ОШ МАМЛЕКЕТТИК УНИВЕРСИТЕТИНИН ЖАРЧЫСЫ. ХИМИЯ. БИОЛОГИЯ. ГЕОГРАФИЯ

ВЕСТНИК ОШСКОГО ГОСУДАРСТВЕННОГО УНИВЕРСИТЕТА. ХИМИЯ. БИОЛОГИЯ. ГЕОГРАФИЯ

JOURNAL OF OSH STATE UNIVERSITY. CHEMISTRY. BIOLOGY. GEOGRAPHY

e-ISSN: 1694-8688
№1(4)/2024, 171-180

ГЕОГРАФИЯ

УДК: 579.64:57.045
DOI: 10.52754/16948688_2024_1(4)_22

IMPACT OF CLIMATE CHANGE ON THE BIODIVERSITY OF BIOLUMINESCENT BACTERIA

КЛИМАТТЫН ӨЗГӨРҮШҮНҮН БИОЛЮМИНЕСЦЕНТТИК БАКТЕРИЯЛАРДЫН АР ТҮРДҮҮЛҮГҮНӨ ТИЙГИЗГЕН ТААСИРИ

ВЛИЯНИЕ ИЗМЕНЕНИЯ КЛИМАТА НА БИОРАЗНООБРАЗИЕ БИОЛЮМИНЕСЦЕНТНЫХ БАКТЕРИЙ

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Abstract

Bioluminescent bacterial species that produce bioluminescence, which is a visual feast in nature, are grouped in Vibrio, Photobacterium, Aliivibrio and Shewanella genera, mostly dominant in marine regions. As new bioluminescent species are isolated and identified every day, the mechanism and evolution of bioluminescence, which is still not fully understood, is beginning to be better understood. Because it is believed that the bioluminescence phenomenon may have evolved at least 40 times since its beginning, and therefore the isolation of bioluminescent species from different countries and sources will allow us to understand this evolution process. In this context, it is important because no study has been done on Izmir Bay before. In addition to determining evolutionary relationships, it is very important to identify bioluminescent bacteria, which have many application areas, and to preserve their biodiversity. Because, like all living organisms, the biodiversity of microorganisms and bioluminescent bacteria is “nature's insurance” policy against disasters. Therefore, all biodiversity is in danger as a result of the climate change we are facing as a result of environmental degradation. Therefore, it should be instilled in all generations that the earth can exist without us.

Keywords: Bioluminescent Bacteria, Izmir Bay, Climate Change, Biodiversity.

КЛИМАТТЫН ОЗГОРУШУНУН БИОЛЮМИНЕСЦЕНТТИК БАКТЕРИЯЛАРДЫН АР ТУРДУУЛУГУНО ТИЙГИЗГЕН ТААСИРИ

Аннотация

Табиятта визуалдык майрам болгон биолюминесценцияны пайда кылган биолюминесцент бактериялык түрлөрү Vibrio, Photobacterium, Aliivibrio жана Shewanella тукумдарына топтоштурулган, алар негизинен деңиз аймактарында басымдуулук кылат. Биолюминесценциянын жаңы түрлөрү күн сайын обочолонуп, идентификацияланып жаткандыктан, биолюминесценциянын механизми жана эволюциясы дагы деле толук түшүнүлө элек, жакшыраак түшүнүлө баштады. Себеби биолюминесценция феномени башталгандан бери эң аз дегенде 40 жолу эволюцияланган болушу мүмкүн деп ишенишет, демек, ар кайсы өлкөлөрдөн жана булактардан биолюминесценттик түрлөрдү бөлүп алуу бул эволюция процессин түшүнүүгө мүмкүндүк берет. Бул контекстте бул маанилүү, анткени Измир булуңунда мурда эч кандай изилдөө жүргүзүлгөн эмес. Анткени, бардык тирүү организмдер сыяктуу эле, микроорганизмдердин жана биолюминесценттик бактериялардын биологиялык ар түрдүүлүгү кырсыктардан «жаратылыштын камсыздандыруусу» болуп саналат. Демек, экологиянын бузулушунун натыйжасында биз дуушар болуп жаткан климаттын өзгөрүшүнүн натыйжасында бардык биологиялык ар түрдүүлүк коркунучта. Демек, жер бизсиз жашай алат деп бардык муундарга сиңирүү керек.

