Scientific Research Publishing

Open Journal of Marine Science, 2020, 10, 203-217
https://www.scirp.org/journal/ojms
ISSN Online: 2161-7392
ISSN Print: 2161-7384

Intertidal Biodiversity and Their Response to Climatic Variables, Temperature and pH—What We Know

P. M. Mohan*, **V. Swathi**

Department of Ocean Studies and Marine Biology, Pondicherry University of Campus, Port Blair, Andaman and Nicobar Islands, India
Email: *pmmtu@yahoo.com, *pmmnpu@rediffmail.com

How to cite this paper: Mohan, P.M. and Swathi, V. (2020) Intertidal Biodiversity and Their Response to Climatic Variables, Temperature and pH—What We Know. *Open Journal of Marine Science*, **10**, 203-217.
https://doi.org/10.4236/ojms.2020.104016

Received: May 30, 2020
Accepted: September 27, 2020
Published: September 30, 2020

Copyright © 2020 by author(s) and Scientific Research Publishing Inc.
This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).
http://creativecommons.org/licenses/by/4.0/
Open Access

Abstract

As per the Essential Climate Variables (ESV) of World Meterological Organisation (WMO), the physical, chemical and biological variables critically contribute to the earth's climate. Among them, the variables such as temperature and pH in the marine environment may affect seriously and in turn it has an impact on the biota, especially in the intertidal environment, where it has brunt force. According to United Nations Framework Convention on Climate Change (UNFCCC), the datasets should provide the empirical evidence needed to predict the climate change and evoluate the mitigation and adaptation measures. Under this context, a review was carried out to know what extent marine scientists understand this factor and what level the biodiversity was evoluated and its impact was analysed in this article. Based on the existing literature review, it was understood that only a few groups that also only few species from these groups were studied in this aspect. The remaining groups and their species and their basic trophic were not evolved in this aspect. So, the marine scientific community, environmentalist and policy makers should take stock on this aspect and give thrust on this study.

Keywords

Climatic Variables, Temperature, pH, Salinity, Marine, Biodiversity

1. Introduction

Climatic change is one of the important factors to consider for the futuristic research activities, especially with biodiversity concern. According to Global Climate Observing System (GCOS), it should be ensured that observations and information needed to address the climate issues are obtained and made available to all potential users. The World Meterological Organisation (WMO) also suggested that under the Essential Climate Variables (ECV) the datasets on EVS should provide the empirical evidence, which needed to understand and predict the climatic change to evoluate the mitigation and adaptation measures to underpin the climatic services [1]. Under this programme, it was suggested generating and archiving data on the variables, wherever possible, using historical dataset. The predication of the future climate states that the temperature is the important factor for the terrestrial and temperature and pH are the two major components to be altered in the marine environment concern. As predicted by IPCC [2], a rise of temperature around 1˚C to 2.5˚C was suggested based on the year 2000 data. The expected outcome of this 20% - 30% of plants and animals may extinct and Island States undergo the sea due to increase of sea level rise. The climate change affected drastically and the ecosystem shifts and numerous extinctions will be resultant [3]-[8].

The effect of climate change is rapid and highly influence in marine ecosystem, especially in the intertidal zone where the upper temperature differences have their impact [9] [10] [11] [12]. If the species cannot acclimatize physiologically or change genetically to cope with temperature increment to move cooler habitats, *i.e.* high latitude [5] [7] [13] [14] [15] [16] [17]. It was proposed that the shift of marine species in an average 19 km/year [11] than the terrestrial shift, *i.e.* 0.6 km/year [5]. Since, the shift range can be predicated well in marine species because of its thermal tolerance limit [18], so as the web interactions changes within ecological community [19].

2. Methodology

Understanding the importance of impact of temperature and pH variables on the intertidal life forms, the existing literature was scanned. The available information was shared here to understand the level of our knowledge on this aspect and discussed the views for the future need on this aspect. Even though good amount of literature is available on the distribution and taxonomy, the impact of the individual group is species were scanty. The available studies were discussed in this article.

3. Intertidal Region

The seashore which covered during the high tide and exposed during the low tide is defined as intertidal zone or littoral zone. This eco zone covers a unique biome with variety of plant and animal [20] [21]. This zone is characterised by unique temperature, ecological factors and micro climates. This zone is divided into four distinct regions:

Lower Littoral Zone - Low Tide Zone

This area is closest to the sea and submerged majority time with seawater. The waves in this region protect the harmful radiation and severe temperature fluctuation. The species lives in this region are larger in size, greater in number, more diverse than the other areas of intertidal zone. The organisms in the low tide zone do not have to be well adapted to drying out and temperature extremes. The common fauna and flora observed in this region are sea anemone, brown sea weed, green algae, chiton, crabs, hydroids, isopods, limpets, mussels, sometimes small fishes.

