R3-2 Fouling organisms on oysters

When and where do the living things that attach to oysters and rafts attach, and how are they related to oyster mortality, costs and labour?

Readers

Fishery cooperatives, local governments (staff in charge of fisheries), research institutions, investors and others without specialist knowledge, who want to check how the living things that attach to oysters and rafts are related to mortality, costs and labour, and how far this is known in figures.

Takeaways

1. Fouling organisms are living things that attach to oysters and rafts and grow there. A raft is a platform floated on the sea from which oysters are hung. The main fouling organisms in Hiroshima Bay are the Mediterranean mussel, barnacles, serpulid tube worms and sea squirts, and the depth at which they attach is said to differ by type. According to the prefecture's 1973 guidance, fouling increases in June and is heaviest in July to August.
2. In autumn 2025, large numbers of farmed oysters died, mainly in the Seto Inland Sea (mortality, or die-off). The national government and Hiroshima Prefecture provisionally regard the cause as a combination of factors centred on high water temperature, and do not list fouling organisms as a factor. The national government's explanatory material for the general public also lists an increase in fouling among the reasons for poor growth and mortality, but gives no amounts or proportions. No data on the amount of fouling on the farming grounds in 2025 have been found either, and the fact that fouling is not among the official factors is not evidence that fouling was not involved.
3. We find no public figures showing how much of the mortality or the costs is due to fouling organisms. The publisher of this paper has been talking with oyster producers in Hiroshima since around 2019. Among what they have said, one voice was that "with barnacle fouling, about 40% die; it varies with the place, but they certainly die", and another was that in some places it is 90%. As with the interviews by the prefecture and the national government, these are not counted values. There is no record of when, where or from how many people these were heard, so the reliability is low to medium.
4. Records in which fouling organisms are said to have been involved in major damage exist, for example for Hiroshima Bay in 1969. In 1969 a species of serpulid tube worm broke out on a large scale, and it was reported that nearly 60% of the oyster rafts in the prefecture were damaged. However, in 1969 no correlation was seen between the amount of fouling and the death rate, and in none of the records is fouling separated from other factors. On the other hand, there are also years, such as 2021 and 2022 in Hiroshima Bay when fouling was heavy, for which the materials this paper examined contain no record of mass mortality.
5. Methods of avoiding or removing fouling, such as hanging deep, drying in the air and dipping in hot water, have existed for a long time, and there are trials in which fouling was reduced. However, we find no trial on Japanese oysters that compared oysters with the fouling removed and oysters without it removed and confirmed that mortality falls. As for public figures showing the labour of the measures, the only ones found are the examples in Hiroshima Prefecture's 1973 guidance and in Kyoto Prefecture's guidance for the rock oyster (iwagaki). The rock oyster is a different species from the Pacific oyster (magaki) grown in Hiroshima and elsewhere.

After reading

When recording fouling organisms on oysters in your own area, write down the following: the date of counting, the depth at which the oysters were hung, the types of organisms attached and their amounts, and the date, method, number of people and time taken when they were removed. Also add the numbers of live and dead oysters on the same raft. Write down the way of counting as well (for example, that individuals consisting of the shell only are counted as dead).

November 2026 · English edition 1 (translation of the Japanese 1st edition) · SeatecHIROSHIMA Ltd.

This is an English translation. The Japanese edition is the authoritative text.

1. Key points

- Fouling organisms are living things that attach to oysters and rafts and grow there. A raft is a platform floated on the sea from which oysters are hung. The main fouling organisms in Hiroshima Bay are the Mediterranean mussel, barnacles, serpulid tube worms and sea squirts, and the depth at which they attach is said to differ by type. According to the prefecture's 1973 guidance, fouling increases in June and is heaviest in July to August. [S1]
- In autumn 2025, large numbers of farmed oysters died, mainly in the Seto Inland Sea (mortality, or die-off). The national government and Hiroshima Prefecture provisionally regard the cause as a combination of factors centred on high water temperature, and do not list fouling organisms as a factor. The national government's explanatory material for the general public also lists an increase in fouling among the reasons for poor growth and mortality, but gives no amounts or proportions. No data on the amount of fouling on the farming grounds in 2025 have been found either, and the fact that fouling is not among the official factors is not evidence that fouling was not involved. [S2, S3, S4, S5, S6]
- We find no public figures showing how much of the mortality or the costs is due to fouling organisms. The publisher of this paper has been talking with oyster producers in Hiroshima since around 2019. Among what they have said, one voice was that "with barnacle fouling, about 40% die; it varies with the place, but they certainly die", and another was that in some places it is 90%. As with the interviews by the prefecture and the national government, these are not counted values. There is no record of when, where or from how many people these were heard, so the reliability is low to medium. [S2, S6]
- Records in which fouling organisms are said to have been involved in major damage exist, for example for Hiroshima Bay in 1969. In 1969 a species of serpulid tube worm broke out on a large scale, and it was reported that nearly 60% of the oyster rafts in the prefecture were damaged. However, in 1969 no correlation was seen between the amount of fouling and the death rate, and in none of the records is fouling separated from other factors. On the other hand, there are also years, such as 2021 and 2022 in Hiroshima Bay when fouling was heavy, for which the materials this paper examined contain no record of mass mortality. [S7, S8, S5, S9, S10, S11]
- Methods of avoiding or removing fouling, such as hanging deep, drying in the air and dipping in hot water, have existed for a long time, and there are trials in which fouling was reduced. However, we find no trial on Japanese oysters that compared oysters with the fouling removed and oysters without it removed and confirmed that mortality falls. As for public figures showing the labour of the measures, the only ones found are the examples in Hiroshima Prefecture's 1973 guidance and in Kyoto Prefecture's guidance for the rock oyster (iwagaki). The rock oyster is a different species from the Pacific oyster (magaki) grown in Hiroshima and elsewhere. [S2, S9, S11, S1, S12]

2. What is happening

Japan: how oysters are farmed

The fouling organisms covered in this paper are living things that attach to oysters and rafts and grow there. A raft is a platform floated on the sea from which oysters are hung. Fouling organisms include barnacles, which

attach by cementing their shells, the Mediterranean mussel, which is a bivalve, and serpulid tube worms, which build calcareous tubes. Mortality (die-off) means the death of oysters that are being farmed.

Oysters are farmed either by hanging them in the sea or by putting them in baskets. A Fisheries Agency document divides the main methods into the hanging method (ropes carrying oysters are hung in the sea) and the basket method (single seed), in which oysters are grown one by one in baskets. The hanging method includes the raft method, in which the ropes are hung from rafts, and the longline method, in which they are hung from long ropes fitted with floats. The raft method allows the rafts to be moved, but the rafts are said to break easily and to be weak against waves; it is practised throughout Japan, including Hiroshima, Miyagi, Okayama and Hyogo. The longline method is strong against waves and is used in some areas with strong wind and waves, such as Miyagi and Iwate. The basket method tends to give oysters of uniform shape, but because it uses the sea as a flat surface, production is limited; it is practised in some places such as Tokushima and Oita. No breakdown of how much is produced by which method is given (the sources of the table in the document include web pages that are not official). [S4]

Oyster farming is work that takes more than a year, from collecting seed in summer to shipping from autumn to spring. The Fisheries Agency's check sheet (2026) sets out the flow of work for the hanging method as follows. In July to August, seed is collected by letting oyster larvae (the young that have hatched from eggs and have not yet attached to anything) drifting in the sea attach to scallop shells (seed collection). After seed collection, and after a stage of raising the spat (small shellfish), growth is deliberately held back until the following spring (March to May) to make hardy seed (hardening). During that period the seed oysters (the small oysters that are the starting material for farming) are inserted into ropes, and in March to May the spacing between the shells is widened to 20–30 cm. From around June they are hung in the sea in earnest (main hanging), and they are harvested from autumn (around October) onwards. The methods of hardening listed include using racks (hardening racks), hanging deep, and bundling the ropes so that they hang densely. In an example in another document of the same Fisheries Agency, seed collection is in May to September of the first year, hardening in October to March, farming from April of the second year, and shipping from October of the third year. A leaflet from Miyagi Prefecture (2019) says that the oysters are landed after about one and a half to 3 years. Oysters are said to spawn in June to August, the larvae to drift for about 2 weeks before attaching to something, and the oysters to mature in 2 to 3 years (quoted from another national guideline). [S4, S9]

Japan: the official view of the mortality, and fouling organisms

In autumn 2025, mass mortality of oysters occurred, mainly in the Seto Inland Sea. The Fisheries Agency's summary of what it heard from the prefectures (as of 6 July 2026) says that in the prefectures of the Seto Inland Sea mortality of 70–90% occurred in the worst-affected places. These are not counted values but ranges obtained from interviews (for details, see chapter 2 of R3-1). [S2]

The national government estimates that the 2025 mortality was a combined event with high water temperature as the common factor. The Fisheries Agency's summary (as of 23 January 2026) estimates that high water temperature was confirmed in common in every sea area, and that mass mortality occurred when it overlapped with other factors that differed from one sea area to another. It states that there are no reports that a known pathogen was the cause of death. The factors listed in the table are six: high water temperature, low oxygen (a state in which the seawater does not contain enough oxygen), shortage of food, excessive farming density, high salinity (a state in which the salt content of the seawater is high) and red tide (a phenomenon in which plankton multiply and the colour of the sea changes); fouling organisms are not among them. In the summary of interviews with the prefectures (July 2026) as well, high water temperature is the common presumed factor, and high salinity, shortage of food, low oxygen and others are also listed. [S2]

The national government's table of countermeasures lists the removal of fouling organisms as one of the responses to shortage of food. The basis given is a single trial in Matsushima Bay, Miyagi Prefecture (2018), and the Fisheries Agency summarises that, from this study, removal was considered effective for the survival of oysters. However, no mass mortality occurred in the year of the trial in the original study, and no difference in survival due to the treatment is shown (chapter 3). In the national government's outline of its efforts for 2026, the only response to shortage of food is the supply of nutrition through the management of nutrients (the nutrition of phytoplankton, such as nitrogen and phosphorus) (a mechanism for increasing the nitrogen and other substances that enter the sea from sewage treatment plants and the like). [S2, S9]

On the other hand, the national government's explanatory material for the general public lists an increase in fouling as one of the reasons for mortality. The Fisheries Agency's "On the situation surrounding oyster aquaculture" (November 2025) says that poor growth and mortality are occurring because of the rise in seawater temperature in recent years, an increase in fouling and other causes. As countermeasures it lists removing the fouling by hot-water treatment (dipping in hot water for a short time), freshwater baths (dipping in fresh water) and air exposure (leaving the oysters out in the air), so as to improve growth and lower the risk of mortality. It gives no amounts or proportions, and no regions or years. The same column also lists deep hanging (hanging the oysters deep) as a countermeasure against high water temperature, and the use of triploids (oysters with three sets of chromosomes) as a countermeasure against weakening caused by continued spawning. [S4]

