Preliminary observations on the effects of artificial light on the marine environment, with special reference to three fish species of commercial value protected by Miramare Marine Reserve

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(Received, January 27, 2003; accepted March 19, 2003)

Abstract - Aims of this study are to give a contribution to the knowledge on the widespread use of light fishing in the Gulf of Trieste, and to obtain a preliminary evaluation of the effects of light fishing on a marine protected area, to improve the quality of marine resource management. The work consists of two main sections: the first one consists of several measurements of underwater light attenuation data collected in the marine environment, characterising the attenuation spectral distribution of different fishing lamps and plotting their vertical profiles of light attenuation in seawater; the second one regards the effects of artificial light on fish behaviour were investigated in laboratory conditions, evaluating levels of aggregation, phototaxis and photokinesis in three species of commercial interest: the sea bass (*Dicentrarchus labrax*), the common grey mullet (*Mugil cephalus*), and the sea bream (*Sparus aurata*). All species responded actively to variations in light intensity, and to some extent to lights of different colours. In continuation to this study, we are currently attempting to transfer the approach used in the aquarium to open sea conditions, utilizing echosounder and fixed recording systems to collect the data.

1. Introduction

Most fish utilize vision as a means of orientation and to perform diurnal activities, light variations can therefore have an influence on their behaviour and circadian rhythms of activity.

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Many species of commercial interest are also affected by artificial light, by schooling and swimming towards the light source; this behaviour has often been exploited by fishermen, who use fishing lamps to improve catches (Ben-Yami, 1976; Kawamura, 1986; Freón and Misund, 1999).

This study presents some preliminary observations on the effects of artificial light on the marine environment, focusing on modalities of underwater light attenuation and on fish reactions to light. The work is organized into two main sections: in the first, we describe the seawater vertical profiles of light attenuation for fishing lamps with different nominal characteristics, considering the energy values both in the entire PAR range and in seven distinct wavelengths of the visible spectrum. In the second, we describe the effects of lights of variable intensity and wavelength on levels of aggregation, phototaxis and photokinesis in three fish species of commercial interest: the sea bass (*Dicentrarchus labrax*), the common grey mullet (*Mugil cephalus*), and the sea bream (*Sparus aurata*). The first part of the work was carried out in the open sea, while the second part was carried out in a confined environment, for logistical reasons. In continuation of such a preliminary study, we are currently testing our results in Miramare Marine Reserve waters, with the aim of obtaining further suggestions for the rationalisation of light fishing and thus improving the management of the marine resources.

2. Material and methods

2.1. Underwater light attenuation

The modalities of underwater light attenuation are described for the following four lamps: 1000 Watt incandescence, 1000 Watt halogen, 1500 Watt halogen and 400 Watt metallic iodide. All the measurements were repeated three times during distinct sampling sessions in order to define underwater optical characteristics in different seawater conditions. Moreover, some commercial fishing lamps were tested during a single sampling session. The four lamps were tested from a 8.56 m motor-boat of the Miramare Marine Reserve, by placing each lamp astern about one meter above sea level and lowering the sensors nearby. The commercial fishing lamps were measured by placing the motor-boat close to a Beta 2000 Trieste Marine fishing vessel. Data were recorded using both a Li-Cor LI-192SA Underwater quantum sensor and three Satlantic sensors. The first instrument measured light intensity throughout the visible spectrum (PAR 400-700 nm), with minimum sensitivity of $0.5*10^{-3}$ $\mu E\ m^{-2}\ s^{-1}$. Two of the Satlantic sensors measured the upward radiance and the downward irradiance, respectively, the third, measured the irradiance in the air, and was used as a reference. Each sensor recorded in one of seven channels, centred on the wavelengths (λ) 411.7, 442.8, 490.6, 510.1, 554.4, 665.2, 682.5 nm. The irradiance sensor sensitivity was $5*10^{-3}$ $\mu W\ cm^{-2}\ nm^{-1}$, the radiance sensor sensitivity was 10^{-4} $\mu W\ cm^{-2}\ nm^{-1}\ sr^{-1}$ and the reference sensor sensitivity was $8.7*10^{-3}$ $\mu W\ cm^{-2}\ nm^{-1}$. In addition, an Idronaut 316 multiparametric sensor was used in order to define the thermohaline properties of the water body during each sampling. For Satlantic sensors, only the downward irradiance and the reference in the air were taken into account, as all values of upward radiance were close to zero. The average energy values both in the PAR range and in each wavelength were calculated for each meter. The vertical profiles of light attenuation were then plotted.

