Title: Analysis of mesh breaking loads in cotton gillnets – a possible solution to ghost fishing

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Authors: Yoshiki MATSUSHITA[1*], Shusuke MACHIDA[2a], Haruyuki KANEHIRO[2], Fumio NAKAMURA[3], and Naoto HONDA[4]

[1] *Faculty of Fisheries, Nagasaki University, Nagasaki, 852-8521, [2]Tokyo University of Marine Science & Technology, Minato, Tokyo, 108-8477, [3]Chiba Prefectural Fisheries Research Center, Minami-boso, Chiba, 295-0024, and [4]National Research Institute of Fisheries Engineering, Fisheries Research Agency, Kamisu, Ibaraki, 314-0408 Japan.*

[*]Corresponding author: Tel: 81-95-819-2803; Fax: 81-95-819-2803. E-mail: yoshiki@nagasaki-u.ac.jp.

[a] Present address: Nippon Marine Enterprises, Ltd, Yokosuka, Kanagawa, 237-0061, Japan.

Abstract

A small number of fishermen in Chiba Prefecture of eastern Japan use cotton gillnet to catch Japanese spiny lobster *Panulirus japonicus*. To examine the advantages of cotton gillnet, we analyzed changes in mesh breaking load of new cotton gillnet used in fishing operation. New cotton gillnet was also soaked in a seawater tank to simulate ghost fishing condition. Average mesh breaking load of new cotton mesh was 50.3 N. This value decreased to 19.0 N after 38 days (approx. 912 hours) and after 82 days (approx. 1968 hours), the mesh could be easily torn (breaking load 0.07 N). Under fishing condition, cumulative soak time was only 744.4 hours over a period of 19 months. Average breaking load at the end of this period was 43.1 N, a strength 86% that of the pre-soaked mesh. The mesh breaking load of cotton gillnet continuously soaked for 744.4 hours was 26.1 N, as estimated from tank experiment data. Thus, cotton gillnet maintains a reasonable strength under typical usage conditions, but will degrade if lost at sea.

和文要旨

綿糸刺網の引っ張り強さの経時変化

松下吉樹（長大水）・町田秀介・兼広春之（海洋大）・仲村文夫（千葉水研セ）・本多直人（水研セ水工研）

千葉県の少数の漁業者は綿糸製の刺網でイセエビを漁獲している。綿糸網の網目の引張強さの変化を，漁業で使用した場合と海水中に連続して浸漬した場合で比較した。新品の平均引張強さは 50.3N であったが，海水に連続浸漬して 38 日後には 19.0N，82 日後には簡単に千切れる程度(0.07N)となった。一方，漁業で使用した綿糸網は，19ヶ月間で累積744.4時間浸漬され，その時点で新品の86%の強度を保っていた。綿糸網の網目の引張強さは，漁業での使用ではそれほど低下しないが，流出した際には急激に低下する。

INTRODUCTION

Ghost fishing, defined as the action of fishing equipment out of human control, is a concern because it is a source of unaccounted mortality in fisheries management. [1,2] A bottom set gillnet is net weighted to lie on the seafloor for a specific period to capture ground fish and crustaceans. However, it sometimes becomes stuck on snags or cannot be recovered because of severed retrieval lines. In some cases, gillnets are left on the sea floor without any efforts to recover it because they are inexpensive. Ghost fishing involving bottom set gillnets was observed experimentally in the coastal waters of England[3] and Portugal.[4] Ghost fishing of synthetic fiber gillnets used for Japanese spiny lobster *Panulirus japonicus* in shallow water also was observed experimentally in Japan.[5] For this experiment, the entire float line contacted the sea floor within 2 weeks. However, the possibility of ghost fishing remained for bottom dwelling organisms, because the webbing was exposed on the sea floor.