The Fisheries Agency's check sheet (March 2026) lists sea squirts (animals with a sac-like body that attach to objects), the Mediterranean mussel and others as fouling organisms, and does not list barnacles. Those it lists are the sea squirt yurei-boya, the sea squirt shiro-boya, colonial sea squirts, the Mediterranean mussel and Polydora (a relative of the bristle worms that bores holes in the shells of shellfish). It says that hot-water treatment is effective at 65°C for 10 seconds, and that dipping in high-salinity water or fresh water may be effective against sea squirts and the like. It explains mortality during grow-out by the burden of spawning and by the loss of physical strength caused by the high water temperature and shortage of food that follow. [S4]

For 2026, the Fisheries Agency's October summary (interviews with the prefectures) says that, following the mass mortality of autumn 2025, each prefecture strengthened monitoring and carried out efforts to reduce mortality, and that "at present, there is no information that producers' oysters have died on a large scale". What is meant by large scale is not stated, and the same summary also includes sea areas where mortality exceeded the guide for normal times (30–50%) (for Hiroshima Prefecture, see chapter 2 of R3-1). In addition, in some sea areas of Iwate Prefecture, there is said to have been mortality of about 50% after fouling was removed by hot-water treatment (the conditions are not stated). The document does not link this mortality to the treatment, and there is no comparison with oysters that were not treated. 50% is the upper end of this guide. The liaison council of the Fisheries Agency, the Japan Fisheries Research and Education Agency (the national fisheries research institution) and others (14 October 2026) also sums up that there has been no large-scale mortality, but that there has been some mortality in several regions. The fishing season is still under way. [S2, S13]

Japan: examples of fouling organisms (outside the Seto Inland Sea) and overseas surveys

The examples this paper found outside the Seto Inland Sea in which fouling organisms are said to have been involved in losses are for particular places and years. In none of them was fouling measured separately from other factors. There is no system for continuously recording the relationship between fouling and mortality, and the examples are biased towards places where damage occurred and someone investigated (this paper's view).

In a survey of rafts in the Ariake Sea in Saga Prefecture (Oura, Tara Town) (2011–2012), the shallower the oysters were hung, the lower were survival and yield. The shallow layer (water depth 1.0–1.9 m) had a higher water temperature than the deep layer (3.1–3.7 m), and also more fouling organisms (about 365 g in the upper layer

and about 80 g in the lower layer per settlement unit [a shell carrying oysters]; read from a figure). The prefecture's report says that most of the fouling organisms were barnacles, but in the figure barnacles account for about 165 g of the about 365 g in the upper layer (about 45%; the proportion is this paper's calculation from the reading of the figure), so that even the largest group does not exceed half. The survival rate in February 2012 was about 4% in the upper layer, about 9% in the middle layer and about 16% in the lower layer, and the yield per settlement unit was about 140–145 g in the upper layer, about 285 g in the middle layer and about 610 g in the lower layer (read from a figure). In every layer the survival rate fell in June from about 45–55% to about 17–22%, and the difference between layers widens from late August onwards. The prefecture presumed that high water temperature and heavy settlement of fouling organisms are closely involved in mass mortality, but because water temperature and the amount of fouling both change with depth, which of them had the effect has not been separated (the water temperature data are those of a private company). [S10]

Saga Prefecture has continued to treat fouling organisms as a problem since then. The prefecture's report for fiscal 2020 writes in its background section that, since fiscal 2018, heavy settlement of barnacles and other organisms on the rafts at Oura has come to trigger mass mortality of oysters, but this report contains no data confirming this. The same report writes that in fiscal 2019, in a trial that prevented fouling by letting a sea anemone (chigire-isoginchaku) attach first, a high effect in preventing fouling organisms and an increase in oyster production were obtained (submitted to a journal; no data are given). The same trial in 2020 was called off because of the fall in salinity after torrential rain. [S10]

In Matsushima Bay in Miyagi Prefecture, besides mortality in years of high water temperature, there was a year in which fouling was presumed to have had a bad effect on survival. In this bay (an enclosed bay with a water depth of mostly 5 m or less), 70–80% of the oysters died in September of fiscal 2012. The cause was thought to be the long-lasting high water temperature and weakening caused by repeated spawning. In fiscal 2013 mortality occurred even though the water temperature was about normal, and it was presumed that the bryozoans (animals that form small colonies) and hydroids (relatives of jellyfish) that had attached to the oysters in large quantities, together with mud, had a bad effect on survival (the proportion that died is not stated). Both are quoted from other reports of the prefecture. The fouling in this bay consists mainly of bryozoans and the Asian date mussel (a small bivalve that forms mats of mud), not barnacles. [S9]

In a survey of the Karatomari farming ground in the Chikuzen Sea (the Genkai Sea side) of Fukuoka Prefecture (July 2011 to January 2012), fouling accounted for most of the waste. What was examined were hanging lines (ropes threaded with shells carrying oysters and hung in the sea) that had been given the treatment for removing the Mediterranean mussel (the hot-water treatment and air exposure described later) on 14 June 2011, and that had then not been given the removal of fouling or the transfer to baskets (growing oysters taken off the collectors [spat collectors: the shells to which oyster larvae are made to attach when seed is collected] in baskets) that are usually carried out before harvest. Fouling such as the Mediterranean mussel, barnacles, the sea squirt shiro-boya and sponges accounted for 90% or more of the weight of the waste, excluding live oysters. On this farming ground, in order to remove the Mediterranean mussel, a combination of hot-water treatment with a high-temperature high-pressure washer and air exposure is carried out in summer. The prefecture's research institution says that this treatment has a certain effect in reducing waste, for example in that fouling does not increase compared with hanging lines that are not tended (a statement in the discussion; no comparative data are shown. At Karatomari only treated hanging lines were measured). On the other hand, it says that this is heavy labour in the hot season, that it also overlaps with the season for fishing from boats, and that labour costs increase. [S11]

What the waste consists of differs with the farming ground and the tending, and the fishers bear the cost of disposing of it. The fouling is removed at landing and costs are incurred for transport and disposal, but the amount of money for the fouling portion is not shown (the same report estimates the cost corresponding to the reduction in the amount handled at the disposal site in Itoshima, assuming that the fishers' share is 3,000 yen

per tonne). The same report considers that the transfer to baskets before harvest is work done mainly for the convenience of shipping, but that if it is done before the fouling (especially the sea squirt shiro-boya) grows, it also has the effect of reducing waste and improving the growth of the oysters (no comparative data are shown). At Itoshima (Kishi district), the other farming ground in the same survey, hardly any control of fouling was carried out, and from August onwards the proportion of shells of dead oysters was higher than at Karatomari, accounting for 27–77% of all the waste. [S11]

Fouling organisms are said to affect not only the growth of oysters but also yield and expenses, through the weight of what is hung and the buoyancy of the facilities. A paper from Miyagi Prefecture (2018) states in its introduction that fouling organisms such as the Mediterranean mussel and sea squirts, which compete with oysters for food, affect the growth and survival of oysters, and that what is hung becomes heavy and falls off, or more floats need to be fitted to the facilities, leading to lower yield and quality and higher expenses. Kyoto Prefecture's guidance on farming the rock oyster (a different species from the Pacific oyster) (2006) also says that the Mediterranean mussel attaches not only to the oysters but also to ropes and other items and makes them extremely heavy, so that the work of hauling them up becomes hard, and that it also lowers the buoyancy of the facilities and becomes a cause of accidents in which they break. Both are general explanations; amounts, costs and how often this happens are not stated. [S9, S12]

We found no figures for Japan showing the share of costs taken up by the cost of measures against fouling. The only surveys that asked businesses are overseas ones. In a survey of shellfish farmers in 7 regions of the United States (published 2011; abstract only checked), respondents answered that the cost of measures against fouling organisms was on average 14.7% of annual operating costs, but the answers are said to have differed greatly between regions (the values for each region are not given in the abstract). 1,375 questionnaires were distributed and the response rate was 37%, so it is possible that businesses troubled by fouling were more likely to answer (this paper's view). The cost of measures for all the businesses in the regions surveyed was estimated to exceed 21 million US dollars, and more than 40% of respondents answered that fouling organisms had affected the sales of their products. The values include clams, scallops and others as well as oysters. The "5–10% of production costs" quoted by an overseas review article (2012) is a quotation from another study (2004), and because we have not checked the original study, this paper does not use it (chapter 5; for the origin of this figure, see chapter 5 of R1). [S14]

Region (Hiroshima and the Seto Inland Sea): rafts

There are no official statistics on the number of rafts in Hiroshima Prefecture; there is only the statement "about 10,000 rafts" in research reports. A report of the Hiroshima Prefectural Technology Research Institute (2020) puts the oyster rafts on the farming grounds in the prefecture at about 10,000, but how and as of when the number was counted is not stated. A 2009 report of the same institute has the same statement, which appears to be a repetition (not an independent confirmation; this paper's inference). The prefecture's guidelines ask that rafts be marked and that the number of rafts and the number of hanging lines set in the rules on the exercise of fishing rights (rules in which a fishery cooperative sets out how its fishing rights are to be used; a fishing right is the right to fish or farm in a defined area of water) be observed, but the total number of rafts is not published. [S7, S15]

The raft generally used in the prefecture is made of bamboo poles laid lengthwise and crosswise and tied with wire, with expanded polystyrene fitted as floats. According to the same report (2020), after about 5 years of use the rafts become industrial waste, apart from some of the expanded polystyrene. From one raft, a little under 700 hanging lines are hung, each made by threading about 35 sets of scallop shells carrying oysters and plastic tubes (spacers) alternately onto a wire. [S15]

Region (Hiroshima and the Seto Inland Sea): fouling organisms

The main fouling organisms in Hiroshima Bay are the Mediterranean mussel, barnacles, serpulid tube worms and sea squirts, and the depth and season at which they attach are said to differ. The guidance on fouling organisms issued by the Hiroshima Prefectural Fisheries Experimental Station in 1973 (checked in the English translation [1980]; we have not seen the Japanese original) writes as follows. The Mediterranean mussel and barnacles tend to attach in large numbers down to a water depth of 3 m, kasane-kanzashi (a species of serpulid tube worm) at 3–6 m, and sea squirts at about 5–10 m (in years of outbreak they attach in every layer). Fouling is light in December to May, increases in June and is heaviest in July to August. The season in which barnacles attach overlaps with the spawning season of oysters and hinders seed collection. [S1]