2.2. Fish reactions to light

Behavioural reactions to light were tested on the following fish species: the sea bass (*Dicentrarchus labrax*), the common grey mullet (*Mugil cephalus*), and the sea bream (*Sparus aurata*).

For each species, 10 adults of medium size (15-20 cm) were tested in a 320x40x60 opaque tank. The light beam was emitted by a 1000 W halogen lamp and reached the fish through a lateral glass window (30x50 cm). Two sets of experiments were carried out: during the first set, the light intensity was progressively increased (from 0.2 to 68 $\mu Es^{-1}\,m^{-2}$: “mM”) or progressively decreased (from 68 to 0.2 $\mu Es^{-1}\,m^{-2}$: “Mm”) in eight discrete steps. During the second set the light colour was shifted throughout the visual spectrum, moving from the shorter to the longer wavelengths (from violet to red: “VR”) or from the longer to the shorter wavelengths (from red to violet: “RV”), using six different colour filters. Three replicates of each experiment were done. The following parameters were analysed from remote video-recorded sessions: 1) mean nearest neighbour distance (MNND), to identify the level of aggregation and, hence, the tendency to school; 2) mean percentage of fish in the area closest to (E) and farther from (A) the light source, to define the degree of positive or negative phototaxis; 3) mean percentage of still fish (S) and fish in rapid movement (RM), to identify the level of inhibition or activation, and thus the photokinetic response of the experimental group of fish.

3. Results

3.1. Underwater light attenuation

A preliminary analysis of the energies recorded close to the fishing vessel indicated that light intensity decreased exponentially along the water column (Fig. 1), as described also by Kirk (1996). Most energy emitted by the lamps was absorbed within the first 12 meters of depth. In all cases, the light intensity recorded deeper than 12 meters was less than 1 $\mu E\,m^{-2}\,s^{-1}$.

The absolute energy values for each lamp were different in the three sampling sessions, due to variations in the thermohaline structure of the waterbody (Figs. 2 and 3) however, the general pattern of the vertical profiles of light attenuation and the differences among lamps remained constant between sessions (Fig. 4). As expected, the 1500 Watt halogen lamp was the most efficient in the PAR range, considering both the absolute energy values within the first meters from the surface, and, the penetration in depth. The second most efficient lamps were the 1000 Watt halogen and the 400 Watt metallic iodide ones; the 1000 Watt incandescence appeared to be the least efficient lamp.

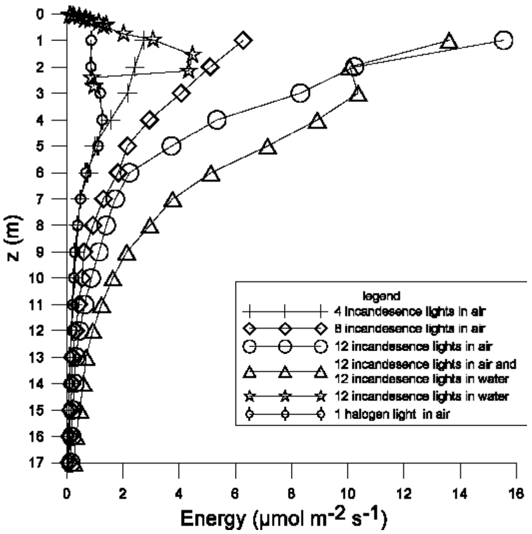

Fig. 1 - Energies recorded close to the fishing vessel indicated that light intensity decreased exponentially along the water column.

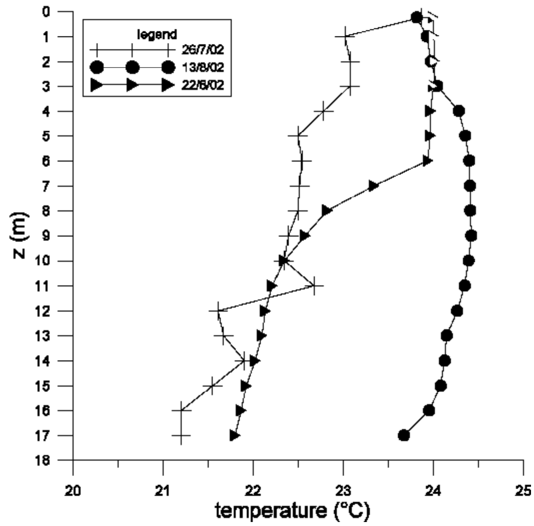

Fig. 2 - Variations in the thermic structure of the waterbody in the three sampling sessions.