Matsuoka *et al.*[6] reviewed ghost fishing and proposed counter measures in three areas; i) prevention of fishing gear loss; ii) retrieval of lost fishing gear; and iii) use of fishing gear designed to degrade if lost. To comply with the recommendation of using fishing gear designed to degrade, artificial materials that are broken down by microbes or ultraviolet light have developed.[7] These materials, however, are still in the development

stage in terms of physical characteristics and cost, and are not ready for introduction into fishing practices.[7]

Due to these considerations, a small number of gillnet fishermen in Chiba Prefecture of eastern Japan use cotton fiber gillnets, which are biodegradable, to catch Japanese spiny lobster. Cotton nets had been replaced by synthetic fiber nets because nets made with synthetic materials catch more fish, do not deteriorate rapidly, and require less maintenance.[8] The situation in Japan is similar; thus, only fishermen in this one community use cotton nets in Japan. In this study, we analyzed changes in mesh breaking load of cotton gillnets used in conventional operation for approximately 19 months. We also continuously soaked cotton gillnets in seawater to simulate ghost fishing conditions while periodically analyzing mesh breaking load. Study objectives include: i) identifying advantages of the cotton gillnet for Japanese spiny lobster fishing, and ii) understanding fundamental requirements of biodegradable materials used in fishing gear by comparing physical characteristics of cotton nets used under fishing and under ghost fishing conditions.

MATERIALS AND METHODS

Lobster fishing using cotton gillnet

Cotton gillnet is used only by fishermen belonging to the Futomi branch of Kamogawa Fisheries Cooperative, Kamogawa city, Chiba prefecture, Japan (Fig. 1). The specifications of the cotton gillnets are shown in Table 1. All parts of the webbing are made of cotton fiber twine, although other parts, such as floatline or leadline, are synthetic fiber, plastic, or lead. The webbing is dyed with an extract of the bark of Burma mangrove *Bruguiera gymnorrhiza* and then with a synthetic dye every 2 to 3 months. Average inner mesh size of new cotton gillnets after antiseptic treatment, randomly measured with a caliper at 30 points, was 87.0 mm (s.d. 1.4 mm).

A voluntary ban on gillnet fishing in this region is established in June and July to conserve spawning lobsters. Gillnet fishing also is discouraged for approximately 1 week around the full moon every month because catch decreases. The maximum number of gillnets per operation is set at 18 voluntarily to prevent overfishing. Fishermen set gillnet in the evening and retrieve it the next morning (10–12 hours soak time). Then gillnets are dried under the sun and stored. Although fishermen share labor for the maintenance of cotton gillnets, each fisherman owns approximately 100 gillnets and rotates them.

Changes in mesh breaking load of cotton gillnet under fishing condition

One fisherman in the region was chosen to employ a new cotton gillnet in fishing operations beginning 1 August 2004. Then, 20 to 25 pieces of 3 x 3 mesh from this gillnet were sampled at 1- to 3-month intervals until 21 February 2006 (9 samplings). Breaking loads of these mesh samples in dry condition were measured using the ISO 1806 method.[9] Hooks of the tensile testing instrument (Shimadzu AGS 500B, Load capacity 5kN, Load measurement accuracy ± 1% of reading down to 1/50 of load cell capacity, Crosshead speed accuracy ± 0.5% of set speed) were set at opposite knots of the center mesh of each sample and crosshead speed was adjusted between 25 to 55 mm/minutes so that the mesh broke in 20±3 seconds. We analyzed mesh breaking load and elongation at break ($\frac{\ell - L}{L} \times 100$ (%), where ℓ represents inner mesh size (mm) at break and L represents inner mesh size (mm)). We also recorded where the broke occurred (knot or bar). Several samples showed a wide variation in mesh breaking load, which prevented adjustment of time to break of 20±3 seconds.

The breaking load of a new synthetic fiber mesh (Polyamid multifilament, 933 Rtex, average inner mesh size 75.3 mm) typically used for lobster fishing also was measured in the same manner.

Areas of gillnet where samples were taken were patched with new cotton webbing, and floatlines and leadlines were marked to prevent sampling from these areas again. A

depth logger (Alec Electronics Ltd. MDS-MkV/D, resolution 0.05 m, recorded at 10-minute intervals) and a temperature logger (Onset Computer Corp., StowAway TidbiT, resolution $0.4^{o}C$, recorded at 12-minute intervals) were attached to the anchor line to detect set and retrieval of the gillnet.