The same guidance says that the Mediterranean mussel hinders the growth of oysters, and also gives examples with figures. It says that when an average of 3 Mediterranean mussels are attached to one oyster, growth falls by about 20%, and with 7 by about 40%. It then gives an example of a calculation under an assumption: if the production of shucked meat from one raft is assumed to be 3 tonnes, a 40% decrease corresponds to 1.2 tonnes. However, the name, place, year and method of the original study behind the figures for the fall in growth are not stated (the references include materials of the prefectural fisheries experimental station from 1958–1965), and whether they apply as they are to Hiroshima Bay today is not known. [S1]

On the other hand, the same guidance says that a little fouling is not always bad. It writes that experienced producers regard a little fouling by serpulid tube worms or sea squirts as a good sign (it is said that this is because fouling on the edge of the shell promotes growth), but that if it increases abnormally it does nothing but harm. [S1]

The same guidance says that in seed collection the timing of putting in the spat collectors (shells and the like for the larvae to attach to) is important. It cites the result of an experiment showing that if they are put in too early, sea squirts and barnacles attach and, in addition, a film of bacteria and diatoms (small algae) forms and the settlement of spat decreases (60–70% of that on new spat collectors when they are put in 6–9 days before oyster settlement begins, and 40–60% at 12–15 days before; the source of the experiment is not stated). [S1]

The publisher (SeatecHIROSHIMA Ltd.) has been talking with oyster producers in Hiroshima since around 2019. In those interviews, one voice was that "with barnacle fouling, about 40% die; it varies with the place, but they certainly die", and another was that in some places it is 90%. As with the interviews by the prefecture and the national government (Tables 4 and 5 of R3-1), these are not counted values. There is no record of when, where or from how many people they were heard. Among those for which the person who heard them remembers the time and place is an interview with a producer on Ninoshima island in Hiroshima City around 2019 (for the reliability, see chapter 5).

Among those this paper found, the largest record in which fouling organisms are said to have been involved in major damage is the outbreak of kasane-kanzashi in Hiroshima Bay in 1969 (however, there was no correlation between the amount of fouling and the death rate, and its distribution overlapped with that of a red tide; see the next paragraph). According to Arakawa (1971), in autumn 1969 kasane-kanzashi increased abnormally on the coastal farming grounds of the inner bay of Hiroshima Bay (Jigozen, Itsukaichi, Kusatsu, Kaita and others), and it was reported that nearly 60% of the oyster rafts in the prefecture (about 6,000 rafts) were damaged. Production was expected to fall to about 63% (around 20,000 tonnes) of the initial forecast (32,000 tonnes of shucked meat), and the damage was estimated at 2.5 billion to 3.0 billion yen (at the time). East of Ondo and Kurahashi, there were no signs of an outbreak. The author says that in normal years this worm occurs only on a small scale and is hardly a problem in oyster farming. [S8]

However, the 1969 damage too has not been separated from effects other than fouling. In the survey of October 1969, the death rate of oysters averaged 19.0% (5.4–39.4% depending on the farming ground) on farming

grounds where the outbreak occurred and 6.2% (4.4–7.7%) on farming grounds where it did not, and the weight of the meat was about 20% lower. On the other hand, no correlation was seen between the amount of kasane-kanzashi attached and the death rate, and the author says there is room for re-examination. In a document of the prefecture's fisheries division from December (quoted in the paper), the death rate on farming grounds where the outbreak occurred averaged 40% and reached a maximum of 60%. Because the distribution of the red tide of the same summer (Protoeutreptia) and the distribution of kasane-kanzashi almost overlap, the author suspects a common environmental factor. Around the islands, damage thought to be due to flatworms (small worms with flat bodies) and to deterioration of the environment was also conspicuous. [S8]

The fouling organisms of Hiroshima Bay today are surveyed every year by a foundation of Hiroshima City. The Hiroshima City Agriculture, Forestry and Fisheries Promotion Center, a public interest incorporated foundation, surveys the numbers of larvae and of settled individuals of fouling organisms that have a bad effect on the growth of oysters, at survey points within Hiroshima Bay (Tsukune, Eba, Ninoshima, Mitaka, Nagahama, Etajima Bay and others) and around Okurokami-jima island (the waters off Kure City and the eastern part of the prefecture are not included). For the Mediterranean mussel, larvae are sampled in the sea from January (in 2024, from 9 January), and settlement is counted as the number settling per day by hanging palm rope (rope of palm fibre; from March 2019, 10 mm in diameter and 32 cm long) at a water depth of 5 m (0 m and 5 m at 2 points) for one week as a rule. For barnacles, wild oyster spat (spat of wild oysters that attach afterwards) and serpulid tube worms, a settlement unit of 3 scallop shells joined together is hung at water depths of 1 m and 5 m for one week as a rule, and the number per shell per day is counted (in 2024, from 26 August to 7 October or 2 December). In the summer seed collection season, the numbers of oyster spat and barnacles attached to seed-collection lines hung as a trial (trial lines) are also counted (in 2024, 53 times within Hiroshima Bay and 52 times in the Okurokami-jima sea area), and the Center gives guidance by issuing seed-watch bulletins and aquaculture information. [S5]

Settlement of the Mediterranean mussel in recent years has been on the low side, and the foundation says there was no major effect (Table 1). The index for the Mediterranean mussel (the average number settling per day, per survey) was 1 in 2024, below the normal value (the 2014–2023 average of 15) and the second lowest value in the past 10 years. 2023 was the lowest in the past 10 years, and the foundation describes the settlement in 2023 and 2024 as "not such as to have a major effect on oyster aquaculture". On the other hand, 2022 had 28 within Hiroshima Bay (normal value 16) and 8 in the Okurokami-jima sea area (normal value 8), both the third highest values in the past 10 years (the rankings are the same as in chapter 2 of R1). However, the type of rope changed in 2019, the normal values and rankings mix the values from the two types of rope, and no correction is described. The criterion for judging a "major effect" is not stated either. [S5]

Table 1 Numbers settling in Hiroshima Bay, and the foundation's judgement (survey by the Hiroshima City Agriculture, Forestry and Fisheries Promotion Center)

Year	Mediterranean mussel (within Hiroshima Bay)	Barnacles and serpulid tube worms	When guidance to avoid fouling began, etc.
2018	21 (normal value 21). Fifth highest in the past 10 years (second in the Okurokami-jima sea area)	—	Mid-February
2019	Below the normal value	Serpulid tube worms increased	Early March
2020	Below the normal value	No major effect	Early February

Year	Mediterranean mussel (within Hiroshima Bay)	Barnacles and serpulid tube worms	When guidance to avoid fouling began, etc.
2021	—	Barnacles in substantial numbers on some farming grounds (11.8 in the 1 m layer, 2.3 in the 5 m layer; a maximum of 101.6 in the 1 m layer at Eba)	Early March
2022	28 (normal value 16). Third highest in the past 10 years	No major effect	Mid-January
2023	Lowest in the past 10 years. No ma - jor effect	Serpulid tube worms increased	Late April. Guidance to take care over moving rafts and over hanging work
2024	1 (normal value 15). Second lowest. No major effect	Barnacles 2.6 in the 1 m layer, 0.8 in the 5 m layer; serpulid tube worms 3.9 (increased at some points)	Early May. Guidance to take care over moving rafts and over hanging work

Note: For the Mediterranean mussel, the figure is the number settling per rope per day, averaged per survey (the thickness and length of the rope changed in March 2019). For barnacles and serpulid tube worms, it is the average over all points of the number per shell of the settlement unit per day. What prompted the start of guidance was, in 2018–2022, the time when medium-sized larvae began to increase; in 2023, early-stage larvae; and in 2024, an increase in the number settling. "—" indicates a value not examined in this paper. [S5]

For wild oyster spat (spat of wild oysters that attach afterwards), settlement in substantial numbers was confirmed in early September (in some years up to the middle of the month) in every year from 2018 to 2023 (in 2022 and 2023, at the Mitaka point), and the foundation gave guidance to take care over "late settlement", in which wild oyster spat attach afterwards to hanging lines that are already hung. For 2024, the foundation says that the settlement of wild oyster spat was not such as to have a major effect on oyster aquaculture. For none of the years are figures given for losses due to late settlement or for the labour of dealing with it. [S5]

In measurements by the prefecture's research institution, 16–40% of the total weight of the lines of oysters being harvested was residue (what remains other than the shucked meat and the shells), such as fouling organisms, seaweed and shell fragments. In the fiscal 2014 project report of the prefecture's Fisheries and Marine Technology Center, oysters on rafts at 2 farming grounds in the prefecture were measured line by line in November, January and March. The wet weight (the weight with the water still in it) of residue such as barnacles, the Mediterranean mussel, sea squirts, seaweed and shell fragments was 9,444–21,129 g, which was 16–40% of the total weight. Per raft (assumed to have 688 hanging lines), the residue is estimated at 6.5–14.5 tonnes and the shucked meat at 2.0–5.0 tonnes. The residue also includes seaweed and shell fragments and is not the weight of the fouling organisms alone, and the names of the 2 farming grounds are not stated either. The document does not assess whether this amount is large or small. [S16]

In the prefecture's official materials, fouling organisms are treated mainly as "something that hinders growth", and are not treated as a cause of mortality. The foundation of Hiroshima City surveys fouling organisms as something that has a "bad effect on the growth of oysters". The project reports of the prefecture's Fisheries and Marine Technology Center (fiscal 2018 and fiscal 2020–2025) contain no project that surveys the larvae or settlement of fouling organisms, and in the classification of technical support, "fouling organisms" accounted for 1 of 20 cases in fiscal 2024 and 0 of 22 cases in fiscal 2025. The information handled by the prefecture's website for producers (the Fisheries Platform) (observations of water temperature and the like, larval surveys for seed collection, information on production and shipping, and so on) does not include information on fouling

organisms either. On the other hand, there is older research: the 1973 research report of the prefectural fisheries experimental station carries studies on the control of fouling organisms (I–III), and there is also a 1968 paper on the settlement of the Mediterranean mussel in Hiroshima Bay (this paper has not read their main texts). The fiscal 2012 project report writes that, in a trial, the oyster lines were hung in the lower layer "to avoid fouling". [S5, S16]

In the Buzen Sea (Fukuoka Prefecture), at the western end of the Seto Inland Sea, the Mediterranean mussel attached to oysters in large quantities in 1997. According to a research report of Fukuoka Prefecture (1999), the Mediterranean mussels per collector in late October weighed 5–308 g in 1995–1996. In 1997 the figure was 600 g or more on all farming grounds and over 1,500 g on the heavily affected grounds, the first large-scale fouling since oyster farming began in the Buzen Sea. The mortality rate of oysters in October is under 40% in ordinary years, but in 1997 it was 57.1–73.0%, except on the 2 farming grounds where fouling was relatively light (40.9% and 37.7%). In a survey in December 1997, the average shucked meat per oyster was 15.5 g on rafts without fouling, and about 8.5–11 g (read from a figure) on rafts with heavy fouling (1,100–2,500 g per collector), which did not reach 80% of the normal value (14.3 g). The shells of the surviving oysters were deformed into a long, narrow shape and their value as a product fell, and some rafts sank into the sea under the weight of the Mediterranean mussels. [S11]