The analysis of energy attenuation in the seven wavelengths produced the following results:

1. The two halogen and the incandescence lamps had a similar attenuation spectral distribution: the shorter wavelengths 411.7 and 442.8 nm (violet) were characterised by the lowest energies and scarce penetration. The longer wavelengths 665.2 and 682.5 nm (red) had definitely higher energies at the surface, but underwent rapid attenuation. The central wavelengths 490.6 nm (blue) and 510.1 nm (green) had intermediate energies at the surface but showed fairly good penetration. The 554.4 nm (green) wavelength was peculiar, as it

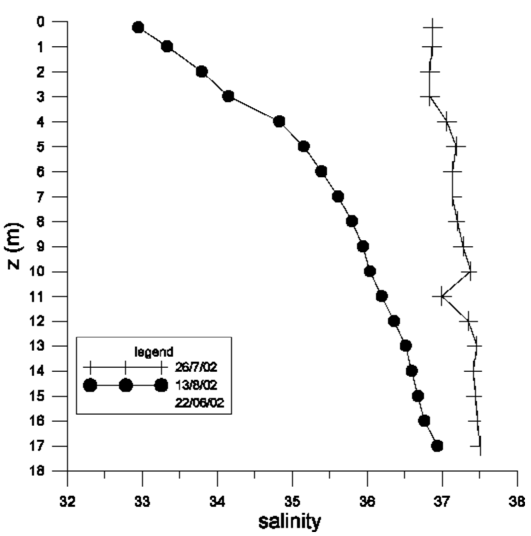

Fig. 3 - Variations in the haline structure of the waterbody in the three sampling sessions.

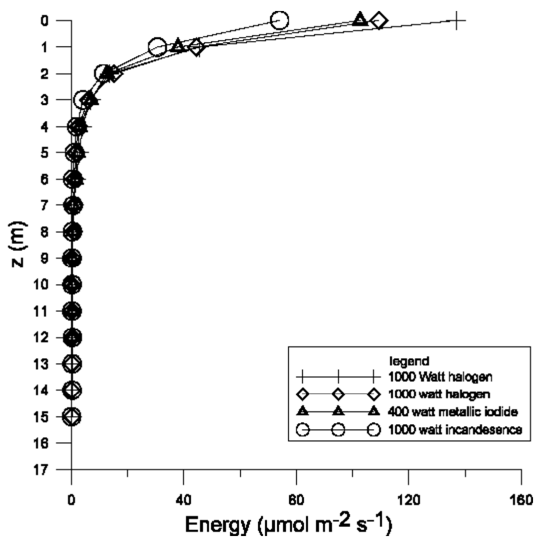

Fig. 4 - General pattern of the vertical profiles of light attenuation in the PAR range for four different lamps.

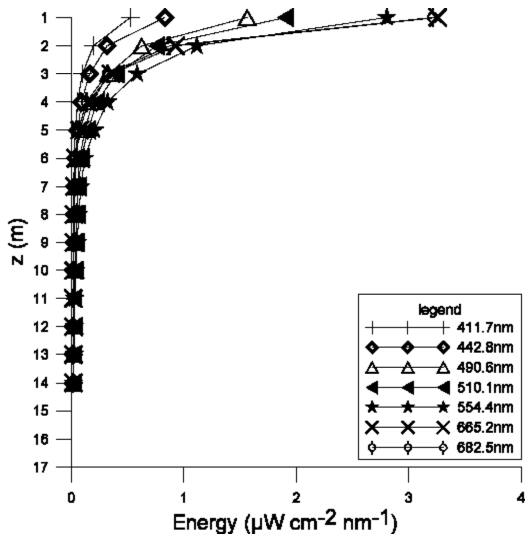

Fig. 5 - Energy attenuation in the seven wavelengths for light emitted by 1500 Watt halogen lamp.