Changes in mesh breaking load of cotton gillnet under continuous soak condition

Another new cotton gillnet was soaked continuously in a seawater tank to simulate ghost fishing net condition at the Chiba Prefectural Fisheries Research Center, approximately 20 km away from the fishing ground (Fig. 1) beginning 3 August 2004. Seawater was pumped into the tank from the sea floor of the nearest coast and the tank was screened by a plastic sheet to prevent sun exposure. A temperature logger (same as above) was attached to the submerged gillnet. Comparison of values recorded simultaneously from the tank and fishing ground (anchor line) showed a difference in water temperature of less than 1.0 ^{o}C. Thus, the seawater in the tank and at the fishing ground was considered to be the same. Mesh samples were taken on 10 September 2004 (38 soak days, approx. 912 hours), 6 October 2004 (64 soak days, approx. 1536 hours), and 25 October 2004 (82 soak days, approx. 1968 hours). Dried cotton mesh samples were analyzed as mentioned previously using the ISO 1806 method. [9]

Reduction in mesh breaking load of cotton gillnets

The reduction in mesh breaking load of nets under fishing and continuous soak conditions was considered a function of cumulative soak time. The relative strength of cotton mesh after cumulative t soak time (R_t) is calculated as:

$$R_t = S_t / S_n \qquad (1)$$

Where S_t and S_n are mesh breaking load after cumulative t soak time and breaking load of new mesh, respectively. Then, degradation rate of mesh breaking load after cumulative t soak time (D_t) is:

$$D_t = 1 - R_t \qquad (2)$$

We fitted the average value for mesh breaking load at each sampling to a 2-parameter cumulative distribution function (cdf) of the Weibull distribution, commonly used for life data analysis. The degradation rate of mesh breaking load after cumulative t soak time (D_t) can be modeled as:

$$D_t = 1 - \exp\left(-\frac{t^m}{\eta}\right) \qquad (3)$$

Where m and η are the shape and scale parameters of the cdf of the Weibull distribution, respectively. These parameters were estimated by the least squares nonlinear regression analysis.

RESULTS

Records from the depth logger attached to the anchor line indicated that the gillnet was set at 3 to 8 m depth while fishing. We calculated each soak time (hours) from these records; cumulative soak time of the gillnet tested is shown in Fig. 2. The tested gillnet was used 65 times over a period of approximately 19 months, for a cumulative soak time of 744.4 hours. Fig. 3 shows the frequency distribution of intervals between last to next uses of the tested gillnet. One- to nine-day intervals accounted for approximately 70% of the values, but three periods of continuous use (0-day interval) also were observed. These continuous soak periods were recorded in early August at the start of the fishing season. Fishermen could not sufficiently share labor for gear maintenance because of the large catch expected, and the cotton gillnet could be dried rapidly by the strong sunlight in mid-summer. In contrast, longer intervals (10–27 days) were recorded in autumn and winter, probably due to rough weather.

Changes in mesh breaking load and elongation at the break in nets under fishing and under continuous soak conditions are shown in Figs. 4 and 5. Average values for mesh breaking load and elongation at break of new cotton gillnet were 50.3 N (s.d. 7.0 N) and 20.2% (s.d. 1.9%), respectively. Mesh breaking load of new cotton gillnet was less than

half the value found for a new synthetic fiber (Polyamid) gillnet (105.8 N, s.d. 15.0 N).

In addition, elongation at break was smaller for new cotton gillnet than for new synthetic gillnet (30.4%, s.d. 3.1%). Knots of the mesh were broken for all measurements for both new cotton and synthetic gillnets.

Mesh breaking load and elongation at break of the cotton gillnet gradually decreased as time elapsed; the average values of mesh breaking load and elongation at break reached 43.1 N and 15.1%, respectively, (86% and 75% of values for a new cotton gillnet; $p<0.01$) on 21 February 2006 (approximately 19 months of use). The nets exhibited breaks most often at the knots, but breaks at bars of the mesh accounted for 0-17% of periodical measurements.

The reduction in the mesh breaking load and elongation at break occurred more rapidly for continuously soaked cotton gillnet (Figs. 4 and 5). The average value for mesh breaking load decreased to 38% (19.0 N, s.d. 4.2 N) of initial value after 38 days (approx. 912 hours), and the mesh could be torn easily after 82 days (approx. 1968 hours, 0.07 N, s.d. 0.07 N). Elongation at break at this time was nearly 0 and could not be measured within the accuracy of the testing machine. Under these conditions, 95% (19/20) of the mesh pieces were broken at bars.

The data indicated that continuously soaked cotton gillnets degraded more quickly than

did cotton gillnets under fishing condition. However, cumulative soak time of the cotton

gillnet under fishing condition was only 744.4 hours, corresponding with only approx.