However, in the Buzen Sea there was also mortality of 66–70% on 3 farming grounds in 1995, when fouling was light (Kanda 67.4%, Hachiya 69.8%, Unoshima 66.4%). The scale of mortality cannot be explained by fouling alone. It is reported that in this region, as of December 1998, the spread of the machines for the work of hauling up the oysters (shell-removing machines) was under 50% and much of the work was done by hand, and that fouling increased the burden of labour. [S11]

In 2026, several prefectures of the Seto Inland Sea have noted that fouling organisms are abundant, but they do not give amounts. The remarks column of the prefectures' action plans compiled by the Fisheries Agency (August 2026) has "Mediterranean mussels are abundant this year" for Kagawa Prefecture and "barnacles are abundant this year" for Tokushima Prefecture. The October version has "heavy fouling by the sea squirt shiro-boya" for some sea districts of Fukuoka Prefecture. Yamaguchi Prefecture includes thorough removal of fouling in its plan for 2 fishery cooperatives that farm in baskets. In some of those sea areas, 70% of the triploid seed introduced in 2025 is said to have died. The column for Hiroshima Prefecture contains no mention of fouling organisms. None of them states a relationship with mortality. The column for Ehime Prefecture also contains a statement about fouling, but it is not included here because it is covered in R7-C05 of this series (Uwa Sea: organisms that foul shellfish aquaculture [pearl oysters and oysters]). [S2]

There are also years in which fouling was heavy but no major damage was reported. In Hiroshima Bay, the settlement of the Mediterranean mussel in 2022 was the third highest in the past 10 years, and in 2021 barnacles attached in substantial numbers on some farming grounds (Table 1). However, the materials this paper examined contain no record of mass mortality in these 2 years (according to the prefecture's fisheries division, production was 18,200 tonnes in fiscal 2021 [July 2021 to June 2022] and 17,100 tonnes in fiscal 2022, and in every fiscal year from 2018 to 2024 it was in the range of 16,100–18,200 tonnes; Table 3 of R3-1). For Kagawa Prefecture and Tokushima Prefecture, which noted in 2026 that "Mediterranean mussels are abundant" and "barnacles are abundant", the Fisheries Agency's October summary gives mortality of about 20–50% in some sea areas of Kagawa Prefecture and mortality at or below the normal level in Tokushima Prefecture (the guide for normal times is 30–50%). The information for producers issued by the Buzen Sea Laboratory of Fukuoka Prefecture recorded fouling by sea squirts, barnacles and others throughout the area in the autumns of 2023 and 2024. For 2024 it describes growth as "generally good", and for 2023, while recording mortality of about 20–40% in September and October and of 30–50% in November (the November issue says that on site the mortality has subsided), it does not attribute the mortality to fouling, and recommends management such as transfer to baskets (there are no figures for the amount of fouling). Reports of fouling tend to be biased towards years in

which damage occurred, and years like these are thought to be less likely to remain in the record (this paper's view). [S7, S2, S5, S11]

Region (Hiroshima and the Seto Inland Sea): the mass mortality of autumn 2025, and the factors listed

In Hiroshima Prefecture, oyster mortality occurred throughout the prefecture from September 2025 onwards (for the scale of the mortality, see chapter 2 of R3-1). [S7, S6]

The prefecture and the national government list environmental factors that differ by district, and do not list fouling organisms. In its documents of November to December 2025, the prefecture presumed that the main cause in the central and eastern parts of the prefecture was a physiological disorder (a disorder of the workings of the body) caused by simultaneous exposure to high water temperature and high salinity (a presumption based on the literature). For the western part of the prefecture, it infers that low oxygen had an effect in addition to high water temperature (to be verified). The table by fishery cooperative that the Fisheries Agency compiled from what it heard from the prefecture (January 2026, "Presumed factors (from interviews with the prefecture)") is as follows. [S2, S6]

- Prolonged high water temperature and low oxygen: the farming grounds of Hatsukaichi City, Hiroshima City and Saka Town [S2]
- High water temperature and high salinity: 7 fishery cooperatives of Kure City (Hayase, Aga, Kurahashi Seibu, Hiro, Ondo, Yasuura, Kurahashijima), Higashihiroshima City, Takehara City and Osakikamijima Town, Onomichi City and Fukuyama City, and 4 fishery cooperatives of Etajima City (Oki, Kanokawa, Fukae, Ogaki-cho) [S2]
- Prolonged high water temperature only: Otake City, 6 fishery cooperatives of Etajima City (Mitaka, Higashie, Mino, Etajima, Uchinomi, Kirikushi), and Yoshiura and Tabara in Kure City [S2]

In no district are fouling organisms listed as a factor. Fouling organisms do not appear in the tables for Okayama, Hyogo, Yamaguchi, Kagawa, Tokushima and Osaka in the same document either. [S2]

The prefecture's expert panel compiled a provisional opinion in May 2026 and does not touch on fouling organisms (the same as in chapter 5 of R1). The panel has 6 members: 1 each from Fukui Prefectural University and Hiroshima University, 3 from the Japan Fisheries Research and Education Agency, and 1 private-sector consultant. The panel meets in person and in closed session (only the opening is public), and the prefecture publishes a summary. The provisional opinion of 26 May 2026 listed the possibility that external factors had an effect. These are that the period of high water temperature was long, that there was little rain in the rainy season (said to be the fourth lowest in the past 50 years, but the location and period are not stated), the resulting change in the food environment, and low oxygen and high salinity depending on the sea area. As factors on the side of the oysters, it lists the possibility that the mature state continued because there was little rain and so little stimulus to spawn, and the fact that oysters with larger soft parts (the meat inside the shell) die more easily. The possibility that red tide or disease was the cause is described as "extremely low", and the final opinion is to be compiled in March 2027. The summaries of the 4 meetings held from January to September 2026 contain no mention of fouling organisms. [S3]

Shortage of food is regarded not as a direct cause but as one of the environmental stresses. At the meeting of 25 March 2026, it was reported that the risk of mortality rises when the weight of the oysters increases during the period of high water temperature. In the light of this, the experts advised that shortage of food should be treated not as a direct factor in the mortality but as one of the environmental stresses. At the same meeting it was considered that sufficient grounds had been assembled for ruling out the possibility of disease and red tide. The word "fouling" does not appear in the production and shipping measures of the prefecture's guidelines for fiscal

2026 either (in the guidelines as a whole, only as "fouling residue" [what is left over from the fouling] in the table of waste). [S7, S3]

No data showing the amount of fouling on the farming grounds in 2025 have been found (chapter 5). The fact that fouling is not among the official factors is not evidence that fouling was not involved.

3. Existing measures, and how they are assessed

Existing measures exist for each of fouling organisms, mortality and labour, and many have long been used in the field. For the methods of reducing fouling organisms there are trials in which they worked, but there are only a few records that confirm with figures their effect in reducing mortality, or their cost and labour. For the measures against mortality and for labour too, the size of the effect has hardly been confirmed (for mortality, see chapter 3 of R3-1; for labour, chapter 3 of R3-3).

Measures against fouling organisms: avoiding by timing and depth

The basic method of avoiding fouling is to avoid the times and depths at which fouling is heavy. A 2011 report of the prefecture says that in Hiroshima Bay deep hanging, in which the hanging lines are hung 4–5 m deeper, is practised mainly to avoid fouling by the Mediterranean mussel and others. The report says that deep hanging also helps to avoid the high water temperature of the surface layer, but that it is not sufficient as a measure against mortality. On the basis of its surveys of larvae and settlement, the foundation of Hiroshima City gives guidance to avoid fouling by deep-hanging cultivation (growing the oysters hung deep) and other means from the time when fouling begins to increase (the same as in chapter 3 of R1). The time when the guidance began differed from year to year in 2018–2024, from mid-January to early May (Table 1). The foundation also holds training sessions for oyster farmers, based on the results of the seed collection surveys and other information. There were 4 oyster aquaculture training sessions in fiscal 2024, with a cumulative total of 34 participants (the sum of the participants at each session). The content of the training, and whether it dealt with fouling organisms, is not stated in the report. [S5, S16]

That fouling decreases with depth can also be seen in recent figures. On the foundation's settlement units, settlement of barnacles was lower at a water depth of 5 m than at 1 m, and the average over all points in 2024 was 2.6 in the 1 m layer and 0.8 in the 5 m layer (in 2021, 11.8 in the 1 m layer and 2.3 in the 5 m layer; per shell per day). A 2008 public relations magazine of the prefecture's research institute writes that the farming method of moving rafts offshore in summer to avoid red tide, fouling organisms and the like is common. The 1973 guidance recommends growing the oysters on farming grounds with little fouling in the season when fouling is heavy, and moving the rafts around October to farming grounds where meat fullness is good. [S5, S16, S1]

In trials that changed the way of hanging and the timing, fouling also decreased. In a 1998 trial in the Buzen Sea, when 3 hanging ropes were bundled together and hung deep, the Mediterranean mussels attached were 40 per collector, about a quarter of the usual number. The growth of the oyster shells also improved (29.9 mm against 17.2 mm in one month at Tsunemi, and 6.1 mm against 1.6 mm in 11 days at Unoshima). On rafts hung in mid-May, where they are ordinarily hung in March to April, no Mediterranean mussels had attached (this was learned from interviews and was not a planned trial). [S11]

The limits are the depth of the farming grounds, delayed growth, and mortality that depth alone cannot prevent. The farming grounds of the Buzen Sea have a water depth of 8 m or less, so the deep hanging at 5–10 m practised in Hiroshima and Miyagi is not possible, and it is said that if the time of hanging is delayed the growth of the oysters is also delayed. Saga Prefecture also says that the farming ground at Oura is shallow and that the deep hanging at 10 m or deeper practised in other prefectures is not possible. Saga Prefecture also carried out a trial of growing oysters in the intertidal zone (the place that is above the sea surface when the tide goes out)

from summer to autumn. The group that was grown in the intertidal zone off Muta in Tara Town from 21 February to 11 October 2012 and then put out offshore had a survival rate of 37.8% at the end of the trial (28 February 2013). This is higher than the 5.7% of the group put out offshore on 15 May (the control). However, growth was slow: the average shell height was 51 mm against 87 mm and the average weight 18.6 g against 58.2 g, which did not reach the shipping size of 40 g (whether the weight is in shell or not, the number of individuals in the trial and the number of replicates are not stated). The prefecture says that using the intertidal zone until October can reduce mass mortality in summer but delays growth, and regards effective ways of using it, such as the period of use, as an issue to be resolved. It was a trial in one year at one place, the report does not touch on fouling organisms, and the values are not for Hiroshima. In Hiroshima in 2025, according to interviews with producers, oysters offshore died regardless of the hanging depth, the mortality rate on the coast was higher in the lower layer, and at Hatsukaichi the lower part of the hanging lines was wiped out by low oxygen. No records of the cost or labour of deep hanging were found in publicly available materials. The foundation's monitoring is limited to the northern part of Hiroshima Bay, Etajima Bay and the waters around Okurokami-jima island. [S3, S5, S10, S11, S6]