Mid-Littoral Zone - Mid Tide Zone

The region is submerged half of the time of tidal fluctuations. The plant and animal species are living in this region but not as diver as Low Tide Zone. The organisms in the mid tidal zone are snails, sponges, sea stars, barnacles, mussels, sea palms and crabs.

Upper Mid-Littoral Zone - High Tide Zone

The zone is submerged during the high tide only. Very few plants and animals survived in this region. The most of the animals in this region are mobile (Crab) or attached to the substrate (Barnacles). The organisms in the high tidal zone are seaweeds, marine algae, sea anemone, starfish, chiton, crabs, mussels, nudibranchs and hermitcrabs.

Splash Zone

The splash zone is located above the upper mid-littoral zone. The water splash during the high tide by the wavers and never submerged with water.

4. Results and Discussion

4.1. Temperature

All organisms have an influence on climatic variables in the range of molecular to ecosystem scales because the temperature dependent process is imminent [22] [23] [24]. Comparative to terrestrial species marine ectotherms act faster because of its sedentary nature and short life spans prevent escape from the change of environmental regimes [25] [26]. The flora and fauna existed in the intertidal regime responding quicker than the higher trophic level [27] [28] [29], because this quicker response leads to surge of deficiency of food chain [30]. Even though, semidiurnal and diurnal tidal effect along with seasonal variable may affect the intertidal organism to the tune of 2.5˚C over a single tidal cycle [31], the temperature increment of air may affect further on this fact leads to some kind of thermal extremes for the intertidal flora and fauna.

The temperature increment affected the Boreal Barnacle *Semibalanus balanoides* larval development [32] [33]. The blue mussel *Mytilus edulis* exhibited impaired respiration and metabolism change [34] [35] [36]. The pink coralline algae show impaired growth in the intertidal environment [37]. The Pacific Oyster *Crassostrea gigas* (**Figure 1**) located in the intertidal zone adapted to massive temperature fluctuations around 2˚C in a tidal cycle. Additionally, the exposure to high thermal variability can cause shifts in gene expression patterns which set limits for physiological function [38]. The sea star *Crossaster papposus* (**Figure 2**) has lecithotrophic larvae which have less susceptible to environmental change than the planktotrophic larvae of asteroid species.

Figure 1. *Crassostrea gigas* [75].

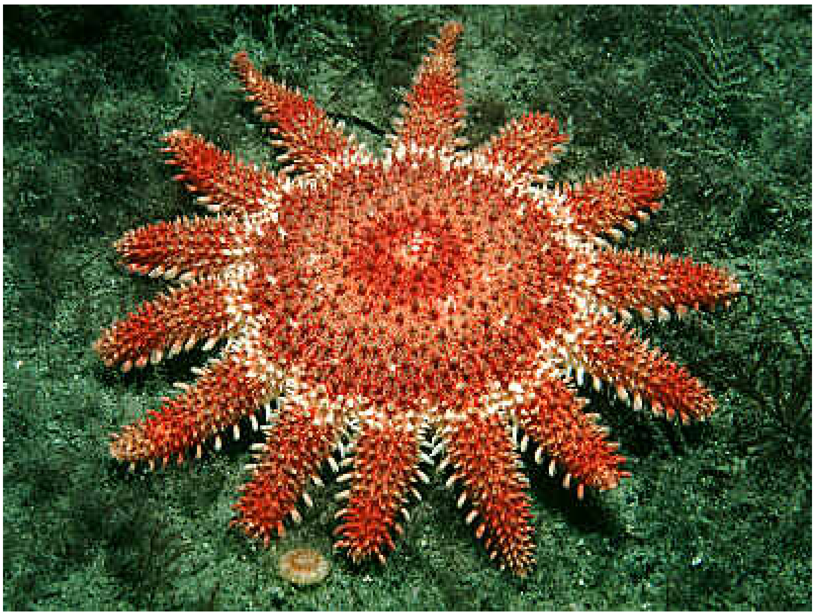

Figure 2. *Crossaster papposus* [76].

The enhanced respiration rates of faunal community through temperature raise affect the carbon balance of macroalgae assemblages which declines net productivity of seaweed and due course of time species richness [39]. The crab has good sustainability for temperature and pH variation in the intertidal regions. However, the effect of these combined two factors leads to decline its resistivity and its population. This in turn exhibited a potential long term adverse effect on the ectotherm. The sea anemone *Actinia equina* (**Figure 3**) in the rocky Mediterranean coast exhibited the growth of polyp will shunted along with reduced biomass during the raise of temperature [40]. The brown dinoflagellates (*Symbiodinium californium*, A. T. Banaszak, R.Iglesias-Prieto & R. K. Trench

Figure 3. *Actina equina* [77].

and S. muscatinei, La Jeunesse & R. K. Trench) called zooxanthellae translocate during the high temperature to the host [41] [42].