31 days. The relation between cumulative soak time and degradation rate of mesh

breaking load of nets under fishing and continuous soak conditions were plotted and

fitted to the cdf of the Weibull distribution (Fig. 6). Estimated parameters for these two

conditions also are presented in Table 2. Shape parameter *m* in the cdf of the Weibull

distribution for both conditions exceeded 1, suggesting "wear out", that is, cotton mesh

degrades with passage of time. Scale parameter η was greater for the net under fishing

condition, suggesting that the time scale for gradation is longer than the net under

continuous soak condition. Also, characteristic life ($\eta^{\frac{1}{m}}$), indicating 63.2% degradation

from the initial value, was 1335.7 hours for the net under fishing condition and 923.5

hours for the net under continuous soak condition. The breaking loads of mesh under

fishing condition were almost equal to the initial value until 447.7 hours of cumulative

soak time. The degradation rates of mesh breaking load gradually increased since then,

and reached to 14 % after 744.4 hours of cumulative soak time. On the other hand, the

reduction in the mesh breaking load of the net under continuous soak condition still

occurred more rapidly than for the net under fishing condition. The reduction rate of

mesh breaking load continuously soaked for 744.4 hours was estimated at 48 % from

equation (3).

DISCUSSION

The reduction in the breaking load of mesh occurs by mechanical degradation such as wear, fatigue, and/or exposure to ultraviolet light. In addition, natural fibers are degraded by microorganisms. The mesh breaking load of cotton gillnet under fishing condition decreased due to friction against rocks, reefs, or the boat, tension during retrieval, and exposure to the sun. However, the degradation rate for nets under these conditions was 14%, a value acceptable for fisherman involved in fishing practices. In contrast, the continuous soak experiment conducted in a tank without any other possible influences involved degradation of cotton gillnet only through microbial action. A reduction in mesh breaking load of the net under continuous soak conditions occurred more rapidly than in the net under fishing condition, despite the influence of fewer factors. Thus, degradation of cotton gillnet can be prevented by maintenance procedures such as drying and dying nets. Interviews with fishermen in the region revealed that they use cotton gillnets for 5 to 10 years. In contrast, nets left in the underwater environment for a long time experience a rapid reduction in the mesh breaking load and become very fragile, preventing efficient fishing. Thus, cotton gillnet is well suited for

dealing with the ghost fishing issue, because it maintain strength if properly maintained but degrade rapidly if left underwater continuously.

The cotton gillnet, however, is used only for Japanese spiny lobster fishing in this region. The Japanese spiny lobster is sedentary and seldom moves to other fishing grounds.[10] Only a limited number of fishermen who have rights to access the fishing ground can utilize the resource. In general, the capture performance of gillnets is closely related to the elasticity of the mesh; nets with reasonable elasticity result in a better catch.[11] Therefore, it is likely that the cotton gillnet have poorer capture performance compared to synthetic gillnets. However, fishermen can earn a reasonable living fishing for Japanese spiny lobster using lower performance fishing gear because the lobsters have a high market value. Different conditions in other fisheries may require consideration before introducing cotton material fishing gear.

Cotton fibers have been used for fishing nets for a long time until the introduction of synthetic fibers. Cotton fiber provides a good balance between strength and biodegradability. These characteristics are desirable for fishing materials to mitigate ghost fishing consequences. Tabata and Kanehiro[7] discussed the need to for lifespan control technology when developing synthetic biodegradable materials for marine use. Presently, synthetic biodegradable materials can be categorized into 3 groups: i)

modified natural polymers, ii) biopolymers, and iii) synthetic polymers. Synthetic polymers, especially some aliphatic polyesters such as polylactic acid (PLA) and polycaprolactone (PCL), has been studied for fishing gear use.[7] PLA is the most common biodegradable material in terms of production amount, but required 11.4 months for biodegradation in water at 25°C and 48 months at 13°C.[12] In contrast, the breaking load of monofilament twine made of PCL was reduced to approximately 50% of the initial value after 2 days of continuous soaking in coastal seawater.[13] Thus, biodegradability in water is quite different even for similar aliphatic polyester materials (*e.g.*, PLA and PCL). New biodegradable materials are being developed by blending multiple aliphatic polyesters, to balance life span and fishing performance characteristics (Kanehiro, personal communication). Lifetime of cotton gillnet under continuous soak condition was 923.5 hours (38.5 days), a value between those of PLA and PCA. Thus, the results we present here provide guidance in the development of synthetic biodegradable materials for fishing gear. Future synthetic biodegradable materials for gillnet fishing should degrade as readily cotton fiber, but should require less maintenances and lower costs.

