

The impact of ocean warming on the kelp distribution in the high latitude region

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Keywords: Kelp, ocean warming, high latitude region, ocean temperature

Abstract: Kelp is a big brown alga and provides net productivity, significant habitat, and ecosystem functions globally. However, kelp forest is affected by climate change as seawater temperature was increased. This study analyzes the impacts of ocean warming on the distribution of kelp forests in the Northern Hemisphere and Southern Hemisphere. Results show that the kelp population has northward movement or disappearing individuals in the Northern Hemisphere, and the movement of kelps is not significant in the Southern Hemisphere. However, some evidence has shown that kelps are abundant in relatively higher southern latitude with low sea surface temperature. Both abiotic factors and biotic factors drive the kelp distribution change, such as the concentration of nutrients, sea temperature, and benthic organisms. The main driving factor of the kelp distribution change is ocean temperature, which highly affects kelp's reproductive process. Thus, both the Northern and Southern hemispheres' kelp forests tend to move poleward with increased seawater temperature.

1. Introduction

Kelp is a big brown alga within the Kingdom of Chromistan, and nearly 99% of brown algae are marine. The kelp forest is one of the most significant and diverse ecosystems globally, and its biomass and primary production are significant. Net productivity of kelp forest is more than shelf plankton and open ocean. Kelp forest supports many food webs and links directly to grazing and detritus. The kelp forest also provides nursery habitat for fish species and biogenic storm defence [1]. Moreover, kelp forest also has a regulatory function in the whole ecosystem, such as water quality enhancement, carbon fixation, wave attenuation. Thus, the kelp forest has ecologically important. Furthermore, this kelp forest is also socioeconomically important. The kelp farm can bring many economic benefits and work opportunities for people, supporting local fisheries [1].

Recently, kelp forests have decreased in some regions, and the main driver is climate change. Climate change is one of the most significant global impacts in recent decades. Global temperature has increased and resulted in a series of important changes in ecosystems, such as sea surface temperature increased, ocean acidification, acid rain, and ice sheet melting. These changes had significant impacts on local ecosystems, as well as global ecosystems. Ocean occupied over 70% surface area on the Earth, and it has many different ecosystems. Kelp is one of the significant ecosystems in the ocean. This ecosystem was sensitive to climate change, and seawater temperature highly affected their distribution. For example, kelps need water temperatures below 20°C. However, seawater temperature has risen in recent decades. Over the past five decades, seawater temperature has increased at least 0.65°C in the southeast Indian Ocean, leading to kelp forest decreased in low latitude ocean [2].

At present, most kelp studies focus on local regions or small areas; however, the effects of climate change are global. This study analyzes the impacts of ocean warming on the distribution of the kelp forest globally. The object is to study the distribution of kelp in the higher-latitude regions and the moving situation and its controlling factors.

2. Effects of kelp distribution under climate change

Due to global warming and the continuous increase in sea surface temperature (SST), marine systems worldwide are significantly affected, especially those kelp populations in the coastal marine systems [3, 4]. Smale found that the increasing temperature redistributed the kelp population since the macroalgal species are sensitive to temperature changes [1]. Most kelp species in temperate regions have declined and lost their lower-latitude habitat since the increased temperature leads to a higher mortality rate of kelp and results in the changes of habitat' environmental conditions, which then causes the kelp spores to move to the regions where have a higher habitat availability [1].

2.1 Northern Hemisphere

The change in the kelp population is especially significant for the regions that temperature changes most dramatically: the Arctic region and the sub-polar areas in the Northern hemisphere [4]. Recent research mostly shows that the kelp species are experiencing the northward movement or disappearing individuals in southern regions.

Franco et al. found that the minimum SST of the sub-polar region northeast of the Atlantic Ocean was from 8 to 16.3°C and the maximum SST increased from 15.1 to 24.6 °C [5]. Also, the kelp population in the arctic region increased, and the habitat expanded due to the increased SST while the higher-latitude temperate kelp species move northward [6]. Franco et al. used the AUC-MaxEnt model to simulate the distribution of a cold-water kelp species with high abundance on the north-western coast of Europe from 2002-2009. They predicted the distribution of this species in 2100 [5]. According to Figure 1, the researchers found that the range of presence of the species shifted northwards and spread out over 100 years, with the species reaching as far north as England's southwest corner and as far south as the west coast of Portugal between 2002 and 2009. After 100 years, however, the species will reach as far north as Norway and will no longer be found along the Spanish coast. Also, they extend to the southeast of Iceland. At the same time, the researchers found that the probability of the species occurring in each region also changed. The species was mainly distributed on the west coast of Portugal and the northwest coast of Spain during 2002-2009. Still, in 2100, Figure 1 shows that the species will be mainly distributed along with all coastal areas of Ireland and the northwest coast of England. The entire population is moving northwards.