4.2. pH

The studies on the pH of marine water suggested that during the end of 21st Century, the CO_2 level may be increased to three to four fold than the pre-industrial levels [43] [44] [45]. This increment may effect on the surface of the water and increase the dissolved CO_2 and in turn alter the seawater pH which was not seen in the last 300 million years by the change the carbonate chemistry [46]. The year 2016, carbon dioxide parts in the atmosphere surpassed 400 ppm (parts per million), the highest since the Pliocene epoch, a geological period known for its warm temperatures. Morris and Taylor [47], Truchot [48] and Wootton *et al.*, [49] reported that in the tide pool studies the pH changed from 9.5 to 6.5 which was higher than the proposed value of next century predication on the surface water. Feely *et al.*, [45] and Hofmann *et al.*, [50] reported that the intensity of upwelling increased and in turn the deep hypercarbanic waters mixing in the surface water also lowering the pH towards acidic side.

The change of pH was termed as Ocean Acidification (OA) as mentioned by Caldeira and Wickett [51] and Meehl *et al.*, [44]. This large variation of pH may affect the biota's metabolism, growth and reproduction [52] [53] [54] through the intracellular pH homeostasis [55]. This may lead to ecological implications by the way disappearance of the particular species or genetical modification of the same and in turn affect the local biodiversity with the result of disturbed community composition [55] [56] [57] [58]. Further, the change of pH may be affected the intertidal regions of the ocean than the deeper habitats [32] [50] [59]. This fact is very much significant for the crustaceans and snails [32] [60] [61]. However, it was not affected the teleost fish and brachyuran crabs but increased its availability more [52] [62] [63]. Another interesting findings also observed that the early life history of organisms (embroyonic, larval or juvenile stages) show more response on the OA factor than the latter stages of their life history [54] [64] [65]. This factor was very much significant for mollusks, echinoderm and crustaceans [32] [60] [66] [67]. The studies on the porcelain crab *Petrolishthes cinctipes* stated (**Figure 4**) that the survival rate of juvenile reduced to the tune of 30% in hepercapnic waters influence [68]. The above studies were clearly mentioned that the whole life history of a fauna or flora should be studied [69] to understand the impact of OA in the marine environment. The California mussel—*Mylitis californiansis* (**Figure 5**) precipitated smaller shells with less thickness due to pH level towards acidic [70]. The coralline algae recruitment and deficient growth were observed under acidic conditions [71].

As reported by Alenius and Munguia [72] the species *Paradella dianae* (**Figure 6**) from the Isopod living in the intertidal regions showed its variation among the consumption of oxygen, swimming speed, food response varied when the pH conditions varies. As reported by Orr *et al.*, [43] and Bednaršek *et al.*, [73], the OA may also reduce calcification in planktonic organisms. The pH fluctuate daily ≥ 0.5 pH units and up to ≥1 pH level on temperate rocky shores [49]. The coral reef environment suggested that the pH varies ≥ 0.5 pH units day and night cycles Birkeland *et al.*, [74].

5. Conclusion

The existing literature was stated that the studies on intertidal fauna and flora for the impact on climatic variables executed only for few groups of organisms. The number of other intertidal fauna like polycheate, sponges, hydroids, bryozoans, etc., (**Table 1**) is not known for its effect on the temperature and pH changes in the intertidal mechanism, which is highly essential for the food web of marine trophic as a total. If scientific community does not understand its effect, which in turn estimation of the range extension of faunal distribution will become more cumbersome and effect on the climatic variable will not be understood fully

Figure 4. *Porcelein crab* [78].

Figure 5. *Mylitis californiansis* [79].

Figure 6. *Parandella dianae* [80].

Table 1. Intertidal faunal and floral distribution.

Intertidal Organisms		
Upper littoral zones	Mid littoral zones	Lower littoral zones
Periwinkles	Mussels	Hydrozoans
Littorina scabra	*Mylitis californianus*	*Porpita porpita*
Nerita atropurprea		*Physalia physalisa*
Nerita articulata	Barnacles	*Velella velella*
Nerita Costata	*Semibalanus balanoides*	*Obelia geniculata*
LIttorina scutulata	*Chthamalus malayanus*	*Aurelia aurita*
Blue green algae	*Lepas anatifera*	*Doto Sp*
		Shrimps
Green algae	Chitons	*Periclimenes brevicarpalis*

