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Nighttime lighting alters the composition of marine epifaunal communities

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Marine benthic communities face multiple anthropogenic pressures that compromise the future of some of the most biodiverse and functionally important ecosystems in the world. Yet one of the pressures these ecosystems face, nighttime lighting, remains unstudied. Light is an important cue in guiding the settlement of invertebrate larvae, and altering natural regimes of nocturnal illumination could modify patterns of recruitment among sessile epifauna. We present the first evidence of nighttime lighting changing the composition of temperate epifaunal marine invertebrate communities. Illuminating settlement surfaces with white LED lighting at night, to levels experienced by these communities locally, both inhibited and encouraged the colonization of 39% of the taxa analysed, including three sessile and two mobile species. Our results indicate that ecological light pollution from coastal development, shipping and offshore infrastructure could be changing the composition of marine epifaunal communities.

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Background

Assemblages of sessile marine benthic invertebrates act as engineers that support some of the world's most diverse ecosystems, sustain local fisheries, provide coastal protection and attract tourism [1]. Despite these important services, many such assemblages are threatened globally by multiple anthropogenic pressures including bottom fishing, coral bleaching, hypoxia and ocean acidification. Nighttime artificial light represents an as yet unexamined disturbance, that will likely alter the composition of sessile invertebrate assemblages by interfering with patterns of reproduction and recruitment among their constituent species [2]. The intensity, spectral composition and periodicity of natural light are important cues both for synchronizing the timing of broadcast spawning events [3, 4], and in guiding larval recruitment into suitable habitats for post settlement survival and reproduction [5, 6]. 22% of the world's coastal regions [2] (excluding Antarctica) are experiencing artificial light at night from a variety of sources, including coastal towns, harbours, offshore infrastructure in the form of oil, gas and renewable energy installations, shipping and light fisheries [2]. Where this artificial light is illuminating shallow benthic communities, it is likely giving rise to a range of unanticipated effects including sub-optimal settlement site selection and a consequent increase in post settlement mortality, and extending the time where light is available to guide the settlement process.

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We investigated how nocturnal illumination by white LEDs, a technology forecast to dominate the lighting industry by 2020 [7], influenced the colonisation of sessile and mobile temperate invertebrates in newly available habitats. Our results indicate that colonization can be improved or hindered by white LED lighting at intensities encountered in the environment, hence nighttime lighting has the potential to re-structure the composition of both existing and recovering assemblages by altering the recruitment of new individuals.

Methods

We quantified colonisation of thirty six previously bare 10 x 10cm roughened grey PVC settlement panels over twelve weeks of deployment from 1st July 2013 on a floating raft in the Menai Strait, UK (53.229507° lat; -4.153227° lon). Panels were deployed vertically at 20cm depth in pairs on eighteen separate wooden boards, with each pair of panels treated as one treatment replicate in the analysis to avoid pseudoreplication. Each treatment pair was either not artificially lit (control), or lit to either 19 lux or 30 lux (measured using a ATP DT-1300 LUX meter) at the water's surface using cool white LED's (n=6 replicate boards per treatment). These lux levels were comparable to those found at the water's surface adjacent to nearby assemblages of epifaunal invertebrates exposed to nighttime lighting (5 to 21.6 lux). The spectral power distribution of the make and model of cool white LED strips used is provided in Bennie *et al*. [8]. All lights were powered via a 12V battery trickle charged using a solar panel (Sunware 24W -3265), and switched on at dawn and off at dusk using a CellOptick 12V photocell. The boards were deployed vertically to simulate substrates that would be both suitable for colonisation by temperate epifauna, and exposed to artificial light (for example pier pilings, vertical rock faces, sea defences, floating pontoons etc), and randomly allocated across two rows of nine slots. Light trespass across treatments was avoided by facing panel fronted boards in the same direction so that any stray light illuminated the back face rather than the experimental face of the neighbouring board (Figure S1). A separate sheet of grey PVC was used to guide the light down the experimental face of each board, minimizing light trespass onto adjacent boards (Figure S1). At the end of the colonisation period, panels were brought back to the lab and preserved in 4% formalin pending analysis. The abundance of each taxon (identified to the lowest practicable resolution) was quantified as either the number of individuals, or percentage cover for colonial mat forming taxa. The composition of the resulting communities was compared separately for percentage cover and numerical abundance data using Multivariate Analysis of Variance (MANOVA, CRAN: Vegan) performed on Bray-Curtis dissimilarity matrices calculated from square root and log(x+1) transformed data respectively. Differences in numerical abundance and percentage cover were tested individually for each taxon. Percentage cover data were analysed using either a gaussian Generalized Linear Model (GLM) performed on fourth root transformed data, or a quasibinomial GLM performed on raw data where transformation failed to satisfy linear modelling assumptions. Numerical abundance data were fitted with poisson and negative binomial GLMs, and zero adjusted poisson (ZAP) and negative binomial (ZANB) regression models (CRAN: pscl), with the most parsimonious model (that which displayed the lowest AIC) being selected. Individual tests were not performed on species recorded in less than half of the replicates as they were deemed to have occurred too infrequently to draw reliable conclusions using any of the above approaches.