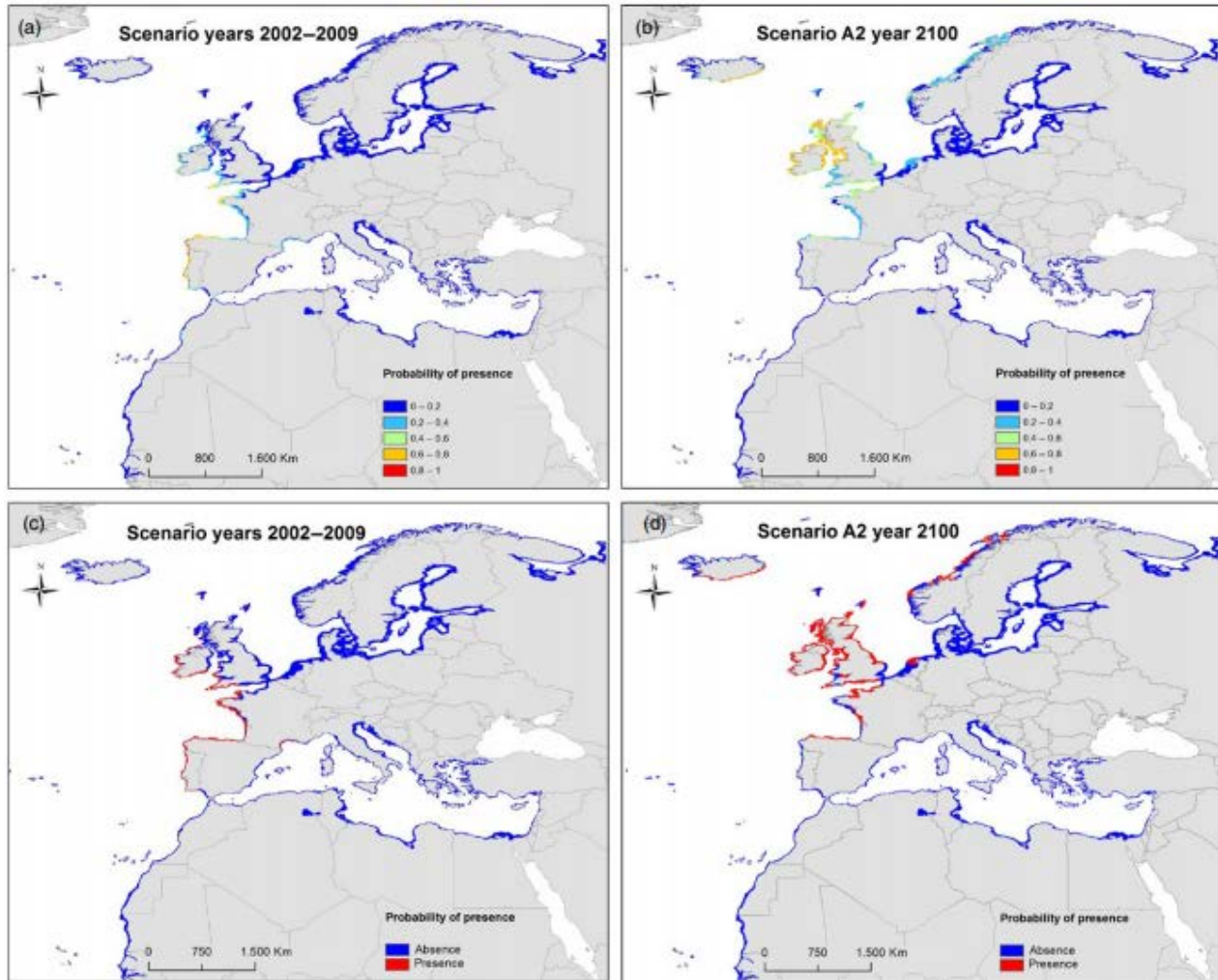


Fig. 1 The Prediction of change of Kelp habitat's range in the northeast of Atlantic Ocean [Europe west coast] between 2002 and 100 years after by using AUC-MaxEnt model [5]

Also, a study by Raybaud et al. showed similar predictions [7]. As shown in Figure 2 that by using three RCP scenarios, it predicts that those areas on the west coast of northern Europe where kelp is most likely to occur at the beginning of the 21st century will gradually move to higher latitudes in the next century due to elevated SST, from the southernmost to the northernmost part of Norway, gradually moving northward from $\sim 60^{\circ}\text{N}$ to 70°N [7].