Continued

Enteromorpha	*Ischnochiton dispar*	Sea anemone
Calerpa	*Stenoplax limaciformis*	*Stoichatis Sp*
Padina	*Chiton stokesii*	*Anthopleura elaegantissima*
Brown algae	*Acanthochitona hirudiniformis*	*Anthopleura anathogrammica*
Halymenia Sp	*Acanthochitona ferreirai*	*Dardamus Sp*
Halimeda Sp	*Chaetopleura lurida*	*Stichodactyla haddoni*
	lepidachitona beanie	Sponges
	Callistoplax retusa	*Oceanapia saggitaria*
	Callisstochiton expressus	*Neopetrosia sp.*
	Flat Worms	*Haliclona sp.*
	Pseudoceros coralliophilus	*Ircinia fusca*
	Thysanozoon sp	*Cinachyra Arabica*
		Dysidea fragilis
	Limpets	*Phyllospsongia calciformis*
	Acmaea stellaris	*Chondrilla australiensis*
		Bryozoans
	Polychaetes	
		Sea weeds
		Electra indica
	Sipunculids	
		Crabs
	Oyster	*Thalamita Sp*
	Saccostrea cucullata	*Ochypoda Sp*
		Sesarma longipes
	Clam	*Clibanarius Sp.*
	Tridacna crocea	*Uca anulips*
		Uca vocans
		Uca marionis
		Paguras Sp
		Cancer magister
		Hemigrapsus nudus
		Oregonia gracilis
		Cardiopoma carnifex
		Limpets
		Acmaea stellaris
		Barnacles
		Balanus glandula
		Semibalanus cariocus

Continued

	Polliapes polymeras
	Mussels
	Mylitis californianus
	Sea urchins
	Echinothrix calamaris
	Diadema stosum
	Stongylocentrotus purpuratus
	Isopod
	Isotea wosnesenki
	Sea Star
	Pisaster ochraeus
	Linkia Leavigata
	Culcita novaquinea
	Asterias Rubens
	Oyster
	Saccostrea cucullata
	Sea Cucumber
	Holothuria sp
	Zooplankton

for the intertidal biodiversity. Not only that, the need to understand the impact of climatic variable to the fauna and flola of the intertidal regions as needed for Globla Climatic Observation System and if the scientist, not able to provide a clear cut information, the mitigation efforts was also not successful for future developmental aspects.

Acknowledgements

I thank the Authorities of Pondicherry University for providing the facilities to execute this work in their Port Blair Centre. I also acknowledge the Indian Institute of Tropical Meteorology (IITM), Pune, under the Ministry of Earth Sciences for providing fund through Metflux Project.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] WMO World Meterological Organisation (2020). https://public.wmo.int/en/programmes/global-climate-observing-system/essential-climate-variables

[2] IPCC (2007) Intergovernmental Panel on Climate Change (2007). Fourth Assessment Report. Intergovernmental Panel on Climate Change Secretariat, Geneva. http://www.ipcc.ch https://doi.org/10.1017/CBO9780511546013

[3] Hughes, L. (2000) Biological Consequences of Global Warming: Is the Signal Already Apparent? *Trends in Ecology & Evolution*, **15**, 56-61. https://doi.org/10.1016/S0169-5347(99)01764-4

[4] Davis, M.B. and Shaw, R.G. (2001) Range Shifts and Adaptive Responses to Quaternary Climate Change. *Science*, **292**, 673-679. https://doi.org/10.1126/science.292.5517.673

[5] Parmesan, C. and Yohe, G. (2003) A Globally Coherent Fingerprint of Climate Change Impacts across Natural Systems. *Nature*, **421**, 37-42. https://doi.org/10.1038/nature01286

[6] Root, T.L., Price, J.T., Hall, K.R., Schneider, S.H., Rosenzweig, C. and Pounds, J.A. (2003) Fingerprints of Global Warming on Wild Animals and Plants. *Nature*, **421**, 57-60. https://doi.org/10.1038/nature01333

[7] Parmesan, C. (2005) Biotic Response: Range and Abundance Changes. In: Lovejoy, T.E. and Hannah, L., Eds., *Climate Change and Biodiversity*, Yale University Press, New Haven, 41-55.

[8] Rosenzweig, C., Karoly, D., Vicarelli, M., Neofotis, P., Wu, Q. and Casassa, G. (2008) Attributing Physical and Biological Impacts to Anthropogenic Climate Change. *Nature*, **453**, 353-357. https://doi.org/10.1038/nature06937

[9] Southward, A.J., Hawkins, S.J. and Burrows, M.T. (1995) Seventy Years' Observations of Changes in Distribution and Abundance of Zooplankton and Intertidal Organisms in the Western English Channel in Relation to Rising Sea Temperature. *Journal of Thermal Biology*, **20**, 127-155. https://doi.org/10.1016/0306-4565(94)00043-I

[10] Hoegh-Guldberg, O. and Bruno, J.F. (2010) The Impact of Climate Change on the World's Marine Ecosystems. *Science*, **328**, 1523-1528. https://doi.org/10.1126/science.1189930

[11] Sorte, C.J.B., Williams, S.L. and Carlton, J.T. (2010) Marine Range Shifts and Species Introductions: Comparative Spread Rates and Community Impacts. *Global Ecology and Biogeography*, **19**, 303-316. https://doi.org/10.1111/j.1466-8238.2009.00519.x

[12] Somero, G.N. (2010) The Physiology of Climate Change: How Potentials for Acclimatization and Genetic Adaptation Will Determine "Winners" and "Losers". *Journal of Experimental Biology*, **213**, 912-920. https://doi.org/10.1242/jeb.037473