Ачкыч сөздөр: Биолюминесценттик бактериялар, Измир булуңу, Климаттын өзгөрүшү, Биологиялык ар түрдүүлүк.

ВЛИЯНИЕ ИЗМЕНЕНИЯ КЛИМАТА НА БИОРАЗНООБРАЗИЕ БИОЛЮМИНЕСЦЕНТНЫХ БАКТЕРИЙ

Аннотация

Биолюминесцентные виды бактерий, производящие биолюминесценцию, которая является визуальным пиршеством в природе, сгруппированы в роды Vibrio, Photobacterium, Aliivibrio и Shewanella, преимущественно доминирующие в морских регионах. Поскольку новые виды биолюминесценции выделяются и идентифицируются каждый день, механизм и эволюция биолюминесценции, которая до сих пор не до конца понята, начинает лучше пониматься. Потому что считается, что явление биолюминесценции могло эволюционировать как минимум 40 раз с момента его возникновения, и поэтому изоляция биолюминесцентных видов из разных стран и источников позволит нам понять этот процесс эволюции. В этом контексте это важно, поскольку ранее никаких исследований в Измирском заливе не проводилось. Помимо определения эволюционных связей очень важно идентифицировать биолюминесцентные бактерии, имеющие множество областей применения, и сохранить их биоразнообразие. Потому что, как и все живые организмы, биоразнообразие микроорганизмов и биолюминесцентных бактерий является «страховкой природы» от стихийных бедствий. Таким образом, все биоразнообразие находится под угрозой из-за изменения климата, с которым мы сталкиваемся в результате ухудшения состояния окружающей среды. Поэтому следует внушать всем поколениям, что земля может существовать и без нас.

Ключевые слова: Биолюминесцентные бактерии, Измирский залив, Изменение климата, Биоразнообразие..

Introduction

Bioluminescence, which is the production and emission of light by living organisms as a result of a chemical reaction (Figure 1), is observed in many organisms, including fish, insects, medusa, dinoflagellates, fungi, squids and bacteria (Peat and Adams, 2008). While higher creatures such as insects and medusa only produce light in the form of intermittent flashes or flashes, the light produced continuously at a wavelength of 490 nm in bioluminescent bacteria demonstrates the uniqueness of the light produced by bacteria (Haygood, 1993).

Bioluminescent bacteria are common in marine environments and are rarely found in freshwater, brackish water and soil environments (Hastings and Nealson, 1981). Bioluminescent bacteria are found in a wide range of ecological niches (fish light organs, mammalian intestines and nematode intestines) and habitats (marine, freshwater, symbiotic relationship with terrestrial and host).

They have widespread distribution and are quite abundant (Meighen, 1994). If we look at the sources of bioluminescent bacteria in marine environments, sea water and sediments come first (Ramesh et al., 1990). Of course, in marine regions, they are found not only in shallow coastal areas but also in deep pelagic areas (Kita-Tsukamoto et al., 2006).

They can live freely in marine habitats, as well as with various living and non-living marine organisms, and can colonize marine animals as saprophytes, commensals and parasites (Dunlap and Kita-Tsukamoto, 2002). When they live freely in seawater, their numbers are quite low (0.01-40 cells/mL). When they colonize the specialized organs of some living things, their numbers reach quite high figures (10^6-10^9 cfu/g) (Kita-Tsukamoto et al., 2006). In particular, certain bioluminescent species enter into species-specific symbiotic relationships with various marine fish and squids and inhabit highly specialized light organs (Nealson and Hastings, 1992). Due to this bacterial bioluminescence, many marine fish species acquire bioluminescent properties (Peat and Adams, 2008).

The sea is a habitat that preserves its mystery and about which very little is known. In addition, considering that it is the habitat where many living creatures live, it increases its mystery even more. Such reasons direct researchers to this habitat. As a result of research conducted in various seas, marine bioluminescent bacteria have been isolated and identified (Ersoy, 2005).

Bioluminescent bacteria use approximately 20% of their cellular energy to carry out this process. When we start from this point, it becomes clear that bioluminescence cannot only be a visual phenomenon. Researchers who think this way have begun to investigate the biological role of bioluminescence in recent years. However, how this phenomenon can be implemented has begun to be examined. When we consider it from an evolutionary perspective, since these organisms have acquired this quality and this phenomenon exists in nature, there are certainly areas where this process can be reflected (Ersoy, 2005).