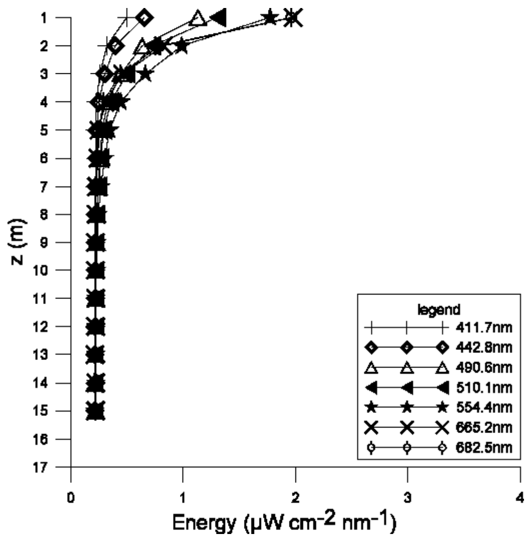

Fig. 6 - Energy attenuation in the seven wavelengths for light emitted by 1000 Watt halogen lamp.

had rather high energy at the surface and the highest energy values from two meters of depth onwards (Figs. 5, 6, 7).

2. The 400 Watt metallic iodide lamp had an outstanding performance: it emitted a very strong energy at 411.7 nm (violet), characterised by high energy values at the surface and a penetration of about 8-9 meters, whereas for all other lamps the depth of energy extinction was about 5-7 meters. The other wavelengths had low energy values from the surface downwards (Fig. 8).

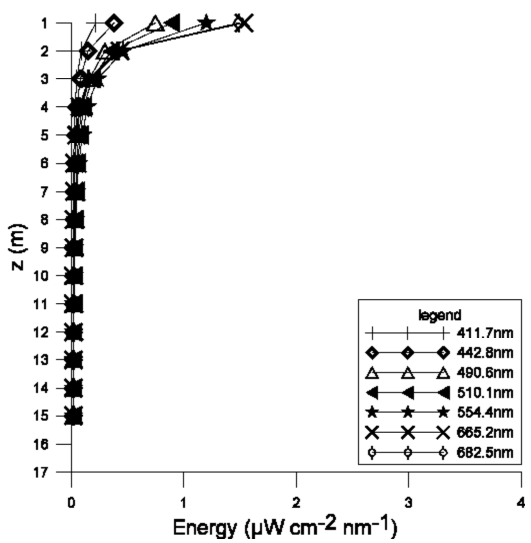

Fig. 7 - Energy attenuation in the seven wavelengths for light emitted by 1000 Watt incandescence lamp.

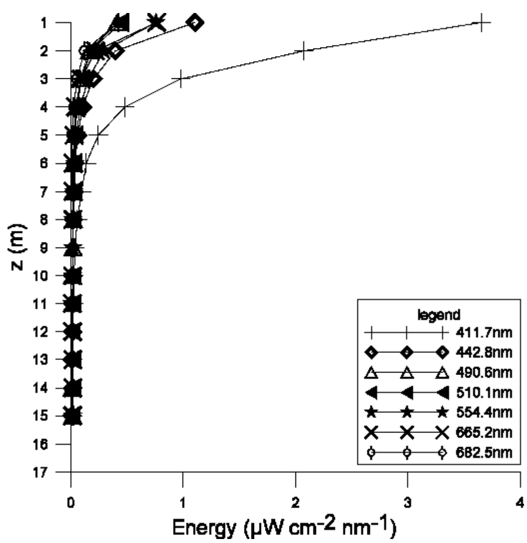

Fig. 8 - Energy attenuation in the seven wavelengths for light emitted by 400 Watt metallic iodide lamp.

3.2. Fish reactions to light

All three species showed a significant response to changes in light intensity, although each of them had distinct behavioural reactions (Tables 1 and 2). The sea bass responded more to the progressive light intensity reduction by showing aggregation and lower activity level. The degree of attraction to light was not highly affected by its intensity, except for a slight negative phototaxis at low light. The common grey mullet showed higher positive phototaxis than the sea bass at all intensities. Besides, the grey mullet showed conspicuous aggregation and was progressively more attracted to light as this decreased. The grey mullet, as well as the sea bream, underwent gradual inhibition of activity during both experiments. Furthermore, the sea bream showed high aggregation and strong attraction to light when this was gradually increased.

Coloured lights also had a significant effect on the behaviour of all three species (Tables 3 and 4). The sea bass was particularly affected by lights of shorter wavelength when they were presented at the beginning of the experiment, and reacted to colours such as blue and green with aggregation, inhibition of activity and negative phototaxis. Overall, the grey mullet was very reactive to coloured light; it responded particularly to blue and violet by showing positive phototaxis, and to red by showing negative phototaxis together with a moderate activation. The sea bream appeared to be repelled by all monochromatic lights, independent of the colour.

4. Discussion and conclusions

Though preliminary, these results lead to some important considerations.