[13] Walther, G.R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., *et al.* (2002) Ecological Responses to Recent Climate Change. *Nature*, **416**, 389-395. https://doi.org/10.1038/416389a

[14] Thomas, C.D., Cameron, A., Green, R.E., Bakkenes, M., Beaumont, L.J., Collingham, Y.C., *et al.* (2004) Extinction Risk from Climate Change. *Nature*, **427**, 145-147. https://doi.org/10.1038/nature02121

[15] Parmesan, C. (2006) Ecological and Evolutionary Responses to Recent Climate Change. *Annual Review of Ecology, Evolution, and Systematics*, **37**, 637-669. https://doi.org/10.1146/annurev.ecolsys.37.091305.110100

[16] Hickling, R., Roy, D.B., Hill, J.K., Fox, R. and Thomas, C.D. (2006) The Distributions of a Wide Range of Taxonomic Groups Are Expanding Polewards. *Global*

Change Biology, **12**, 450-455. https://doi.org/10.1111/j.1365-2486.2006.01116.x

[17] Thomas, C.D. (2010) Climate, Climate Change and Range Boundaries. *Diversity and Distributions*, **16**, 488-495. https://doi.org/10.1111/j.1472-4642.2010.00642.x

[18] Sunday, J.M., Bates, A.E. and Dulvy, N.K. (2012) Thermal Tolerance and the Global Redistribution of Animals. *Nature Climate Change*, **2**, 686-690. https://doi.org/10.1038/nclimate1539

[19] Kordas, R.L., Harley, C.D.G. and O'Connor, M.I. (2011) Community Ecology in a Warming World: The Influence of Temperature on Interspecific Interactions in Marine Systems. *Journal of Experimental Marine Biology and Ecology*, **400**, 218-226. https://doi.org/10.1016/j.jembe.2011.02.029

[20] Crisp, D.J. and Southward, A.J. (1958) The Distribution of Intertidal Organisms along the Coast of the English Channel. *Journal of Marine Biological Association*, **37**, 157-208. https://doi.org/10.1017/S0025315400014909

[21] BD Biological Dictionary 2020. https://biologydictionary.net/intertidal-zone

[22] Cain, S.A. (1944) Foundations of Plant Geography. Harper Brothers, New York, London.

[23] Atkinson, T.C., Briffa, K.R. and Coope, G.R. (1987) Seasonal Temperatures in Britain during the Past 22,000 Years, Reconstructed Using Beetle Remains. *Nature*, **325**, 587-592. https://doi.org/10.1038/325587a0

[24] Fly, E.K., Monaco, C.J., Oicebourde, S. and Tullis, A. (2012) The Influence of Intertidal Location and Temperature on the Metabolic Cost of Emersion in *Pisaster ochraceus*. *Journal of Experimental Marine Biology and Ecology*, **422-423**, 20-28. https://doi.org/10.1016/j.jembe.2012.04.007

[25] Carr, M.H., Neigel, J.E., Estes, J.A., Andelman, S., Warner, R.R. and Largier, J.L. (2003) Comparing Marine and Terrestrial Ecosystms: Implications for the Design of Coastal Marine Reserves. *Ecological Applications*, **13**, 90-107. https://doi.org/10.1890/1051-0761(2003)013[0090:CMATEI]2.0.CO;2

[26] Helmuth, B.T. and Denny, M.W. (2003) Predicting Wave Exposure in the Rocky Intertidal Zone: Do Bigger Waves Always Lead to Larger Forces? *Limnology and Oceanography*, **48**, 1338-1345. https://doi.org/10.4319/lo.2003.48.3.1338

[27] Smith, P.E. (1985) Year-Class Strength and Survival of O-Group Clupeoids. *Canadian Journal of Fisheries and Aquatic Sciences*, **42**, 69-82. https://doi.org/10.1139/f85-263

[28] Barlow, J., Hill, P.S., Forney, K.A. and DeMaster, D.P. (1998) US Pacific Marine Mammal Stock Assessments, 1998, California.

[29] Jenouvrier, S., Barbraud, C. and Weimerskirch, H. (2003) Effects of Climate Variability on the Temporal Population Dynamics of Southern Fulmars. *Journal of Animal Ecology*, **72**, 576-587. https://doi.org/10.1046/j.1365-2656.2003.00727.x

[30] Johnson, C.R., Banks, S.C., Barrett, N.S., Cazassus, F., Dunstan, P.K., Edgar, G.J., Gardner, C., Haddon, M., Helidoniotis, F., Hill, K.L., *et al.* (2011) Climate Change Cascades: Shifts in Oceanography, Species' Ranges and Subtidal Marine Community Dynamics in Eastern Tasmania. *Journal of Experimental Marine Biology and Ecology*, **400**, 17-32. https://doi.org/10.1016/j.jembe.2011.02.032

[31] Helmuth, B. (1999) Thermal Biology of Rocky Intertidal Mussels: Quantifying Body Temperatures Using Climatological Data. *Ecology*, **80**, 15-34. https://doi.org/10.1890/0012-9658(1999)080[0015:TBORIM]2.0.CO;2

[32] Findlay, H.S., Kendall, M.A., Spicer, J.I. and Widdicombe, S. (2009) Future High CO_2 in the Intertidal May Compromise Adult Barnacle (*Semibalanus balanoides*)

Survival and Embryo Development Rate. *Marine Ecology Progress Series*, **389**, 193-202. https://doi.org/10.3354/meps08141

[33] Mieszkowska, N., Firth, L. and Bentley, M. (2013) Impacts of Climate Change on Intertidal Habitats. *Marine Climate Change Impacts Partnership*: *Science Review*, **2013**, 180-192.

