally useful, underlying different risks for the cultivated fishes, the farms and the coral reef environment. According to our data and by using fish parasites as bioindicators, the inner part of Segara Anakan Lagoon (Area 2 and 3) appears to be a non-favorable site for, e.g., the commercial cultivation of grouper. This is not due to nutrient pollution or eutrophication but generated through volatile, regularly changing environmental conditions (e.g., rainy vs. dry season, sedimentation, salinity). The sampled groupers and two commercial fish species showed the same result. In contrast, the environmental status surrounding the cultivated groupers in Lampung Bay and on the Thousand Islands appears to be still favorable, indicating relatively natural environmental conditions at the mariculture sites in 2002/2003 and 2005, respectively. According to our knowledge, no major disease outbreak has occurred in the farm on the Thousand Islands, with some problems in the *E. coioides* mariculture in Lampung Bay. The application of the star graph is an easy and understandable tool to compare different tropical locations and environments, and might be applicable for a regular monitoring of grouper mariculture sites and their conditions. The study of 35 grouper specimens (possible within 2 weeks) within definitive intervals (e.g., each season) seems to be sufficient to monitor the environmental status and change at a respective sampling site, especially considering already existing routine parasitological examination in properly managed grouper mariculture. Further studies are needed to compare the above-studied sites with other tropical environments in order to better define threshold values and to detect small-scale local and seasonal variation.

We have attempted to present a method that can visualize habitat differences by using parasite metrics together on a single figure. Using this approach, we could demonstrate that fish parasites can be successfully used to compare the environmental situation of different Indonesian localities, a mangrove ecosystem in southern Central Java (LF, LS), a mariculture site (CM) and the natural surroundings (CE) in Lampung Bay, South Sumatra, and a mariculture site (MM) in the Thousand Islands, North Java coast. We are aware that the selection of specific parasite bioindicators is a matter of discussion, with different parasite metrics indicating different, but possibly also interconnected environmental factors. However, the chosen bioindicators within the present study successfully determine environmental differences at the chosen tropical localities (also see Rückert et al. 2009b). For the first time, a star graph is applied to visualize differences in parasite composition and diversity. We do suggest that the

sampled lagoon can be considered problematic for intensive grouper mariculture, while the already established mariculture sites in Lampung Bay and the Thousand Islands still provide suitable conditions for the cultivated fish. Because parasitic infestations and fish diseases are major obstacles to successful fish farming, and these organisms likewise can describe the "health" status of the fish and the environment, fish parasite indicators and the use of the star graph should be further developed and can be a future method of choice to measure tropical ecosystem health.

Acknowledgments This paper was presented at the International Symposium of the Fisheries Society of the British Isles (FSBI) in Cardiff, Wales, 21-25.07.2008. Financial support was provided by the German Academic Exchange Service (DAAD) (SR), the German Federal Ministry for Education and Science (BMBF Grant No. 03F0391A, (HWP, SR)) within the framework of the joint Indonesian-German research program SPICE (Science for the Protection of Indonesian Coastal Marine Ecosystems), and the German Research Council (DFG PA 664/4-1 and 2) (HWP). We are thankful to two anonymous reviewers that helped to improve the manuscript.

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