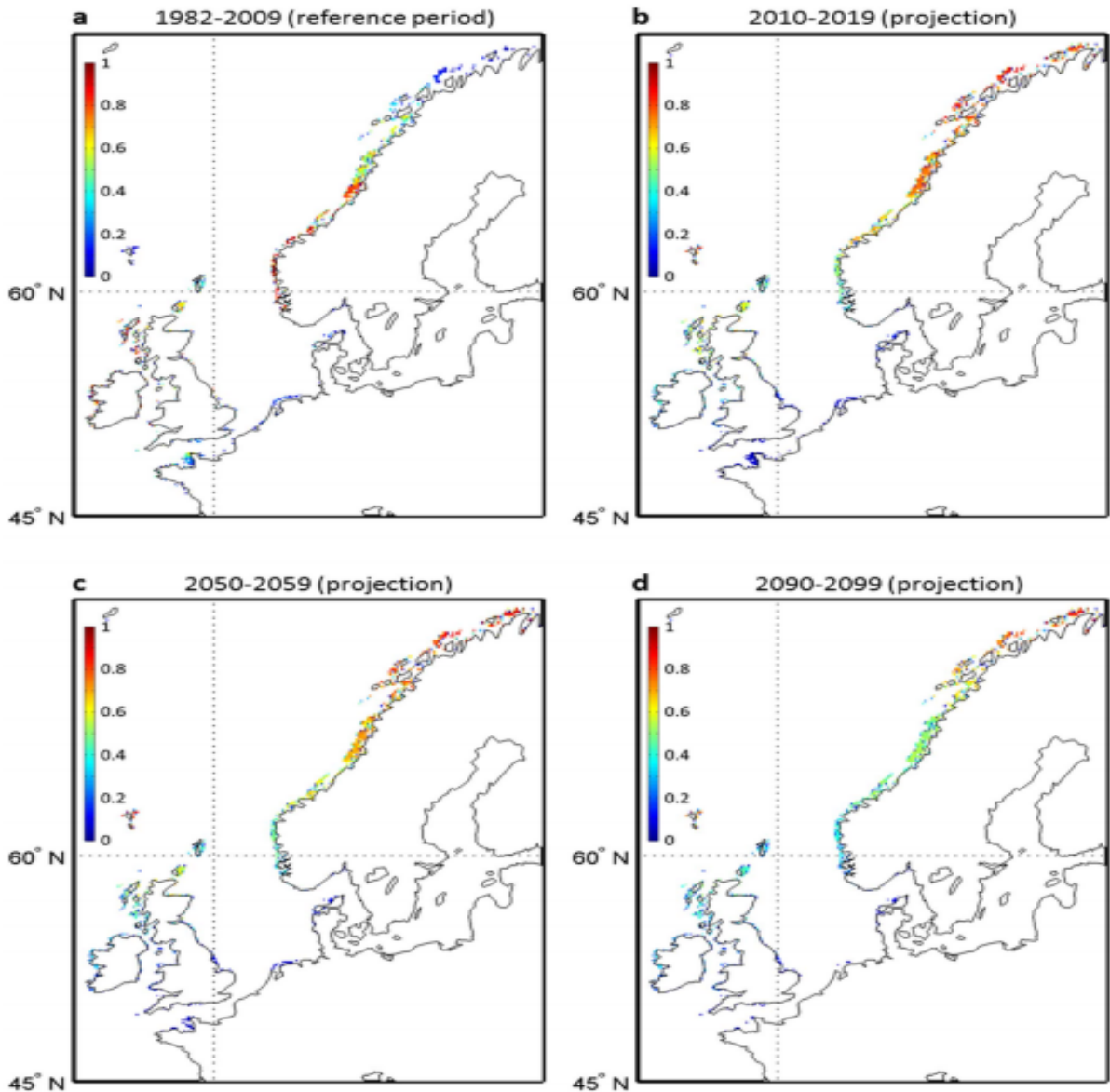


Fig. 2 Current and predicted distribution probability of dominant kelp in the northwest of Europe. A mean probability of occurrence for the period 1982–2009. b–d, projected changes in the spatial distribution of the kelp for the decades 2010–2019 (b), 2050–2059 (c), and 2090–2099 (d) [7]

Besides the northeast Atlantic kelp species, the kelp species at the northwest of the Atlantic Ocean (the east coast of Canada) are not observed a significant northward shifting trend of cold-waters kelp population during the 150yrs period [4]. According to the observation from Merzouk and Johnson, although there is no observation on the change of distribution, the researchers found that these northern kelp species show a higher abundance in the northern part of their habitat, and the northern population keeps increase [4].