[34] Berge, J., Bjerkeng, B., Pettersen, O. and Schaanning, M.S. (2006) Effects of Increased Sea Water Concentrations of CO_2 on Growth of the Bivalve *Mytilus edulis*. *Chemosphere*, **62**, 681-687. https://doi.org/10.1016/j.chemosphere.2005.04.111

[35] Beesley, A., Lowe, D.M., Pascoe, C.K. and Widdicombe, S. (2008) Effects of CO_2-Induced Seawater Acidification on the Health of *Mytilus edulis*. *Climate Research*, **37**, 215-225. https://doi.org/10.3354/cr00765

[36] Thomsen, J., Gutowska, M.A., Saph.rster, J., Heinemann, A., Trubenbach, K., Fietzke, J., Hiebenthal, C., Eisenhauer, A., Krtzinger, A., Wahl, M. and Melzner, F. (2010) Calcifying Invertebrates Succeed in a Naturally CO_2-Rich Coastal Habitat But Are Threatened by High Levels of Future Acidification. *Biogeosciences*, **7**, 3879-3891. https://doi.org/10.5194/bg-7-3879-2010

[37] Porzio, L., Buia, M.C. and Hall-Spencer, J.M. (2011) Effects of Ocean Acidification on Macroalgal Communities. *Journal of Experimental Marine Biology and Ecology*, **400**, 278-287. https://doi.org/10.1016/j.jembe.2011.02.011

[38] Podrabsky, J.E. and Somero, G.N. (2004) Changes in Gene Expression Associated with Acclimation to Constant Temperatures and Fluctuating Daily Temperatures in an Annual Killifish *Austrofundulus limnaeus*. *Journal of Experimental Biology*, **207**, 2237-2254. https://doi.org/10.1242/jeb.01016

[39] Tait, L.W. and Schiel, D.R. (2013) Impacts of Temperature on Primary Productivity and Respiration in Naturally Structured Macroalgal Assemblages. *PLoS ONE*, **8**, e74413. https://doi.org/10.1371/journal.pone.0074413

[40] Chomsky, O., Kamenir, Y., Hyams, M., Dubinsky, Z. and Chadwick-Furman, N.E. (2004) Effects of Feeding Regimeon Growth Rate in the Mediterranean Sea Anemone *Actinia equina*. *Journal of Experimental Marine Biology and Ecology*, **299**, 217-229. https://doi.org/10.1016/j.jembe.2003.09.009

[41] Verde, E.A. and McCloskey, L.R. (1996) Photosynthesis and Respiration of Two Species of Algal Symbionts in the Anemone *Anthopleura elegantissima* (Brandt, 1835). *Journal of Experimental Marine Biology and Ecology*, **195**, 187-202. https://doi.org/10.1016/0022-0981(95)00080-1

[42] Bergschneider, H. and Muller-Parker, G. (2008) Nutritional Role of Two Algal Symbionts in the Temperate Sea Anemone *Anthopleura elegantissima* Brandt. *Biological Bulletin*, **215**, 73-88. https://doi.org/10.2307/25470685

[43] Orr, J.C., Fabry, V.J., Aumont, O., Bopp, L., Doney, S.C., Feely, R.A., Gnanadesikan, A., Gruber, N., Ishida, A., Joos, F., *et al.* (2005) Anthropogenic Ocean Acidification over the Twenty-First Century and Its Impact on Calcifying Organisms. *Nature*, **437**, 681-686. https://doi.org/10.1038/nature04095

[44] Meehl, G.A., Stocker, T.F., Collins, W.D., Friedlingstein, P. and Gaye, A.T. (2007) Contribution of Working Group I in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In the Physical Science Basis. Cambridge University Press, Cambridge.