Measures against fouling organisms: hot-water treatment

Hot-water treatment, dipping in hot water for a short time, removes fouling well. In a 2015 trial in Matsushima Bay, Miyagi Prefecture (a project subsidised by the Fisheries Agency), when a treatment of dipping in seawater at 65°C for 10 seconds was carried out once in July, the fouling (wet weight) in October at the point on the inner side of the bay was 19.0% of that of the untreated group (247.6 g against 1,301.8 g). The group treated twice, in July and September, had 27.1%, and the difference from the single treatment was not clear. At the point on the bay-mouth side, fouling was heaviest in December, and the group treated once had about 47% of the fouling of the untreated group (313.3 g against 663.4 g) and the group treated twice about 26% (174.2 g) (this paper's calculation). With freshwater treatment, dipping in tap water for 1 minute, the fouling in October at the point on the inner side of the bay was about 45% of that of the untreated group (591.6 g against 1,301.8 g, this paper's calculation; this does not agree with the "22.4%" in the main text of the paper; see chapter 5). On the other hand, in December at the point on the bay-mouth side, the Mediterranean mussels that the freshwater treatment had failed to remove grew, and the fouling was greater than in the untreated group (1,150 g against 663.4 g). The authors say that, leaving aside the Mediterranean mussel, the freshwater treatment also had a certain effect. [S9]

However, it has not been shown that this treatment improved the survival of the oysters. No mass mortality occurred in the year of the trial, and the survival rate in December was 74–94% (inner side of the bay) and 77–91% (bay-mouth side) in every group. In December on the inner side of the bay, the group treated once (about 74%) had a lower value than the untreated group (about 80%) (read from a figure). The sample for each group at each sampling was, as a rule, one cluster, with no replicates. The meat fullness index (the proportion of the weight of the meat with the water removed) was higher in the treated groups at some points and higher in the untreated group at others. The authors say that hot-water treatment is the most effective for removing fouling and that treatment in July is best. [S9]

In Hiroshima too, conditions for hot-water treatment had been set out since the 1970s. The prefecture's 1973 guidance gives, for the young Mediterranean mussels and barnacles on seed-collection lines before they are moved offshore, a method of dipping in hot water at 55–60°C for 10–15 seconds and returning them immediately to seawater at ordinary temperature. It says that almost all Mediterranean mussels with a shell height of up to 1–2 cm die and that the oyster spat are not harmed, while warning that losses occur if the temperature or time is wrong. In a table in the same guidance (from a 1972 article in a trade magazine; the place of the trial and the number of individuals are not stated), in hot water at 60°C all Mediterranean mussels of 1–2 cm died in 5 seconds. At the same 60°C, the death rate of oysters with a shell height of 1–2.5 cm was 0% up to 10 seconds, 8%

at 15 seconds, 20% at 30 seconds and 60% at 60 seconds. At 55°C, all the Mediterranean mussels died in 15 seconds, and for the oysters the rate was 0% up to 30 seconds and 10% at 60 seconds. To kill all Mediterranean mussels with a shell height of 4–5 cm took 60 seconds at 60°C. [S1]

In Miyagi Prefecture too, methods of removing fouling by heat are practised in the field. In Miyagi Prefecture, besides the method of dipping for about 30–10 seconds in hot water at 60–70°C, the methods of pouring boiling water over the base shells (the shells carrying oysters) once they have been hoisted up and of burning them with a burner are also practised. A 1999 paper from Fukuoka Prefecture listed hot-water treatment as a method of dipping in hot water at 70°C for 3 seconds, and said that in Miyagi Prefecture, where the farming of wakame seaweed thrives alongside that of oysters, hot-water treatment using the cauldrons for boiling wakame had become widespread (this paper has not checked the present state of practice of the method using boiling cauldrons). A 2002 document from Miyagi Prefecture recommends removing fouling by warm water, air exposure and manual work 1 to 2 months before harvest. [S9, S11]

The limits are the narrowness of the range of temperature and time (the table of the 1973 guidance above), equipment, and the effect on spawning. Saga Prefecture says that, because hot-water treatment and burning require dedicated equipment, they have not been carried out in the prefecture. In a tank trial in Miyagi Prefecture (2017; one-year-old oysters; 10 oysters at a time, 3 runs for each group), with treatments of 60°C for 30 seconds and 70°C for 10 seconds, the oysters spawned 10–30 minutes after the treatment in all 3 trials. There was no spawning in the untreated group, and the treated oysters did not die even when kept for one month. The authors see a possibility that this action of inducing spawning could be used as a measure against "egg-carrying", in which the gonads remain and shipping is delayed. [S9, S10, S1]

Measures against fouling organisms: air exposure, burning and washing

Air exposure needs almost no equipment, but it depends on the weather and on labour. The 1973 guidance says that air exposure is a method that uses the difference between the body temperature at which the Mediterranean mussel dies, 38–40°C, and that at which the oyster dies, 44–48°C. It says that on a clear day with a dry wind most young Mediterranean mussels die in 2–3 hours, but that on a cloudy, humid day not many die even in 5–6 hours (in the case of spat collectors in the intertidal zone). The work of removing kasane-kanzashi from offshore rafts by air exposure is done by laying the lines out on top of the raft and treating a third of them at a time, and takes 1–2 days in clear autumn weather. The same guidance says that one raft (about 600 lines) is handled by 6 people (2 men and 4 women) and 1 boat, and puts the cost at 155 dollars (as shown in the English translation). In an experiment in clear winter weather, the death of serpulid tube worms was 17.5% in 1 hour, 92.0% in 3 hours and 96.2% in 6 hours, but in practice 3 to 4 times as long is said to be needed. [S1]

There are records of air exposure having worked. In 1969, sun-drying for half a day or more (usually 1–2 days) achieved "fairly good results" at some farms, such as Kusatsu and Itsukaichi. On the other hand, it is said to have taken up space and to have involved losses of oysters that fell off. The guidance also writes that the growth of the oysters improves after burning and after air exposure. In a figure in the 2002 document from Miyagi Prefecture, meat fullness is about as high in the air-exposure group as in the warm-water group (conditions and numbers are not stated). In the national government's 2026 summary, air exposure in the eastern part of Hiroshima Prefecture is listed as a means of strengthening the seed by making the spat resistant to heat, and air exposure in the central part is listed without its purpose being shown (under the heading of measures against mortality). We found no materials on how much producers use air exposure as a measure against fouling. [S2, S8, S9, S1]

Papers of 1971 and 1999 said that burning was widely practised in Hiroshima, but we found no materials on the present state of practice in Hiroshima. The 1971 paper says that the method of burning with a burner is generally practised in the Hiroshima area as a measure against the Mediterranean mussel (growth is said to be good after

burning, but whether this is the stimulus of the heat or the effect of removing the fouling is unknown). The 1999 paper from Fukuoka Prefecture also says that in Hiroshima Prefecture the method of burning has become widespread because the collectors are strung on wire. [S8, S11]

The method of burning was also judged sufficiently effective in the Buzen Sea in Fukuoka Prefecture, where the collectors are hung on ropes. According to the same 1999 paper, when the fouling organisms on collectors were burned with a portable gas burner at the Tsunemi farming ground on 1 July 1998, 2 weeks later all the sea squirt shiro-boya on the burned collectors had fallen off (an observation from photographs; no numbers are given). The ropes that the flame had touched also did not break and fall for up to 2 months afterwards. In a trial in which ropes were burned directly, dry ropes burned through within 5 seconds, but wet ropes were unchanged at 20 seconds and partly broke at 30 seconds. The author says that the time for which the flame touches the rope is short and the effect on the rope is extremely low, and that burning is a sufficiently effective method of removal when the Mediterranean mussel has attached in large quantities. However, the observation is from one farming ground, and the survival and growth of the oysters after burning are not described. [S11]

In the farming of the rock oyster (a different species from the Pacific oyster) in Kyoto Prefecture, burning with a large gas burner took less than half the time of manual work with spatulas and the like. The treatment took 42 person-hours per 1,000 spat collectors (3 people × 14 hours), and the rock oysters, many of which fell off with manual work, hardly fell off at all. The way of applying the flame that kills only the Mediterranean mussels without killing the oysters was 15 seconds per clump corresponding to one spat collector (about 7 seconds per side). The Kyoto guidance says that burner treatment is not needed in years with few fouling organisms. [S12]

In the rough estimate in Kyoto Prefecture's guidance for the rock oyster, the time taken by the removal of fouling alone is not separated out. In the guidance, the working time for 3 years of farming on a raft of 1,250 spat collectors is estimated at a total of 768 person-hours (rough estimate). Of this, burner treatment is 54 person-hours each in the first year (including re-hanging) and the second year (108 person-hours in total, this paper's calculation), and "the work of breaking up the base shells, removing the fouling and shipping", which includes the removal of fouling, is 330 person-hours. The time related to fouling is contained in both of these, and this is an example from a different species (the rock oyster) and a different region. [S12]

Scraping off and washing work, but the labour is great. The 1973 guidance says that the work of scrubbing with brushes is done by 5–6 people with about 30 lines hoisted at the same time, at 135–150 dollars per raft (as shown in the English translation). It says that with high-pressure water (a force of about 28 kg per square centimetre) only the tips of the tubes of the serpulid tube worms come off and the worms remain. Freshwater baths are said to take 50 hours at 15–20°C and 30 hours at 20–25°C for the Mediterranean mussel, and saturated brine is said to work but to be laborious for long lines. With the method of towing the raft and shaking the fouling off, many oysters fell off and removal was partial. In the Chikuzen Sea in Fukuoka Prefecture, a high-temperature high-pressure washer and air exposure are combined, and this is said to have a certain effect in reducing waste, while being heavy labour in the hot season (chapter 2). [S11, S1]

No chemical is recommended for removing fouling organisms. The 1973 guidance introduced a trial in which hardly any barnacles attached to spat collectors sprayed with DDT or BHC, and then said that it did not recommend the use of agricultural chemicals. It also said that there is no chemical that is cheap, causes no pollution and acts only on fouling organisms. DDT and the constituents contained in BHC (α-, β- and γ-hexachlorocyclohexane) are now Class I Specified Chemical Substances (substances whose manufacture and use are prohibited in principle) under the Chemical Substances Control Law, and cannot be used for anything other than the uses specified by Cabinet Order (except for testing and research). The same Enforcement Order (a Cabinet Order that sets out the detailed provisions of the law) also regulates the organotin compounds that were used in antifouling paints and fishing nets (chapter 3 of R1). We found no national or prefectural materials specifying chemicals that may be used to remove fouling organisms from oysters. [S1, S17]

Does removing fouling organisms reduce mortality?