In addition to being a visual feast that exists in nature, bioluminescence has the potential to be used in industrial and biotechnological fields. Research conducted in this direction has shown that this process can be used in many areas such as medicine and the food industry. Cancer, once considered one of the worst diseases, can now be destroyed by bioluminescence without side effects. Again, through this process, it is possible to determine the microbial load in various areas and to get rid of various environmentally harmful toxic wastes. Although it has various application areas, this process can also explain the origin of microorganisms, a subject that all researchers are curious about.

Because the ability of bioluminescent bacteria to detoxify toxic O_2 derivatives has enabled these creatures to survive in an anaerobic environment while their living conditions are aerobic. In this context, bioluminescent bacteria appear to be representative prokaryotes (Ersoy, 2005).

The Importance of Marine Ecosystem and Microbial Diversity

When we look at the earth from space, it becomes clear why our planet should be called an ocean instead of a land. Because more than 70% of the world's surface is covered with interconnected aquatic habitats. Life in the oceans began approximately 3.5 billion years ago, and for two-thirds of our planet's existence, only microorganisms existed as life forms. Accordingly, we can say that the development and continuity of all other marine life forms depend on the past and present activities of microorganisms (Munn, 2019). Tiny microorganisms reach huge numbers in such habitats. When we look at the studies on the densities of microorganisms; it is observed that the number of bacterial and archaeal cells in marine environments is in the range of 10^{28} - 10^{29}, including the first 10 cm of the sediment. It is thought that the number of viruses in the oceans is approximately 10^{30}. These numbers are unimaginably high. If we include subsurface sediments, this number will be 10 times higher. If we were to place all the marine virus particles end to end, we could say that they could be up to 10 million light years apart. This size is 100 times the distance in our own galaxy (Munn, 2019).

Bright *Dark* *Bright* *Dark*

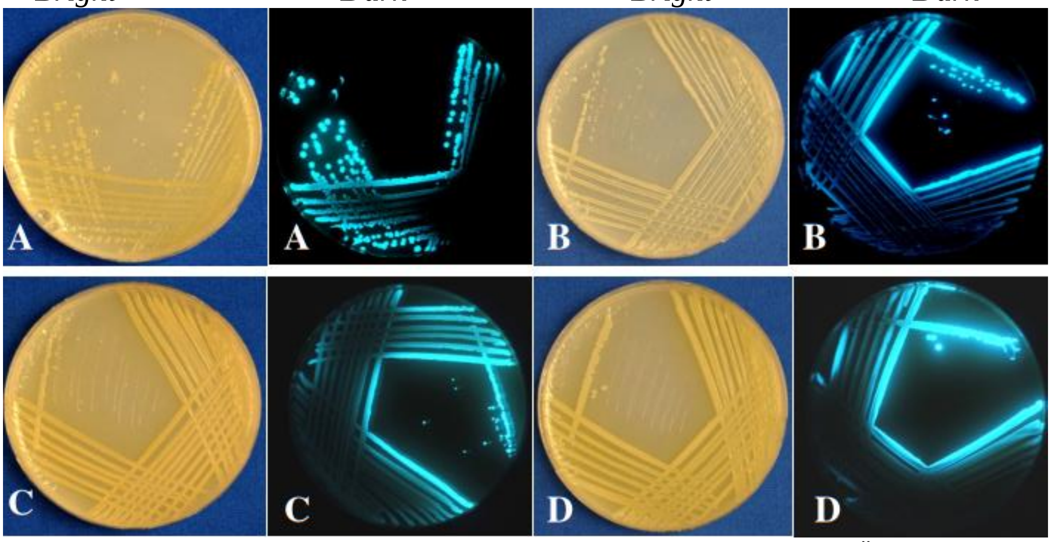

Fig. 1. Images of bioluminescent bacteria in bright and dark fields (Ersoy Ömeroğlu, 2011).

We now know that marine microorganisms play a very important role in the continuity of our planet. Indeed, problems such as human population growth, fishing, ocean acidification and marine pollution affect the survival of our planet as they have an impact on microorganisms. Microbial processes shape the living world. Microbial life and the earth have evolved together, and the activities of microorganisms affect the physical and geochemical characteristics of our planet. Really microorganisms; It is the driving force responsible for fundamental planetary processes such as changes in the composition of the atmosphere, oceans, soil and rocks.