[45] Feely, R.A., Sabine, C.L., Hernandez-Ayon, J.M., Ianson, D. and Hales, B. (2008) Evidence for Upwelling of Corrosive "Acidified" Water onto the Continental Shelf. *Science*, **320**, 1490-1492. https://doi.org/10.1126/science.1155676

[46] Sabine, C.L., Feely, R.A., Gruber, N., Key, R.M., Lee, K., Bullister, J.L., Wanninkhof, R., Wong, C.S., Wallace, D.W.R., Tilbrook, B., *et al.* (2004) The Oceanic Sink for Anthropogenic CO_2. *Science*, **305**, 367-371. https://doi.org/10.1126/science.1097403

[47] Morris, S. and Taylor, A.C. (1983) Diurnal and Seasonal Variation in Physic-Chemical Conditions within Intertidal Rock Pools. *Estuarine*, *Coastal and Shelf Science*, **17**, 339-355. https://doi.org/10.1016/0272-7714(83)90026-4

[48] Truchot, J.P. (1986) Changes in the Hemolymph Acid-Base State of the Shore Crab *Carcinus maenas*, Exposed to Simulated Tidepool Conditions. *Biological Bulletin*, **170**, 506-518. https://doi.org/10.2307/1541858

[49] Wootton, J.T., Pfister, C.A. and Forester, J.D. (2008) Dynamic Patterns and Ecological Impacts of Declining Ocean pH in a High-Resolution Multi-Year Dataset. *Proceedings of the National Academy of Sciences of the United States of America*, **105**, 18848-18853. https://doi.org/10.1073/pnas.0810079105

[50] Hofmann, G.E., Smith, J.E., Johnson, K.S., Send, U., Levin, L.A., Micheli, F., Paytan, A., Price, N.N., Peterson, B., Takeshita, Y., *et al.* (2011) High-Frequency Dynamics of Ocean pH: A Multi-Ecosystem Comparison. *PLoS ONE*, **6**, e28983. https://doi.org/10.1371/journal.pone.0028983

[51] Caldeira, K. and Wickett, M.E. (2003) Oceanography: Anthropogenic Carbon and Ocean pH. *Nature*, **425**, 365. https://doi.org/10.1038/425365a

[52] Melzner, F., Gutowska, M.A., Langenbuch, M., Dupont, S., Lucassen, M., Thorndyke, M.C., Bleich, M. and Pörtner, H.O. (2009) Physiological Basis of High CO_2 Tolerance in Marine Ecthothermic Animals: Pre-Adaptation through Lifestyle and Ontogeny? *Biogeosciences*, **6**, 2313-2331. https://doi.org/10.5194/bg-6-2313-2009

[53] Whiteley, N.M. (2011) Physiological and Ecological Responses of Crustaceans to Ocean Acidification. *Marine Ecology Progress Series*, **430**, 257-271. https://doi.org/10.3354/meps09185

[54] Barry, J.P., Widdicombe, S. and Hall-Spenser, J.M. (2011) Effects of Ocean Acidification on Marine Biodiversity and Ecosystem Function in Ocean Acidification. In: Gattuso, J.-P. and Hansson, L., Eds., *Ocean Acidification*, Oxford University Press, Oxford, 192-209.

[55] Pörtner, H.O. and Farrell, A.P. (2008) Ecology. Physiology and Climate Change. *Science*, **322**, 690-692. https://doi.org/10.1126/science.1163156

[56] Kleypas, J.A., Feely, R.A., Fabry, V.J., Langdon, C., Sabine, C.L. and Robbins, L.L. (2006) Impacts of Ocean Acidification on Coral Reefs and Other Marine Calcifiers: a Guide for Future Research. Report of a Workshop. NSF, NOAA and the USGS, St Petersburg.

[57] Guinotte, J.M. and Fabry, V.J. (2008) Ocean Acidification and Its Potential Effects on Marine Ecosystems. *Annals of the New York Academy of Sciences*, **1134**, 320-342. https://doi.org/10.1196/annals.1439.013

[58] Widdicombe, S. and Spicer, J.I. (2008) Predicting the Impact of Ocean Acidification on Benthic Biodiversity: What Can Animal Physiology Tell Us? *Journal of Experimental Marine Biology and Ecology*, **366**, 187-197. https://doi.org/10.1016/j.jembe.2008.07.024

[59] Pörtner, H.O., Gutowska, M., Ishimatsu, A., Lucassen, M., Melzner, F. and Seibel, B. (2011) Effects of Ocean Acidification on Nektonic Organisms. In: Gattuso, J.P. and Hansson, L., Eds., *Ocean Acidification*, Oxford University Press, Oxford, 154-175.

[60] Kurihara, H., Matsui, M., Furukawa, H., Hayashi, M. and Ishimatsu, A. (2008) Long-Term Effects of Predicted Future Seawater CO_2 Conditions on the Survival

and Growth of the Marine Shrimp *Palemon pacificus*. *Journal of Experimental Marine Biology and Ecology*, **367**, 41-46. https://doi.org/10.1016/j.jembe.2008.08.016

[61] Melatunan, S., Calosi, P., Rundle, S.D., Moody, A.J. and Widdicombe, S. (2011) Exposure to Elevated Temperature and PCO2 Reduces Respiration Rate and Energy Status in the Periwinkle *Littorina littorea*. *Physiological and Biochemical Zoology*, **84**, 583-594. https://doi.org/10.1086/662680