We found no controlled trial on Japanese oysters confirming that mortality falls if fouling organisms are removed. The Miyagi trial on which the national government's table of countermeasures relied was from a year without mass mortality, and does not show a difference in survival (see the section on hot-water treatment). The Hiroshima Prefecture study that the national government cites as the basis for deep hanging (Hirata et al., 2011; this paper has not checked the original) is also a study in which meat fullness advanced with deep hanging. Neither compared survival in a year of mass mortality. [S2, S9]

Overseas syntheses of research also say that the effect of removal is not clear. An analysis bringing together 33 studies of bivalve aquaculture (2017; checked in the abstract and supplementary material) found that fouling organisms usually lower the growth, survival and other measures of shellfish. It then found that the performance of shellfish from which fouling had been removed was often the same as or lower than that of shellfish left fouled, and that many of the commonly used measures do not raise productivity. The 33 studies covered do not include studies of the Pacific oyster in Japan or studies of hot-water treatment (the Japanese research is 1 study of scallops). A 2019 review article says that much of the evidence comes from observational studies, and that differences in initial conditions may be mixed in. On the other hand, it says that much evidence from observation and experience strongly indicates the effect of fouling, and introduces that, in manipulative experiments in which fouling organisms were added (relatives of the Mediterranean mussel), commercially meaningful reductions in growth and meat weight were seen. The 2 syntheses include the same researchers and are not independent evidence. [S14]

The prefecture's guidelines and measures against fouling organisms

The prefecture's guidelines are not an obligation based on law, but reference material for production and shipping. The Hiroshima Oyster Production and Shipping Guidelines are a document that the prefecture prepares every year in time for the shipping season, and in the document reporting the fiscal 2021 edition to the prefectural assembly, the column for the legal basis was "—" (none). However, there are also items that copy out obligations under other rules, such as labelling, the rules on the exercise of fishing rights and the waste laws (the meaning is that the guidelines themselves have no basis in law). They are reported every autumn to the Agriculture, Forestry and Fisheries Committee of the prefectural assembly. [S7]

The guidelines have no item on measures against fouling organisms, and no provision on the timing of hanging either. They ask that the specifications of rafts and the number of hanging lines follow the rules on the exercise of fishing rights, and say that oyster shells and "oyster washing residue" are to be disposed of in line with the prefecture's disposal procedure (what is left over from washing may contain fouling organisms that have been removed, but the guidelines do not say so). [S7]

4. What is changing

The prefecture's guidelines for fiscal 2026 and its plan for 2030 have no item on measures against fouling organisms (chapters 3 and 5). The materials on national and prefectural support after the 2025 mortality also have no item linked to fouling organisms (chapter 3 of R3-1). [S7, S18, S19, S20] On the other hand, the national government's explanatory material for the general public lists the rise in seawater temperature in recent years and an increase in fouling side by side as reasons for poor growth and mortality. It gives no amounts or proportions (chapter 2). [S4] Moves to regulate substances that prevent fouling (antifouling agents) are covered in chapter 4 of R1. The water temperature values in the next section are also given in chapter 4 of R3-1.

The marine environment

The water temperature of the seas near Japan is rising more than the world average. In the analysis of the Japan Meteorological Agency, the annual mean sea surface temperature in the seas around Japan has risen at a rate of 1.36°C per 100 years in the statistics for 1908–2025, a larger rise than the world average of 0.63°C (about 2.2 times, this paper's calculation). A document of a council of the Fisheries Agency (April 2026) also describes it as rising at a rate more than twice the world average. The difference of the annual mean from the normal value (the 1991–2020 average) was +1.44°C in 2024, +1.10°C in 2023 and +1.00°C in 2025, and these 3 years are the top three of the years for which there are data (this paper's calculation). The difference from the normal value for July to September was +1.84°C in 2025, the largest value among the years for which there are data (this paper's calculation). The difference from the normal value for October to December (autumn in the Japan Meteorological Agency's classification for sea surface temperature; it is shifted by one month from autumn for air temperature [September to November]) was also +1.49°C in 2024, +1.30°C in 2025 and +1.16°C in 2023, and these 3 years were the top three of the 108 years with data in 1908–2025 (the fourth was 2022 with +0.76°C; the ranking is this paper's calculation). However, the Japan Meteorological Agency's sea areas do not include the Seto Inland Sea, and the trend in the Seto Inland Sea cannot be known from these figures. [S21, S22]

In the observations at Kure, the highest water temperature of the year and the number of days above 20°C are increasing. The prefecture's plan for 2030 shows the results of the fixed-point observations (observations continued at the same point) off the prefecture's Fisheries and Marine Technology Center (Kure City). It says that the maximum water temperature of each year rose by 1.8°C from 1980 to 2025, and that the number of days on which the water temperature exceeds 20°C increased by 19.5 days (about 13%). Both are values from trend lines fitted as straight lines, and the depth and time of the observations, the way the maximum was obtained and the underlying data cannot be checked in publicly available materials. Nor is it stated what the "about 13%" is a proportion of (about 13% if against the about 152 days on the 2025 side, about 15% if against the about 133 days on the 1980 side; read from a figure and this paper's calculation). In the figure, the number of days above 20°C in 2025 is lower than in 2024. The same plan says that with the rise in seawater temperature the basal metabolism of oysters (the energy used to stay alive) is increasing, and that the time of the switch from spawning to building up meat is becoming later (the prefecture's view). [S18]

5. What is not yet known

Where there are no figures

- We found no public figures or peer-reviewed papers, either for Hiroshima and the Seto Inland Sea or for Japan as a whole, showing how much of the mortality or the costs is due to fouling organisms (we searched in Japanese and English through materials and papers of the national government, prefectures and research institutions, and as far as the guidance in English translation). Neither the share of barnacle fouling among the causes of mortality nor the proportion of oysters with barnacles attached that die was found in publicly available materials. In the publisher's interviews with producers there are voices saying "about 40%" and "90% in some places", but as with the interviews by the prefecture and the national government these are not counted values (chapter 2). The similar figures found in publicly available materials all mean something different. The average death rate of 40% on the farming grounds of the 1969 outbreak is a value for a year of kasane-kanzashi (not barnacles), and it also overlapped with a red tide. The guidance's "with 7 Mediterranean mussels growth falls by about 40%" is a value for growth, and the statement that about 45% (this paper's calculation) of the fouling in the upper layer in Saga Prefecture was barnacles is a breakdown of the fouling. The about 40% around Atata-jima island in 2025 is mortality "at the normal level" (Table 6 of R3-1), and the "under 40% in ordinary years" of the Buzen Sea is the mortality rate in October. The "mortality of

about 20–40%" in the September and October 2023 information of the Buzen Sea Laboratory and the "30–50%" in its November information appear in issues that also record fouling, but they do not attribute the mortality to fouling. The examples in which 40% or more, or 90%, died have not been separated from effects other than fouling either. The October mortality rate in the Buzen Sea in 1997 (57.1–73.0% on 6 farming grounds, excluding the 2 farming grounds where fouling was relatively light [40.9% and 37.7%]) is a value for a year in which the Mediterranean mussel (not barnacles) attached in large quantities, and there were also farming grounds with 66–70% in 1995, when fouling was light. The survival rate in the shallow layer in the trial at Oura in Saga Prefecture (about 4%; read from a figure) is a value for a layer where fouling was heavy and the water temperature was also high, and it was about 16% even in the deep layer. The statement in the same prefecture's report for fiscal 2020 that heavy settlement of barnacles and other organisms has come to trigger mass mortality has no data confirming it. For the mortality that reached 90% in some districts in 2025 too, the prefecture and the national government do not list fouling organisms as a factor (chapter 2). [S2, S8, S10, S11, S6, S1]

- We found no data examining how much fouling there was on the farming grounds of Hiroshima in 2025, or how it was related to the mortality. The report on the 2025 survey by the foundation of Hiroshima City (the fiscal 2025 edition) had not been published as of 3 November 2026. [S5]
- For oyster aquaculture in Japan, the only public figures found for the amount of losses due to fouling organisms or the cost of measures were the estimate for the 1969 outbreak (2.5 billion to 3.0 billion yen, at the time) and the per-raft examples in the guidance from the 1970s. The share of fouling costs quoted by an overseas review article (2012) has not been checked against the original study and is not used. Nor did we find materials on which methods (deep hanging, moving rafts, air exposure, hot water, burning, washing) producers in Hiroshima use today, and how often and for how long. [S8, S14, S1]
- The only public figures found showing the labour of the measures are the per-raft examples in Hiroshima Prefecture's 1973 guidance and the examples in Kyoto Prefecture's guidance for the rock oyster (a different species from the Pacific oyster grown in Hiroshima and elsewhere) (chapter 3). [S1, S12]
- These examples of the amount of losses, costs and labour come from the 1969 estimate, the 1973 guidance (the English translation is from 1980) and the 2006 Kyoto Prefecture guidance, and are not values for Hiroshima today. The cost and labour of fouling on fishing nets and aquaculture containers are covered in chapters 2, 3 and 5 of R1. [S8, S1, S12]
- For the waters off Kure City and the eastern part of the prefecture, we have found no monitoring that currently surveys fouling organisms regularly and publishes the results (for the sea area of Kure City, the same as in chapter 2 of R1). There are past records. According to the 1971 paper, the prefectural fisheries experimental station surveyed the main oyster farms in the prefecture in October 1969. The damage from kasane-kanzashi extended east as far as the Kure Channel (Tenno, Yoshiura [now Kure City] and others), and at the farms east of Ondo and Kurahashi (now Kure City) there were no signs of an outbreak (at Yoshiura and elsewhere the amount of fouling was also measured). The references in the English translation of the 1973 guidance also list a report on the damage suffered by oysters near Ondo through competition with the Mediterranean mussel (Arakawa, 1974; given as No. 5 of the research reports of the prefectural fisheries experimental station, but it is not to be found in No. 5 in the catalogue of the prefecture's research reports). It is known that older research on Hiroshima exists (the 1973 studies I–III on control by the prefectural fisheries experimental station, the 1968 paper on the settlement of the Mediterranean mussel, the records of the prefectural fisheries experimental station from 1958–1965 [including the state of mortality and fouling in fiscal 1963], and the 1974 report on the area near Ondo), but this paper has not read their main texts. [S8, S16, S1]