2.2 Southern Hemisphere

The kelp species in the southern hemisphere had a relatively insignificant migration than the kelps in the northern hemisphere. But the evidence still shows that the main population of kelps has a higher abundance in southern latitude with lower sea surface water temperature than those closer to the equator.

Both on Australia's east and west coasts, high latitude areas have higher kelp abundance than lower latitude areas [8]. As it is shown in Figure 2a, on the west coast, the kelps' population is more abundant in the cooler surface water temperature area. 5 of the 6 grids in the 2 sampling locations at 32 °S (average coverage is 50%) show a significantly higher percentage of kelp coverage than the grids of 3

sampling locations at 30 °S & 28 °S. In the northernmost sampling location, 2 grids don't have any of the kelp population. Figure 2b shows that the kelp is more abundant at the southern sampling locations: kelp coverage is higher at 42 °S than it in 36 °S and at 32 °S has barely any kelp population there at the east coast of Australia. It also shows that the kelp population starts to reduce in the area that is most close to the Antarctic region at around the southernmost of Tasmania Island.

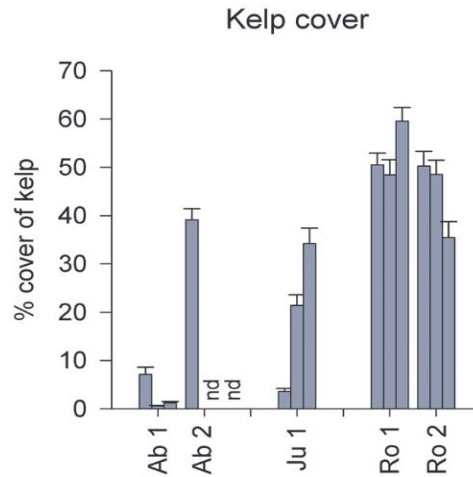


Fig. 3 The coverage of the kelp population of 3 sampling locations on the west coast of Australia. Ab is at 32 °S, Ju is at 30 °S, Ro is at 28 °S [8].

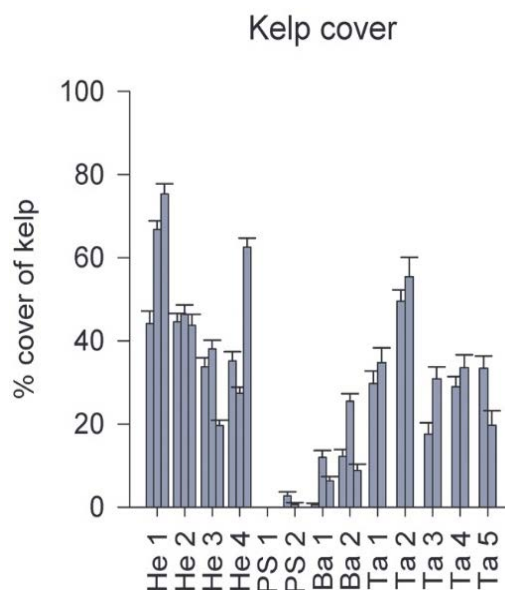


Fig. 4 The coverage of the kelp population of 4 sampling locations on the east coast of Australia. He is at 27 °S, PS is at 32 °S, Ba is at 36 °S, and Ta is at 42- 43°S [8].

However, there is no evidence supporting the relationship between the adult kelps' canopy and sea surface temperature in the southern Indian ocean. But still, Wernberg et al. observed that the spore's density of kelp decreases. In contrast, temperature increases, the northern young kelp densities (5.2 sporophytes per meter square) are much lower than the southern (12.2 sporophytes per meter square) [2].

Moreover, at the southern corner of New Zealand, Thomsen et al. found that the increase SST leads to a decreasing abundance of local kelps but no kelp movement, but still, the lower latitude kelp is less abundant than, the higher latitude kelp and lower latitude kelp population decrease more [9]. During the longest heat wave from 2017-2018 among 30 years, the SST increased over 23 Degree Celsius. Thus, three quarters of the local kelp species showed a reduction. The local dominant kelp species: *Durvillaea poha* at the 2 most northern study sites reduced significantly. At the 42°S, kelp coverage

was around 45%, but after the heatwave, the coverage reduced to less than 20%. What's more, at the 43°S study site, all kelp was locally extinct after the heatwave. At the rest of the 2 study sites at the higher latitude (45°S), the kelps showed a slight reduction after the heatwave, and the coverage decreased from 30% to 25% [9].