[62] Moulin, L., Catarino, A.I., Claessens, T. and Dubois, P. (2010) Effects of Seawater Acidification on Early Development of the Intertidal Sea Urchin *Paracentrotus lividus* (Lamarck 1816). *Marine Pollution Bulletin*, **62**, 48-54. https://doi.org/10.1016/j.marpolbul.2010.09.012

[63] Dupont, S., Ortega-Martínez, O. and Thorndyke, M. (2010) Impact of Near-Future Ocean Acidification on Echinoderms. *Ecotoxicology*, **19**, 449-462. https://doi.org/10.1007/s10646-010-0463-6

[64] Kurihara, H. (2008) Effects of CO_2-Driven Ocean Acidification on the Early Developmental Stages of Invertebrates. *Marine Ecology Progress Series*, **373**, 275-284. https://doi.org/10.3354/meps07802

[65] Ross, P.M., Parker, L., O'Connor, W.A. and Bailey, E. (2011) The Impact of Ocean Acidification on Reproduction, Early Development and Settlement of Marine Organisms. *Water*, **3**, 1005-1030. https://doi.org/10.3390/w3041005

[66] Dupont, S., Havenhand, J., Thorndyke, W., Peck, L. and Thorndyke, M. (2008) Near-Future of CO_2-Driven Ocean Acidification Radically Affects Larval Survival and Development in the Brittlestar *Ophiothrix fragilis*. *Marine Ecology Progress Series*, **373**, 285-294. https://doi.org/10.3354/meps07800

[67] Crim, R.N., Sunday, J.M. and Harley, C.D.G. (2011) Elevated Seawater CO_2 Concentrations Impair Larval Development and Reduce Larval Survival in Endangered Northern Abalone (*Haliotis kamtschatkana*). *Journal of Experimental Marine Biology and Ecology*, **400**, 272-277. https://doi.org/10.1016/j.jembe.2011.02.002

[68] Ceballos-Osuna, L., Carter, H.A., Miller, N.A. and Stillman, J.H. (2013) Effects of Ocean Acidification on Early Life-History Stages of the Intertidal Porcelain Crab *Petrolisthes cinctipes. The Journal of Experimental Biology*, **216**, 1405-1411. https://doi.org/10.1242/jeb.078154

[69] Byrne, M. (2011) Impact of Ocean Warming and Ocean Acidification on Marine Invertebrates Life History Stages: Vulnerabilities and Potential for Persistence in a Changing Ocean. *Oceanography and Marine Biology*, **49**, 1-42. https://doi.org/10.1201/b11009-2

[70] Gaylord, S.A., Palsson, O.S., Garland, E.L., Faurot, K.R., Coble, R.S., Mann, J.D. and Whitehead, W.E. (2011) Mindfulness Training Reduces the Severity of Irritable Bowel Syndrome in Women: Results of a Randomized Controlled Trial. *The American Journal of Gastroenterology*, **106**, 1678-1688. https://doi.org/10.1038/ajg.2011.184

[71] Kuffner, I.B., Andersson, A.J., Jokiel, P.L., Rodgers, K.S. and Mackenzie, F.T. (2008) Decreased Abundance of Crustose Coralline Algae Due to Ocean Acidification. *Nature Geoscience*, **1**, 114-117. https://doi.org/10.1038/ngeo100

[72] Alenius, B. and Munguia, P. (2012) Effects of pH Variability on the Intertidal Isopod, *Paradella dianae*. *Marine and Freshwater Behaviour and Physiology*, **45**, 245-259. https://doi.org/10.1080/10236244.2012.727235

[73] Bednaršek, N., Tarling, G.A., Bakker, D.C.E., Fielding, S. and Feely, R.A. (2014) Dissolution Dominating Calcification Process in Polar Pteropods Close to the Point of Aragonite Undersaturation. *PLoS ONE*, **9**, e109183.

https://doi.org/10.1371/journal.pone.0109183

[74] Birkeland, C., Craig, P., Fenner, D., Smith, L., Keine, W.E. and Riegl, B. (2008) Geologic Setting and Ecological Functioning of Coral Reefs in American Samoa. In: Riegl, B. and Dodge, R.E., Eds., *Coral Reefs of the USA*, Springer, Berlin, 737-761.

[75] WoRMS Image. http://www.marinespecies.org/aphia.php?p=image&tid=140656&pic=66399

[76] Marine Life (2018). http://www.habitas.org.uk/marinelife/

[77] *Actina equine*. https://w.marlin.ac.ukww/species/detail/1561

[78] *Porcelein crab*. http://www.livt.net/Clt/Ani/Art/Cru/Brc/brc025.jpg

[79] Nsf.gov.com (2018). https://www.nsf.gov/news/mmg/mmg_disp.jsp?med_id=61241&from=19.10.2018

[80] Menzies, R.J. (1962) The Marine Isopod Fauna of Bahia de San Quintin, Baja California, Mexico. *Pacific Naturalist*, **3**, 337-348.