Despite such great importance, microbial species are disappearing as a result of human activities. Every hour, six of the world's species disappear forever as a result of human activities. Direct or indirect human activities endanger the biodiversity of our planet in the forms of genes, populations, species and ecosystems. The main causes of variability and loss of marine biodiversity are anthropogenic factors in addition to natural factors. (Pawar, 2016; Imtiyaz et al., 2011).

The main global threats to biodiversity in both coastal and marine ecosystems can be classified under the following headings (Sechrest and Brooks, 2002).

- Diseases
- Overexploitation
- Overfishing
- Extinction
- Genetic or behavioural of taxa
- Global climate change
- Habitat destruction or loss
- Habitat degradation and fragmentation
- Introduced species
- Coastal and marine pollution
- Altered salinity
- Altered sedimentation

Climate change forces species to change their distribution areas and disrupts ecological communities (Lemoine and Böhning-Gaese, 2003). Climate change is caused by changes in ocean temperatures, acidity and water movement patterns as a result of increasing atmospheric carbon dioxide levels and damage to the ozone layer (Relini, 2012).

Climate change manifests itself through changes in atmospheric, hydrological and biogeochemical cycles. Human activities that affect global climate change include air pollution as a result of burning fossil fuels and destruction of forest areas (Sechrest and Brooks, 2002). Climate change can significantly affect marine biodiversity in various ways. The main impacts of climate change on marine biodiversity arise from: increase in ocean temperatures, patterns of ocean currents, sea-level rise, increasing atmospheric CO_2 levels and ocean acidification, excessive nutrient enrichment, oozone depletion and increased UV radiation fluxes and regime shifts (Craig, 2012).

Why should the biodiversity of bioluminescent bacteria be protected?

Recently, four naturally luminescent bacterial genera have been known: *Vibrio*, *Photobacterium*, *Shewanella* and *Photorhabdus*. All identified bioluminescent bacteria belong to the Gammaproteobacteria class, and 15 bioluminescent marine bacteria are known so far. 9 of them are *Vibrio* (*V. cholerae, V. fischeri, V. harveyi, V. logei, V. mediterranei, V. orientalis, V. splendidus* (biotype I), *V. vulnificus* and *V. salmonicida*) species and 4 of them are *Photobacterium* (*P. angustum, P. leiognathi*, *P. phosphoreum* and *P. mandapamensis*) and these species belong to the Vibrionaceae family. The remaining 2 bioluminescent species belong to *Shewanella* (*S. hanedai* and *S. woodyi*) species, which belong to the Alteromonadaceae family. All of these species are Gram-negative, rod-shaped chemoorganotrophic bacteria. They do not form spores and can move with the polar flagella they have. All species of the Vibrionaceae family are facultative anaerobic, but 2 *Shewanella* species are strictly aerobic bacteria (Kita-Tsukamoto et al., 2006).

With the studies carried out in 2007 and 2009, 5 new species were added to the 15 bioluminescent marine bacterial species. In the study conducted by Ast et al. in 2007, bioluminescent bacteria that were in a symbiotic relationship with deep-sea fish were isolated, and as a result of phylogenetic, genomic and taxonomic analyses, it was determined that these isolates belonged to *Photobacterium* but were a new species and were named *P. kishitanii* (Ast et al., 2007). A new *Photobacterium* species was isolated and identified from the water of Sagami Bay in Japan by another study group and was named *P. aquimaris* (Yoshiazawa et al., 2009). There are newly added species and examples of bioluminescent bacteria that have been re-identified and classified under different genera and species.

The question of the evolutionary origins of bioluminescent bacteria has recently gained a new focus. Because *V. fischeri* members have been reclassified under a new genus (*Aliivibrio*). It is frequently reviewed to better define the taxonomy, evolutionary relationships, and origins of luminescent bacteria. The distribution of bioluminescent species among bacteria is still not fully clarified. All species of the terrestrial genus *Photorhabdus* are bioluminescent, but the marine genera that include bioluminescent species (*Aliivibrio, Photobacterium, Shewanella* and *Vibrio*) also include many non-bioluminescent and closely related species (Widder, 2010).