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Prior to analysis, the paired panels in each replicate treatment board were summed for numerical abundance data and averaged for percentage cover data.

Results

Forty seven taxa representing seven phyla were identified on the settlement panels. Communities colonized under artificial light were significantly dissimilar from those colonised under control conditions (MANOVA: $F_{2,15}$ = 2.85, p = 0.005) for taxa quantified using percentage cover. For taxa quantified using numerical abundance, light treatment had no impact on community composition (MANOVA: $F_{2,15}$ = 1.21, p = 0.252), although this was driven by the influence of one outlying data point with unusually low species richness exerting leverage on the analysis (Figure S2). When this data point was omitted, light treatment had a significant impact on the composition of numerically enumerated taxa (MANOVA: $F_{2,14}$ = 1.79, p = 0.018). This was further supported by independent tests performed on individual taxa (Table 1, Figure 1). Of the 47 taxa identified, 13 were present in sufficient abundance for reliable estimates of the impact of LED lighting on abundance to be made. Of these, the abundances of three sessile and two mobile taxa were significantly affected by light treatment (Table 1). Colonization by the colonial ascidian *Botrylloides leachii* was suppressed significantly by both light treatments , (Figure 1, Table 2), while the hydroid *Plumularia setacea* displayed significantly reduced colonization under the 30 lux treatment (Figure 1, Table 2). By contrast, the abundance of the tube building polychaete worm *Spirobranchus lamarcki* a was significantly higher on panels colonized under both artificial light treatments (Figure 1, Table 2), suggesting that white LED lighting encouraged its colonization. Among the mobile taxa, the abundances of the copepod *Metis ignea* and Corophium amphipods were significantly higher under the 30 lux treatment (Figure 2, Table 2).

Discussion

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Artificial light at night changes organism behaviour [9, 10], re-structures communities [11], and alters trophic interactions [8] in terrestrial ecosystems. Nighttime lighting is known to disrupt navigation, increase mortality and alter spatial and temporal activity patterns in marine birds, turtles and fish [12-14], but to our knowledge, the results presented here are the first evidence that it can affect the composition of marine communities. Although a limited number of species were affected in this study, a large proportion (72%) of the taxa colonizing our tiles were present in insufficient abundance to draw reliable conclusions about the impact of LED lighting on recruitment success. LED lighting significantly affected colonization by 39% of the taxa for which tests could be performed, suggesting potentially far reaching impacts on epifaunal marine invertebrates and their associated mobile species.

Although novel, our results are perhaps unsurprising, given the importance of light in guiding recruitment to sessile invertebrate assemblages [5, 6], and the role of this mechanism in optimising post settlement survival . Light is a key factor structuring shallow marine benthic ecosystems both vertically and horizontally [15,16], and a plethora of studies have documented its importance for larval movement, orientation and recruitment over the 20th century. The significant responses observed among sessile invertebrates here are consistent with the life history traits of the species concerned [17-19].

The recent global surge in LED lighting is increasingly illuminating nighttime environments with white light. While these lights hold the potential to reduce expenditure and CO_2 emissions, their broad spectral output compared with traditional sodium based technologies, encompasses a greater range of wavelengths to which a variety of light guided behaviours may be sensitive [20] , including larval recruitment. LED's are forecast to take over as the predominant light source in industrial, commercial, residential and architectural lighting applications by 2020 [7], and they are increasingly popular in shipping and the oil and gas industry. We conclude that such lights can alter the recruitment of sessile marine invertebrates, changing the composition of epifaunal communities.

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The consequences of nighttime lighting for a broader range of marine ecosystems and the services they provide are unknown. The breadth of marine species for which light is an important ecological factor, and its role in guiding broadcast spawning, recruitment, diel vertical migration, communication, navigation and predator prey interactions [2] suggests widespread impacts of artificial light on the structure and function of marine ecosystems may already be occurring.

Data accessibility

The datasets supporting this article have been uploaded as part of the Supplementary Material.

Competing interests

We have no competing interests.

Author contributions

TWD and SRJ conceived the study; MC, SRJ and KG conducted the data collection. TWD performed the analysis and wrote the first draft. All authors contributed to revisions.

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Table 1. The effect of LED lighting on colonisation by sessile and mobile benthic species. Significant results indicate that light treatment explained significantly more variation in taxon abundance when compared to a null intercept only model.