Firstly, an indiscriminate increase of light power from fishing vessels does not appear beneficial, independent of fish behavioural preferences. In fact, the energy produced by artificial

Table 1 - Level of reaction (* = low; ** = medium; *** = high) to changes in light intensity (mM and Mm) in the three tested species, considering aggregation (* > 0.6 MNND; ** 0.5-0.6 MNND; *** < 0.5 MNND), phototaxis (+ = positive; – = negative; * < 30%; ** 30-60%; *** > 60%) and photokinesis (+ = activation; – = inhibition; * < 30%; ** 30-60%; *** > 60%).

	Aggregation		Phototaxis		Photokinesis	
	mM	Mm	mM	Mm	mM	Mm
D. labrax	*	**	** (–)	** (–)	** (–)	** (–)
M. cephalus	**	***	** (+)	*** (+)	*** (–)	*** (–)
S. aurata	**	**	** (+)	* (–)	*** (–)	*** (–)

Table 2 - Trend in the response (k - constant; ↑ = increase; ↓ = decrease) to changes in light intensity (mM and Mm) in the three tested species, considering levels of aggregation, phototaxis (+ = positive; – = negative) and photokinesis (+ = activation; – = inhibition).

	Aggregation		Phototaxis		Photokinesis	
	mM	Mm	mM	Mm	mM	Mm
D. labrax	k	↓	↓ (–)	↑(–)	k	↑(–)
M. cephalus	↓	k	k	↑(+)	↑(–)	↑(–)
S. aurata	↓	k	↑(+)	↓ (–)	↑(–)	↑(–)

Table 3 - Level of reaction (* = low; ** = medium; *** = high) to changes in light colour (VR and RV) in the three tested species, considering aggregation (* > 0.6 MNND; ** 0.5-0.6 MNND; *** < 0.5 MNND), phototaxis (+ = positive; – = negative; * < 30%; ** 30-60%; *** > 60%) and photokinesis (+ = activation; – = inhibition; * < 30%; ** 30-60%; *** > 60%).

	Aggregation		Phototaxis		Photokinesis	
	VR	RV	VR	RV	VR	RV
D. labrax	**	*	** (–)	* (–)	** (–)	** (–)
M. cephalus	***	***	** (+)	** (+)	*** (–)	*** (–)
S. aurata	**	*	** (–)	** (–)	*** (–)	*** (–)

Table 4 - Trend in the response (k - constant; ↑ = increase; ↓ = decrease) to changes in light colour (VR and RV) in the three tested species, considering levels of aggregation, phototaxis (+ = positive; – = negative) and photokinesis (+ = activation; – = inhibition).

	Aggregation		Phototaxis		Photokinesis	
	VR	RV	VR	RV	VR	RV
D. labrax	↓	↓	↓ (–)	↑↓ (–)	↓ (–)	↓ (–)
M. cephalus	k	↑↓	↓ (+)	↑↓ (+)	k	↓ (–)
S. aurata	↓	↑	k	↓ k	↑(–)	↑↓ (–)

lights decreases exponentially along the water column, and tends to be very low after the first meters of depth, as also shown by our data.

Furthermore, exploiting strong white lights may not necessarily improve catches even in the first meters of the water column, as pointed out by other authors (Kavamura, 1986; Arakawa et al., 1998) and suggested also by our results. Indeed, all species tested responded to variations in light intensity and colour, actively. Throughout the experiments, they modified levels of aggregation and rates of activity and showed differential attraction to light. Interestingly, they did not necessarily show a preference for high intensity white lights, sometimes even showing a tendency to escape from strong lights. Such preferences, and in general the behavioural differences recorded among the species, may be related to different levels of photosensitivity, and could represent an adaptation to the distinctive habits and feeding strategies of each species.

Exploiting appropriate lamps may help to develop new fishing techniques and, in particular, to employ selective fishing of species preferentially responding to lights of a specific intensity and colour. For instance, the results obtained in the sea bass and the grey mullet suggested that the use of fairly strong artificial lights could be advantangeous only to attract the fish initially, whereas a subsequent reduction of the illumination and the exploitation of specific coloured lamps may enhance a selective further attraction of the fish. Similar techniques are commonly used during commercial fishing of pelagic species such as *Sardinella aurita* and *Clupea harengus harengus* (Ben-Yami, 1976).

The containment of underwater illumination and the exploitation of selective fishing by means of appropriate lamps might also be beneficial to marine environment conservation, as it would reduce the disturbance caused to all organisms involontarily illuminated by the lamps of light fishing.

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