In order to fully understand the functions, mechanisms and evolutionary origins of bioluminescence, bioluminescent bacteria must be isolated from the habitats where they live and their phenotypic, biochemical and genetic properties must be determined. After these stages, it is necessary to elucidate what benefits the bioluminescent feature provides to the organism in the evolutionary process and the mechanism by which it achieves this phenomenon. The bioluminescence phenomenon has evolved many times since its initial formation and has acquired different mechanisms and properties as a result. It has been determined that some species, which were previously recorded as not being bioluminescent, can now display bioluminescent properties in recent years, and these examples will continue to increase. In addition, revisions have begun to be made in the classifications of some species since 2007, and while they were classified in different genera when they were first identified, they began to be classified in a different and new genus as a result of molecular biological studies. Similarly, new bioluminescent species from different countries and isolation sources have begun to be increasingly isolated, identified and named since the 2000s. Thanks to these new species, revised classifications, and old species found to have bioluminescent properties, the understanding of the bioluminescence phenomenon, its mechanism, and evolution has accelerated (Ersoy Ömeroğlu, 2011).

The fact that seas and oceans are mysterious habitats and the habitat of many different creatures causes their mysteries to increase gradually. Because many creatures that are estimated to live in these habitats have not yet been identified. In this context, many new species, both bioluminescent and non-bioluminescent, are being identified every day from sediment, seawater and marine life samples obtained from various depths of these habitats. Especially the fact that these obtained species have high activities in terms of various microbial activities increases the industrial availability of new organism sources (Ersoy Ömeroğlu, 2011). In addition to all these, marine microorganisms constitute the basic components of plankton, provide marine snow formation, play a key role in sediment formation, form biofilms, form an important part of the food chain in the polar region within sea ice, and microbial activity in hydrothermal vents provides a settlement for life in the deep seas. Therefore, the biodiversity of all microorganisms, including bioluminescent bacteria, must be protected. Because bioluminescent bacteria have many application areas. Bioluminescent bacteria have been used frequently in biotechnological applications in recent years due to the advantages of their luminescence being easy, fast and quantitatively measurable. Their use as detectors to search for carcinogenic compounds or to monitor general toxic activities is a suitable example for these features (Ersoy Ömeroğlu, 2011; Karaboz and Sukatar, 2003). Depending on the developments in genetic engineering and molecular biology, the genes encoding the luciferase enzyme have been cloned in bacteria, and with the development of these cloned lux systems, they have been enabled to serve as "reporters" for special promoters in measuring the activity of other genes (Ersoy Ömeroğlu, 2011; Karaboz and Sukatar, 2003). Bioluminescence has many applications in medicine and the food industry. In medicine, lipopolysaccharide assay has areas of use such as determination of albumin binding capacity, imaging of psychopharmacological substances, diagnosis of dental diseases, cancer diagnosis and treatment, effectiveness of drugs and as a biosensor. Bioluminescence also has many applications in the food industry. It is used to determine microbial load, quality control in products, raw materials and water, determination of contamination, hygienic monitoring, sanitation control, shelf life determination and compliance with HACCP standards (Ersoy Ömeroğlu, 2011; Karaboz, 2002). In the light of this information, a new methodology has developed in the last decade. This method, called bioluminescence imaging, enabled the imaging of small laboratory animals (Sadikot and Blackwell, 2005). The most common areas of bioluminescent imaging are in vivo studies of infection, cancer progression, and regeneration kinetics. With this method, it has also been possible to determine protein-protein interactions, monitor cells in vivo, and image transcriptional and post-transcriptional regulations of genes (Welsh and Kay, 2005). It is possible to increase the examples in terms of application area. Because bioluminescence and its applications have the feature of developing very rapidly and being an alternative to many methods.

As a negative consequence of the exponentially increasing population, pollution sources and their severity are increasing. As a result, the change in climate threatens all life forms, as well as microorganisms that ensure the origin and sustainability of life. In this context, the loss of bioluminescent bacterial species may prevent their use in the above-mentioned application areas and will also cause disruptions in elucidating evolutionary relationships.