Higher classification		Taxon	Mobility	Abundance	χ^2 or *F*	*p*
Arthropoda						
	Amphipoda	*Corophium sp.*[c]	Mobile	n	8.46	0.015
	Cirripedia	*Balanus balanus*[d]	Sessile	n	0.83	0.661
	Copepoda	*Laophonte setosa*[d]	Mobile	n	0.73	0.695
		Metis ignea[d]	Mobile	n	6.10	0.047
	Ostracoda	*Leptocythere pellucida*[c]	Mobile	n	3.21	0.20
Bryozoa	Cheilostomatida	*Electra sp.*[b]	Sessile	%	2.50	0.115
Chordata	Ascidiacea	*Botrylloides leachii*[a]	Sessile	%	8.79	0.003
		Molgula sp.[d]	Sessile	n	3.01	0.222
Cnidaria	Hydrozoa	*Kirchenpaueria pinnata*[d]	Sessile	n	0.27	0.875
		Plumularia setacea[b]	Sessile	%	3.68	0.05
		Ectopleura larynx[f]	Sessile	n	5.13	0.275
Mollusca	Bivalvia	*Anomia ephippium*[c]	Sessile	n	3.26	0.196
Polychaeta	Serpulidae	*Spirobranchus lamarcki*[d]	Sessile	n	19.45	<0.001

[a] Gaussian GLM on 4th root transformed data
[b] Quasibinomial GLM on raw data
[c] Poisson GLM
[d] Negative binomial glm
[e] ZAP
[f] ZANB
n Data quantified as numerical abundance
% Data quantified as % cover
Species where colonization was significantly affected are underlined.

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Table 2. Differences in colonisation between 19 and 30 lux LED lighting compared to controls. Summary results are presented from the models reported in Table 1.

	19 lux		30 lux	
Taxon	*z* or *t*	*p*	*z* or t	*p*
Plumularia setacea[b]	-1.82	0.090	-2.39	0.030
Spirobranchus lamarki[d]	4.11	<0.001	3.81	<0.001
Botrylloides leachii[a]	-2.45	0.027	-4.17	<0.001
Metis ignea[d]	-0.15	0.883	1.97	0.049
Corophium sp.[c]	0	1	2.08	0.038

[a] Gaussian GLM on 4th root transformed data
[b] Quasibinomial GLM on raw data
[c] Poisson GLM
[d] Negative binomial glm
[e] ZAP
[f] ZANB

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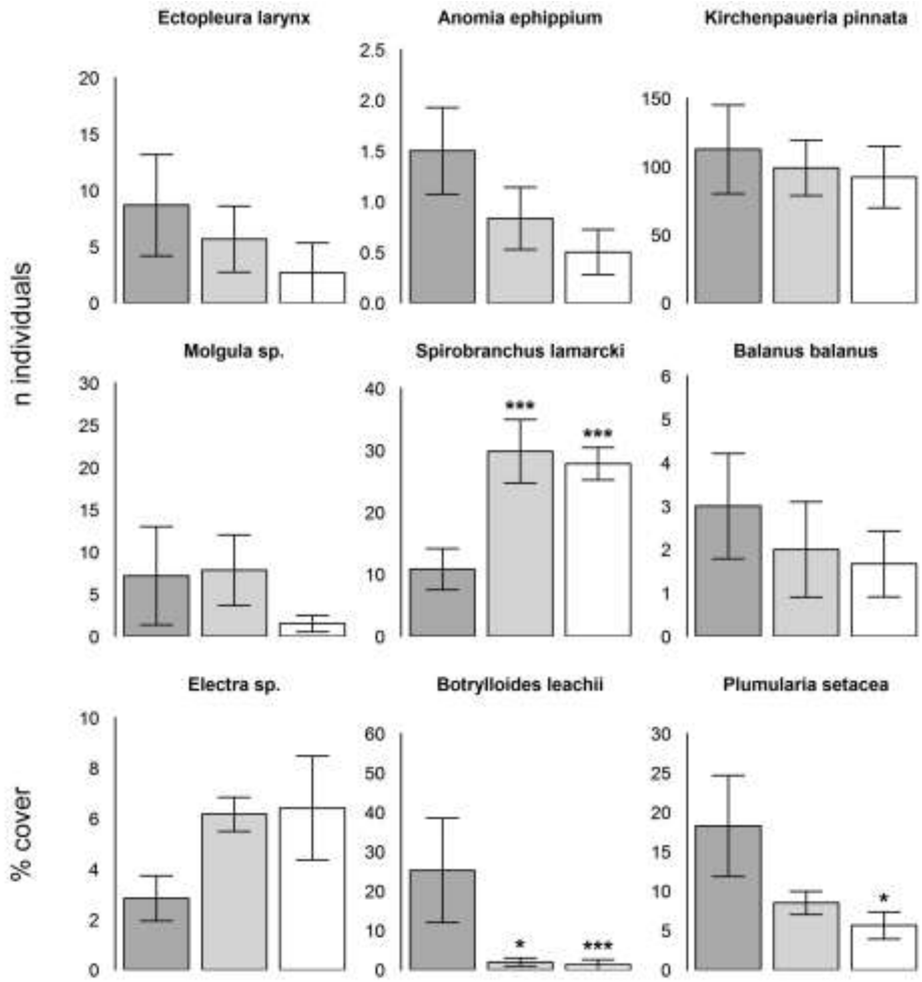
Figure 1. The impact of white LED lighting on the recruitment of sessile marine invertebrates. Dark grey bars are controls, light grey are 19 lux and open are 30 lux at the sea surface. Error bars represent standard errors. Significant differences between each light treatment and controls are denoted for 95% '*', 99% '**' or >99% '***' confidence levels. Statistical output for species significantly affected by light treatment is given in Table 2.