3. Factors of kelp distribution under climate change

Global warming has become a severe environmental problem because of anthropogenic activities. Driven by global warming, the ocean temperature will continue to rise more than 1°C in the Southern Ocean in the next hundred years and according to the simulation results of models [10], the increasing sea surface temperature (SST) is fatal to the stenothermal species and marine primary producers which cannot regulate their body temperature on their own.

With the increasing SST, kelps tend to move and redistribute to the polar regions. According to previous studies, researchers have found that the tendency to move to the Arctic region is stronger. As an important marine primary producer, kelp's distribution is affected by both biotic and abiotic factors.

3.1 Abiotic factors

Primary producers can directly absorb inorganic nutrients and produce organic matters through photosynthesis. The concentration of nutrients in the seawater in the north and south poles is quite different. Most sea areas in the Antarctic region have high concentration levels of nitrate, phosphate, and other nutrients. In contrast, the concentration of nutrients in the Arctic areas is low. However, most of the Southern Ocean areas close to Antarctica are the world-famous HNLC sea area. Thus, iron is the main element that restricts the primary productivity in these areas. Studies have found that the same breed of corn planting in different nutrient supplies would finally lead to the corn's genetic adaption [11]. Therefore, it is convinced that environmental stress can push plants to develop genic adaptation, which would increase the photosynthetic pigment content in cells. Meanwhile, different nutrient supplies can affect the photosynthetic pigment proportion in the plant and reduce the plant's photosynthesis or even lead to the plants' death.

Temperature is also an important factor in limiting the primary productivity of plants. According to research conducted between two kelp species (*Laminaria digitata*, *Hedophyllum nigripes*), as the temperature increases, *Laminaria digitata* had the highest relative growth rate when living in the 15°C waters while the relative growth rate of *Hedophyllum nigripes* peaks when existing in the 10°C seawaters [12]. Meanwhile, the unstable temperature would also affect the reproductive process of kelp. The reproductive process of kelp includes two stages: sporophyte stage and gametophyte stage. The sporophyte is produced through meiosis; it has two flagella that can help the sporophyte move in the water. The sporophyte would attach to rocks, sediments, or other suitable places and develop into a gametophyte. Gametophytes are gender-specific. They can form zygotes after fertilization then develop into the sporophyte. Studies have shown that even in the same sea area, the sporophytes and gametophytes of different kelp species have different temperature tolerance ranges. The gametophytes of *Hedophyllum nigripes* all died at 22°C, but the gametophytes of *Laminaria digitata* were still alive at 22°C and died at 24°C [12]. Therefore, kelp will be distributed due to its unique temperature tolerance in the area with uniform temperature.

3.2 Biotic factors

Kelp forest provides a comprehensive habitat for benthic organisms. However, as the ocean temperature continues to rise, studies have found that the symbiotic ecosystem of kelp would be replaced by some heat-resistant species or some eurythermal species after a strong ocean heatwave, and the biodiversity will decline or even lead to the collapse of the entire kelp forest ecosystem [3, 6].

Research conducted in the tropical nearshore in Brazil showed that the peak value of kelp area appears in 50m deep water in recent years. However, it is predicted that the peak value of the kelp area would appear in the deeper water (100m) in the future 100 years if the temperature keeps increasing [13]. The distribution of kelp beds tends to move toward deeper and colder waters. Therefore, higher

temperatures would affect the structure of the ecosystem of the entire kelp forest by affecting the organisms that live in the kelp forest. If things go on like this, increasing SST would finally lead to the redistribution of the kelp forest.

4. Conclusions and recommendation

This study analyzes the impacts of ocean warming on the distribution of the kelp forest globally. It determined that the distribution of kelp in the higher-latitude regions in the temperate zone will favor moving to near-polar areas due to ocean warming surface temperature.

In this study, kelp populations in the Northern Hemisphere showed more pronounced changes than those in the Southern Hemisphere as they moved northward. Kelp populations in the Southern Hemisphere were more likely to show a local population decrease in abundance. However, both northern and southern hemisphere kelp populations tended to migrate towards colder regions to find a more adapted ecological niche.

Also, studies have shown that kelp forests in some areas tend to move to deeper bottom areas when temperature disturbances are going greater. Therefore, the amount of kelp distributed in shallow coastal waters would decrease apparently. How can kelps find their new habitat? Is it a random selection, or would the gene decide their orientation? Therefore, there are still no clear results about how different kelp species prefer moving to higher latitude regions or to deeper regions in the face of heat stress. Meanwhile, it is clear that the heatwaves would affect the reproductive process of kelp. The thermotolerances vary from species to species. Thus, it is still a hot research issue about how kelps will adjust themselves at a genetic level for adapting the new habitats.

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