The limits of comparison

- In none of the examples in which fouling organisms are said to have been involved in losses is fouling separated from other factors. Conversely, there are also years in which fouling was heavy but no damage was reported (such as 2021 and 2022 in Hiroshima Bay), and reports may be biased towards years in which damage occurred. In 1969 there was no correlation between the amount of fouling and the death rate, and the distribution overlapped with that of a red tide. In the Buzen Sea there was mortality of about the same size in 1995, when fouling was light; in Saga Prefecture water temperature and the amount of fouling change together with depth; and for Matsushima Bay in 2013 it is a "presumption". [S8, S9, S10, S11]

Where the figures disagree

- For the fall in production in the 1969 outbreak, the paper (1971) expected production to be about 63% (around 20,000 tonnes) of the initial forecast, while the English translation of the guidance (1980) says it "fell by about 60%". [S8, S1]
- For the result of the freshwater treatment in the Miyagi Prefecture paper (2018), the main text gives "22.4% of the untreated group", while the values shown (591.6 g ÷ 1,301.8 g) give about 45% (this paper's calculation). [S9]
- For the Mediterranean mussel in the Okurokami-jima sea area in 2024 in the report of the foundation of Hiroshima City, the main text gives a settlement number of 4 (normal value 42) and the table gives 2 (normal value 8); the main text appears to be an error in which the values for larvae were copied (this paper's view; this paper used the values in the table). [S5]
- The main text of the Saga Prefecture report says that "most" of the fouling organisms in the shallow layer were barnacles, but in the figure it is about 45% (this paper's calculation from the reading of the figure). [S10]

Data that are unfavourable to new fouling measures and labour-saving means

- For the 2025 mass mortality, none of the prefecture's documents, the 4 summaries of the prefecture's expert panel, the Fisheries Agency's table of factors, or the list of presumed factors by fishery cooperative gives fouling organisms as a cause. The official explanation is combined stress centred on high water temperature. Fouling organisms are also absent from the presumed factors of the other prefectures of the Seto Inland Sea covered in this paper (chapter 2; Ehime Prefecture is excluded because it is covered in R7-C06 and R7-C29). [S2, S3, S6]
- There are interview accounts that the 2025 mortality occurred offshore regardless of hanging depth, and occurred in both diploids and triploids and in both 2-year and 3-year farming (interviews with producers). However, there are also reports that it was greater the longer the years of farming and in the lower layer on the coast, and somewhat less in the triploid examples. This fits with physiological stress acting on the whole body of the oyster, but it has not been confirmed (this paper's interpretation). [S3, S6]
- Oysters with larger meat are said to die more easily (the prefecture's expert panel; in the prefecture's 2011 study this was seen only in oysters in the middle and lower layers; the author of the study is also a member of the panel, so this is not an independent confirmation; the Okayama Prefecture research institute writes it as a general statement). The national government's explanatory material for the general public says that if fouling is removed and growth is improved, the risk of mortality falls. On the other hand, the prefecture's panel takes account of a report that the risk of mortality rises when weight increases during the period of high water temperature. Improving growth does not necessarily reduce mortality (this paper's interpretation). [S3, S4, S23, S16]
- Even in normal times, some of the oysters die. The research institution of Hiroshima Prefecture gives 20–30% at harvest, the Fisheries Agency gives 30–50% as a general guide (the basis and the way of counting are not stated), and in the Buzen Sea in Fukuoka Prefecture the figure is under 40% in October in ordinary years (the

definitions differ; Table 6 of R3-1). We find no data showing how much of this is due to fouling organisms. [S2, S11, S16]

- Methods of avoiding or removing fouling already exist. There are also methods that need almost no equipment, such as deep hanging and air exposure (no present-day records of cost and labour have been found). Deep hanging has long been practised in Hiroshima, and there are the hot-water treatment of the 1973 guidance, the "fairly good results" of sun-drying in 1969, the 2015 trial of hot-water treatment in Miyagi (fouling about 20% to 50% of that of the untreated group; one cluster for each group, with no replicates), and the burning in the Buzen Sea in 1998 (all the sea squirt shiro-boya on the burned collectors had fallen off 2 weeks later; an observation from photographs at one place). There is also the statement that experienced producers regard a little fouling as a good sign (the 1973 guidance). [S8, S9, S11, S16, S1]
- It is said that there are many studies in which growth and survival do not improve even when fouling is removed (the synthesis of 33 overseas studies). In the Miyagi trial too, no difference in survival was shown, and meat fullness went in opposite directions depending on the point. [S9, S14]
- The foundation of Hiroshima City describes the settlement of the Mediterranean mussel in 2023 and 2024 as "not such as to have a major effect on oyster aquaculture", and says that barnacles too had no major effect in 2020 and 2022. The prefecture's guidelines for fiscal 2026 and its plan for 2030 have no item on measures against fouling organisms, and none of the 22 technical consultations brought to the prefecture's research institution in fiscal 2025 concerned fouling organisms. [S7, S5, S16, S18]
- 2026 was a year with much rain in the rainy season. There was mortality of around 60–70% in some sea areas of the western and central parts of Hiroshima Prefecture (chapter 2 of R3-1), but the Fisheries Agency's October summary says there is no information that producers' oysters have died on a large scale. What is meant by large scale is not stated. Mass mortality may be a year-by-year event that depends on the weather. [S2, S3]
- Oyster aquaculture in Hiroshima Prefecture has been expanding in scale (the average area is about 4 times the national figure, and the area increased by 12% from 2018 to 2023; the increase is this paper's calculation), much of it is run by companies, and the income of individual (household) management entities in the Seto Inland Sea was rising from 2021 to 2024. Repair costs (only repairs of boats, equipment, fishing nets and fishing gear commissioned from shipyards and the like; repairs of rafts and upkeep done by the entity itself are not included) are in the range of 3% to 4% of fishing expenditure (2021–2024 in Table 1 of R3-3; the proportions are this paper's calculation). The cost of measures against fouling cannot be known from these statistics. [S7, S24, S25]
- About 80% of the working hours of individual (household) management entities in the Seto Inland Sea are work on land, and work at sea is about 20% (in 2024, 5,192 hours, 20.6%; this paper's calculation). With methods that reduce only the work at sea, there is an upper limit to the labour that can be saved (this paper's interpretation; however, the cleaning of shells may also be counted as work on land). [S25]

Reliability and the position of the sources

Reliability differs from item to item. The Census is a national statistic, and its reliability can be said to be high. The management statistics are also national statistics, but the values for the Seto Inland Sea are a simple average of 17 management entities in 2024, with no error shown, and the reliability is medium. That the official view for 2025 is a combination of factors centred on high water temperature and does not list fouling organisms is a fact of high reliability. However, the cause itself is provisional, and the final opinion is due in March 2027. The scale of mortality by district comes from interviews, so the reliability is medium. The values from the publisher's interviews (about 40% with fouling, 90% in some places) are also from interviews. These interviews have been accumulated since around 2019, but because there is no record of when, where or from how many people they were heard, the reliability is low to medium. For the share of mortality or costs due to fouling organisms, no data

have been found, and it is not known. There are several reports in Japan of damage coinciding with years in which fouling organisms broke out on a large scale, but there are also years in which fouling was heavy and no damage was reported, and in none of them is fouling separated from other factors, so the reliability is low to medium. The effect of existing fouling measures in reducing fouling is shown by the trials in Miyagi (2015) and the Buzen Sea (1998) (the reliability is medium; in Miyagi, one cluster for each group with no replicates). The effect of existing measures in reducing mortality or costs, and the effect of the prefecture's monitoring and warnings, have not been confirmed by comparisons with controls (self-reporting, comparisons without controls, overlap with the weather), and the reliability can be said to be low.

The position of the sources also calls for care. The agreement between the older research on Hiroshima and today's view includes the line of thinking of the same expert. The person who was a co-author of the 2006 report and the author of the 2011 report was also the person in charge of the 2014 measurement of residue (the measurement this paper used as a clue to the amount of fouling). This person is one of the 6 members of the prefecture's present expert panel, and this cannot be called independent confirmation (the panel also has members from universities and from the Japan Fisheries Research and Education Agency). The same applies to the evidence on the fouling side. The paper on the 1969 damage (1971) and the guidance on fouling organisms (1973) are by the same author, and the 1969 figures in the guidance are not an independent confirmation. The national government's table of countermeasures relies on 1 study each as the basis for the removal of fouling organisms and for deep hanging, and its summaries go beyond what the original studies showed. The 1969 death rate and amount of damage are values from the prefecture's documents quoted in the paper. The 2 overseas syntheses include the same researchers.

The publisher of this paper (SeatecHIROSHIMA Ltd.) runs a business that controls fouling by surface treatment of materials, and is in a position that may compete with the existing measures covered in this paper. It is also developing a system that tracks the positions of oyster rafts and notifies ships of them. This paper does not cover the company's own technology or results. The "new fouling measures and labour-saving means" of chapter 5 include the publisher's business. The publisher's relationships with the organisations taken up in this paper are as follows (as of 3 November 2026; based on information the publisher has made public, the publisher's contracts and records, and the research for this paper). With Hiroshima Prefecture, there is the relationship of having been selected for the prefecture's start-up support programme "HIROSHIMA UNICORN 10" in fiscal 2022 and 2023 (the same as in R2). With Hiroshima University, the publisher has taken part since October 2025, as one company in a consortium, in a research centre of the university (JST COI-NEXT). Michio Imai, co-representative and CEO of the publisher, has served since 1 November 2026 as a researcher (part-time) at a research institute of the university (its institute for the future of the ocean and maritime affairs) (concurrently with his post as co-representative and CEO of the publisher). In addition, the publisher joined a joint research project under the Town & Gown initiative of Kure City and Hiroshima University (an initiative in which the city and the university work together) (the research period was October 2025 to August 2026, and the contract was concluded in March 2026). This joint research is funded by a research grant from Kure City, and the publisher received an allocation of research funds from that grant (April 2026). It has also been selected for Kure City's research grant for the second year (from September 2026). The costs of the demonstration work that the publisher commissioned from the company that is its partner in the joint research also include honoraria to the fishers who helped with the work (2026). This paper does not use the data or results of this joint research. The statements on the number of rafts (chapter 2) and on the moving of rafts and the prefecture's watch system (chapter 3 of R3-1) are based on publicly available materials. Note that 1 of the 6 members of the prefecture's expert panel taken up in this paper (chapter 2) is a person from Hiroshima University. With Kure City, there is also the relationship that from June 2021 to April 2025 the publisher was a tenant of the city's incubation facility (a facility that rents rooms to companies that have only recently been founded) and paid the city fees for the use of a room. Of the regions with which the publisher is involved, the figures for Ishikawa Prefecture (Nanao Bay) and Ehime Prefecture are covered in R7-A (Nanao Bay) and R7-C (Ehime) of this series and are not included in

this paper. Apart from the above, there is no relationship between the publisher and the organisations taken up in this paper (national bodies, research institutions and foundations of the prefecture and cities, fishery cooperatives and fishery mutual aid bodies, the companies named in this paper, and others) of a kind that would affect the content of this paper. Relationships here means transactions, funding, joint research, and officers or employees of the publisher concurrently serving as employees or officers of the organisation. This is the publisher's judgement, made after checking the information the publisher has made public, the publisher's contracts and records, and the research for this paper.