Figure 2. The impact of white LED lighting on colonisation by mobile marine invertebrates. Dark grey bars are controls, light grey are 19 lux and open are 30 lux at the sea surface. Error bars represent standard errors. Significant differences between each light treatment and controls are denoted for 95% '*', 99% '**' or >99% '***' confidence levels. Statistical output for species significantly affected by light treatment is given in Table 2.



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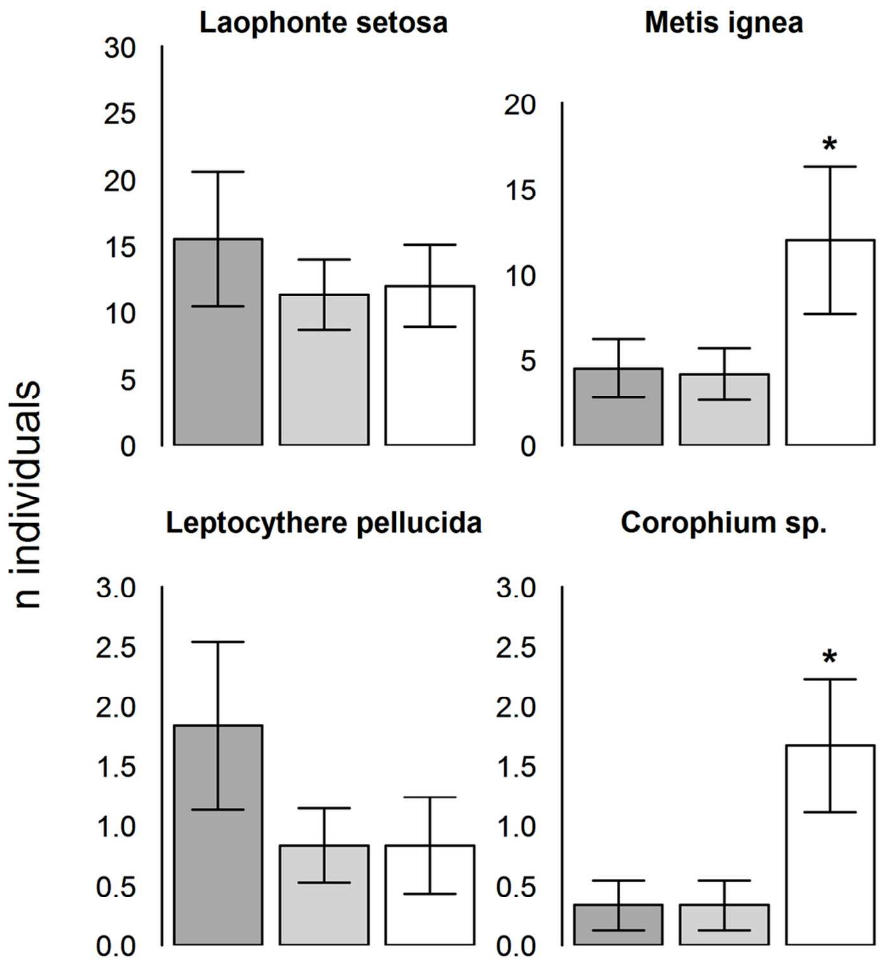

Figure 2. The impact of white LED lighting on colonisation by mobile marine invertebrates. Dark grey bars are controls, light grey are 19 lux and open are 30 lux at the sea surface. Error bars represent standard errors. Significant differences between each light treatment and controls are denoted for 95% '*', 99% '**' or >99% '***' confidence levels. Statistical output for species significantly affected by light treatment is given in Table 2.
99x99mm (300 x 300 DPI)