In this context, the bioluminescent diversity in Izmir Bay in Turkey can be given as an example. It has been determined that there is a high degree of diversity among the bioluminescent species obtained as a result of seasonal sampling from Izmir Bay (Figure 2, Figure 3 and Figure 4). It has been observed that bioluminescent bacteria belonging to the same species, isolated from regions with different physicochemical properties, have a high genetic diversity (Ersoy Ömeroğlu, 2011).

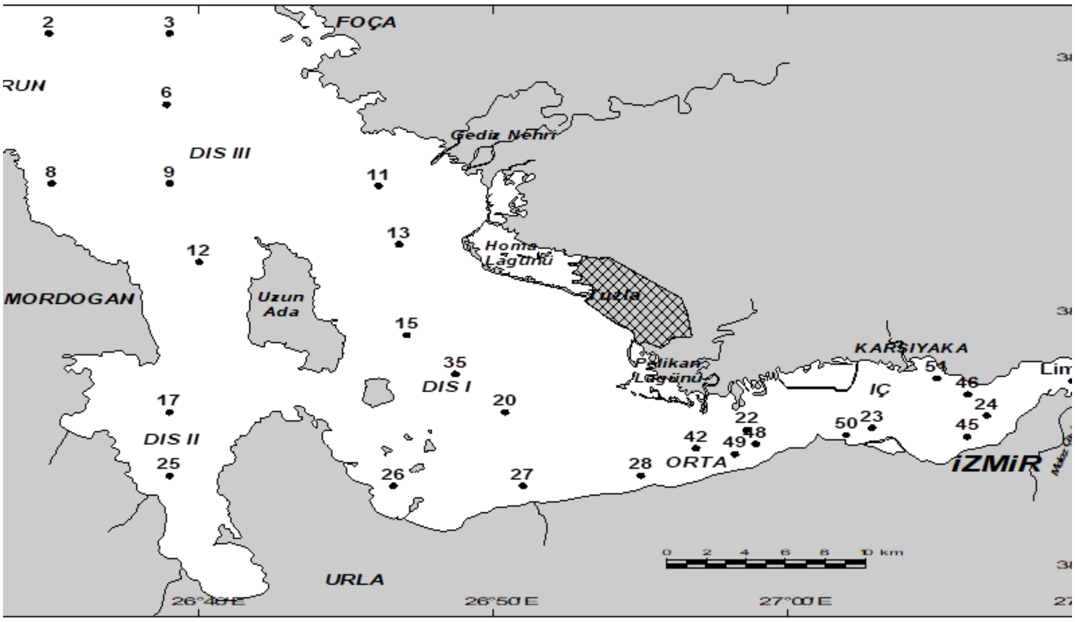

Fig. 2. Location of sampling points of Izmir Bay sea water, sediment and marine organisms (Ersoy Ömeroğlu, 2011).