6. Sources

We examined materials published up to 3 November 2026. We examined mainly national statistics and laws and regulations, materials of the national, prefectural and city governments, reports of prefectural research institutions, and peer-reviewed papers, and we used figures that a separate researcher had checked against the very materials listed as sources (for some of the overseas papers, the abstract only; where a value that had not been checked was used, the main text says so). Among the figures that review articles and national government materials quote from other studies, there are some that we have not checked back to the original study, and the main text marks these as "quoted". Values read from figures are marked "read from a figure". Reliability: A = laws and regulations, statistics, materials of the national government or prefectures; B = papers, reports of research institutions that state their method; C = explanatory materials for the general public, explanations by organisations, guidance with little description of method; D = news reports.

ID	Source (publisher, year)	Type	Reliability	Chapters used
S1	Arakawa (Hiroshima Prefectural Fisheries Experimental Station): guidance on the prevention and removal of fouling organisms on farmed oysters (English translation) (original 1973, English translation 1980; for many of the figures the original study is not stated)	Guidance	C	Chapters 1–3, 5
S2	Fisheries Agency: information on oyster aquaculture; presumed factors and countermeasures (January 2026); presumed factors in each part of the Seto Inland Sea; state of mortality (July 2026; October); the prefectures' action plans (August; October) (in Japanese) (summaries of interviews with the prefectures)	Materials	A	Chapters 1–3, 5
S3	Hiroshima Prefecture: expert panel on oyster mortality (summaries: January 2026; March; May; September) (in Japanese) (summaries by the prefecture of closed meetings)	Meeting	A	Chapters 1–3, 5
S4	Fisheries Agency: On the situation surrounding oyster aquaculture (November 2025); check sheet for the proper farming management of the Pacific oyster (March 2026) (in Japanese) (explanations for the general public; the sources of the tables include pages that are not official)	Explanatory	C	Chapters 1, 2, 4, 5
S5	Hiroshima City Agriculture, Forestry and Fisheries Promotion Center: annual business reports (fiscal 2018; fiscal 2019; fiscal 2020; fiscal 2021; fiscal 2022; fiscal 2023; fiscal 2024; list), Hiroshima City: guidance on the farming of Hiroshima oysters, etc. (in Japanese) (2020–2026)	Report	B	Chapters 1–3, 5
S6	Hiroshima Prefecture: documents of the Agriculture, Forestry and Fisheries Committee of the prefectural assembly, "State of mortality of Hiroshima oysters" (19 November 2025; 9 December; 16 February 2026; 17 April) (in Japanese) (interviews and a survey of shucked meat)	Materials	A	Chapters 1–3, 5

ID	Source (publisher, year)	Type	Reliability	Chapters used
S7	Hiroshima Prefecture: Hiroshima Oyster Production and Shipping Guidelines for fiscal 2026 (Reiwa 8) (introduction; production and shipping measures; state of shipping; statistical data; flow of disposal; complete version), past editions (fiscal 2020; prefectural assembly document for fiscal 2021; fiscal 2022; fiscal 2023; fiscal 2024; fiscal 2025) (in Japanese) (2020–2026)	Guidelines	A	Chapters 1–5
S8	Arakawa: damage to farmed oysters by the abnormal outbreak of kasane-kanzashi in Hiroshima Bay in 1969 (in Japanese) (VENUS 30(2), 1971; the death rate and amount of damage are quoted from the prefecture's documents)	Paper	B	Chapters 1–3, 5
S9	Miyagi Prefecture Fisheries Technology Institute: Ito and Oshino: fouling organisms in Matsushima Bay and methods of removal; Tanabe et al.: induction of spawning by hot-water treatment (2018), Miyagi Prefecture: points to note in the production management of raw oysters (2002, C); Miyagi Fisheries Day (oysters) (in Japanese) (2019, C)	Paper	B	Chapters 1–3, 5
S10	Saga Prefecture: the present state of Pacific oyster farming at Oura and counter-measures (2012; a 2-page research result note in which the figures appear only in charts, which some would rate as C); towards stable production in Pacific oyster farming at Oura (research result information for fiscal 2012 (Heisei 24), 2013); annual report of the Ariake Fisheries Promotion Center (in Japanese) (fiscal 2020)	Report	B	Chapters 1–3, 5
S11	Fukuoka Fisheries and Marine Technology Research Center: Sato: control of the Mediterranean mussel in oyster farming (1999); Naito and Matsui: reduction of oyster farming waste (2013), Buzen Sea Laboratory of the same Center: oyster farming information (15 September 2023; 20 October; 17 November; 11 October 2024; 6 November; information for producers, A) (in Japanese)	Paper	B	Chapters 1–3, 5
S12	Kyoto Prefectural Marine Center: rock oyster farming work manual (removal of fouling organisms with a large burner) (in Japanese) (2006)	Guidance	B	Chapters 1–3, 5
S13	NARO (National Agriculture and Food Research Organization): urgent research project 07026c5 (2026), Ministry of Agriculture, Forestry and Fisheries: announcement of the call for proposals (2026), Fisheries Agency: liaison council on the mass die-off of the Pacific oyster (in Japanese) (2025–26)	Research	A	Chapter 2
S14	Adams et al.: survey of the cost of fouling measures in shellfish aquaculture (2011, abstract only); Sievers et al.: is removal necessary? (2017, abstract and supplementary material); Fitridge et al. (review article) (2012); Bannister et al. (review article) (2019)	Paper	B	Chapters 2, 3, 5
S15	Hiroshima Prefectural Technology Research Institute, Western Region Industrial Research Center: development of an oyster farming raft using PE pipes (2020); gripping and fixing mechanism for automatic oyster shucking; research result sheet (in Japanese) (2025; in cooperation with companies)	Report	B	Chapter 2
S16	Hiroshima Prefectural Technology Research Institute, Fisheries and Marine Technology Center: Akashige et al.: mass mortality and water temperature and precipitation (2006); Hirata: the mortality of 2004–06 (2011); project reports (fiscal 2014; fiscal 2016; fiscal 2020; fiscal 2024; fiscal 2025; list); list of research reports; follow-up evaluation (2009, self-evaluation); public relations magazine (No. 11; No. 12, 2008); research results on seed collection (2008); technical support (in Japanese) (2016)	Report	B	Chapters 2, 3, 5
S17	e-Gov: Chemical Substances Control Law; Enforcement Order of the Chemical Substances Control Law (in Japanese) (in force)	Law	A	Chapter 3
S18	Hiroshima Prefecture: 2030 Hiroshima Prefecture Agriculture, Forestry and Fisheries Action Programme (Chapter 4, Fisheries) (in Japanese) (adopted October 2026)	Plan	A	Chapters 4, 5

ID	Source (publisher, year)	Type	Reliability	Chapters used
S19	Fisheries Agency and others, 9 ministries and agencies: policy package for damage from oyster mortality due to high water temperature and other causes (in Japanese) (December 2025)	Policy	A	Chapter 4
S20	Hiroshima Prefecture: main support measures for damage from oyster mortality (as of 1 April 2026); outline of measures and projects for fiscal 2026 (April 2026; July); items expected to be proposed (December 2025), Hiroshima Prefectural Assembly: Prefectural Assembly Newsletter No. 82 (in Japanese) (2026)	Policy	A	Chapter 4
S21	Fisheries Agency: Basic Plan for Fisheries (2022); documents of the Fisheries Policy Council (request for advice; schedule; background) (2026); On the reform of fisheries policy (in Japanese) (July 2026, summary of the comprehensive strategy)	Plan	A	Chapter 4
S22	Japan Meteorological Agency: monthly precipitation at Hiroshima (2025; 2026); normal values; long-term trend of sea surface temperature (seas around Japan); time-series data (in Japanese) (released March 2026, viewed November 2026)	Observation	A	Chapter 4
S23	Fisheries research institute of the Okayama Prefectural Technology Center for Agriculture, Forestry and Fisheries: overview of oyster farming (fiscal 2018; fiscal 2021; fiscal 2024); water quality environment and growth of the Pacific oyster; figures of results (in Japanese) (2020–2026)	Report	B	Chapter 5
S24	Ministry of Agriculture, Forestry and Fisheries: Census of Fisheries (for 2023, by class of management entity; by region; oyster aquaculture; people engaged in work at sea; work on land (by top-ranking item in sales value); work on land (individual management entities); number of people in work on land (individual management entities); successors; fishery workers over the years; fishery workers by sex and age class; fishery workers by own-household fishing only and employed in fishing; enrolment in fishery mutual aid (by top-ranking item in sales value); explanation of terms; the same tables for 2018), Hiroshima Prefecture: the prefecture's results of the 2023 Census of Fisheries; the prefecture's statistical tables; tables by city and town (in Japanese) (2020–2025)	Statistics	A	Chapter 5
S25	Ministry of Agriculture, Forestry and Fisheries: Statistical Survey on Fishery Management, final figures of the survey of individual management entities (summaries: 2021; 2022; 2023; 2024; for 2024, state of operations; expenditure; list of tables); 2025 (Reiwa 7) first report (in Japanese) (2023–2026; for 2024 the Seto Inland Sea figure is a simple average of 17 management entities, and the average for the 5 main producing areas is a weighted average)	Statistics	A	Chapter 5

Related materials: R1 The burden of biofouling at sea, R2 Seaweed and seagrass beds and the living things of the sea, R3-1 Oyster mortality (die-off), R3-3 The workforce and manual work of oyster aquaculture, R5-2 How the positions of oyster rafts are communicated, R6 What is changing (why now), R7-A13 Fouling organisms on egg cockle (torigai) aquaculture baskets, R7-C05 Uwa Sea: organisms that foul shellfish aquaculture (pearl oysters and oysters), R7-C06 Uwa Sea: oyster mortality in Ainan Town, R7-C29 Seto Inland Sea side: oyster mortality in Imabari City, R7-D16 Fouling on nets that protect nori (laver) from being eaten, I1 List of assessments