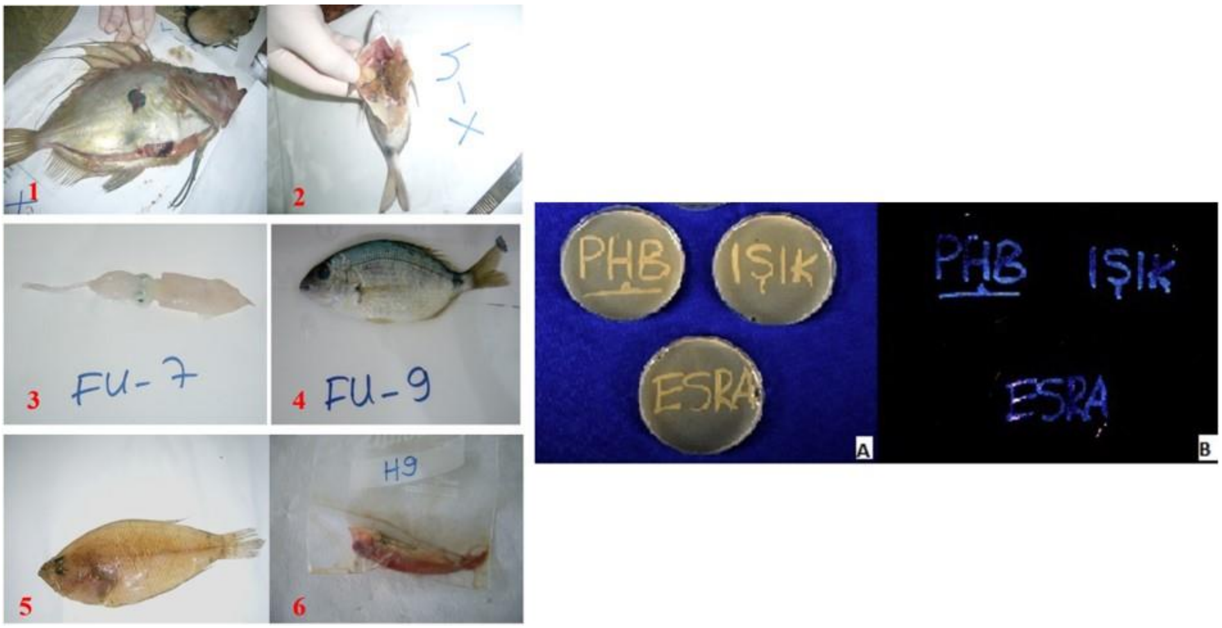

Fig. 3. Fish and squid samples from which bioluminescent isolates were obtained. 1: *Zeus faber*, 2: *Diplodus vulgaris*, 3: *Alloteuthis subulata*, 4: *Diplodus annularis*, 5: *Citharus linguatula* and 6: *Lepidotrigla cavillone* (Ersoy Ömeroğlu, 2011). Growth of bioluminescent bacteria on Sea Water Complete agar medium, A: in the light, B: in the dark (Ersoy Ömeroğlu and Karaboz, 2010).

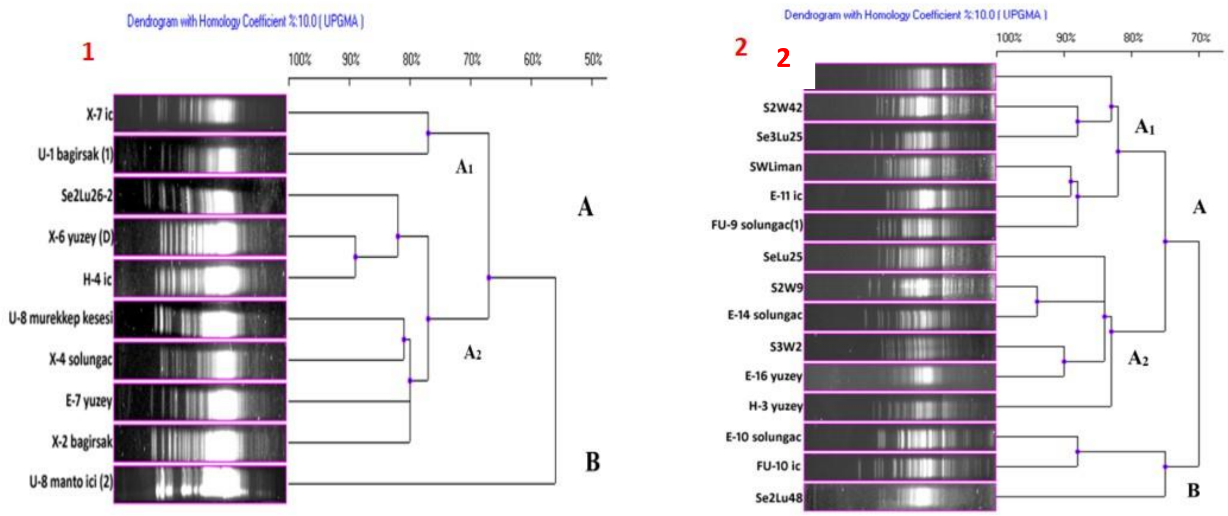

Fig. 4. Pulsed-Field Gel Electrophoresis dendrogram of bioluminescent strains identified as *Shewanella woodyi* (1) and *Vibrio gigantis* (2) from Izmir Bay by the PFGE technique, which is the gold standard in determining clonal relationships (Ersoy Ömeroğlu, 2011).

Conclusion

All generations must understand that biodiversity is nature's "***insurance policy***" against disasters. The microbial diversity we have is a global treasure. If we consume this reservoir, we will have to switch from a sustainable way of life to an unsustainable way of life. Therefore, we need a global change. Global change begins with understanding that we cannot be without the world, but the Earth can easily be without us.

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