ACKNOWLEDGMENTS

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FIGURE CAPTIONS

Fig. 1. Fishing ground where cotton gillnet was used in lobster fishing and location where continuous soak experiments were conducted.

Fig. 2. Cumulative soak time (hours) of the cotton gillnet under fishing condition from 1 August 2004 to 21 February 2006. Solid circles designates dates when the tested gillnet was soaked, and arrows, when samples were taken.

Fig. 3. Frequency distribution of intervals between last to next uses of the cotton gillnet under fishing condition, with the exception of an interval during closed season (July and August).

Fig. 4. Change in mesh breaking load with passage of time.

Solid circles show the average value under human control condition, blank circles indicate continuous soak condition, bars indicate standard deviation.

Fig. 5. Change in mesh elongation at break with passage of time.

Solid circles show the average value under human control condition, blank circles

indicate continuous soak condition, bars indicate standard deviation.

Fig. 6. Relation between cumulative soak time and degradation rate of mesh breaking loads for cotton nets under fishing and continuous soak conditions.

Solid circles show the average value under fishing condition, blank circles indicate continuous soak condition.

Table 1. Specifications of the cotton gillnet

Twine	20s[*] ×2×3
Mesh size	87.0 mm (s.d. 1.4 mm)[**]
Hanging ratio	0.62
Length	26 m (750 meshes)
Depth	0.85 m (15.5 meshes)

* English cotton yarn number; ** measured by a caliper.

Table 2. Estimates of parameters of mesh breaking load degradation curves under fishing and continuous soak conditions fitted to a 2-parameter cumulative distribution function of the Weibull distribution

	Fishing condition	Continuous soak
Shape parameter m	2.98	1.96
Scale parameter η	2.13×10^9	6.32×10^5
sum of the squares of the residuals	1.66×10^{-2}	1.98×10^{-6}
characteristic lifetime ($\eta^{\frac{1}{m}}$)	1335.7 hours	923.5 hours

E140

Fishng ground

Seawater tank
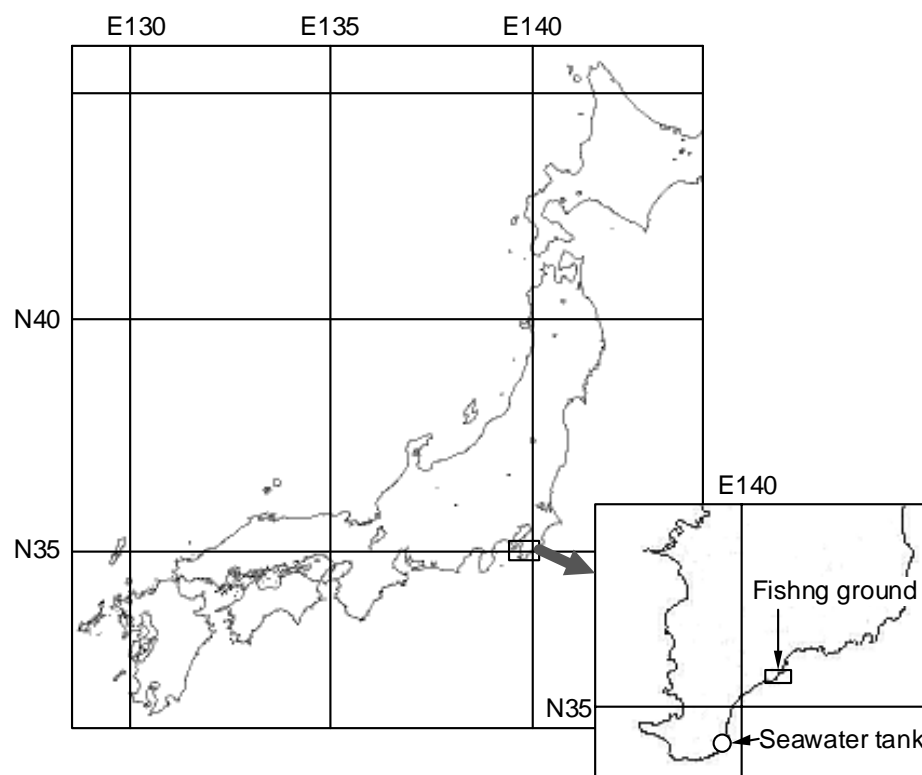
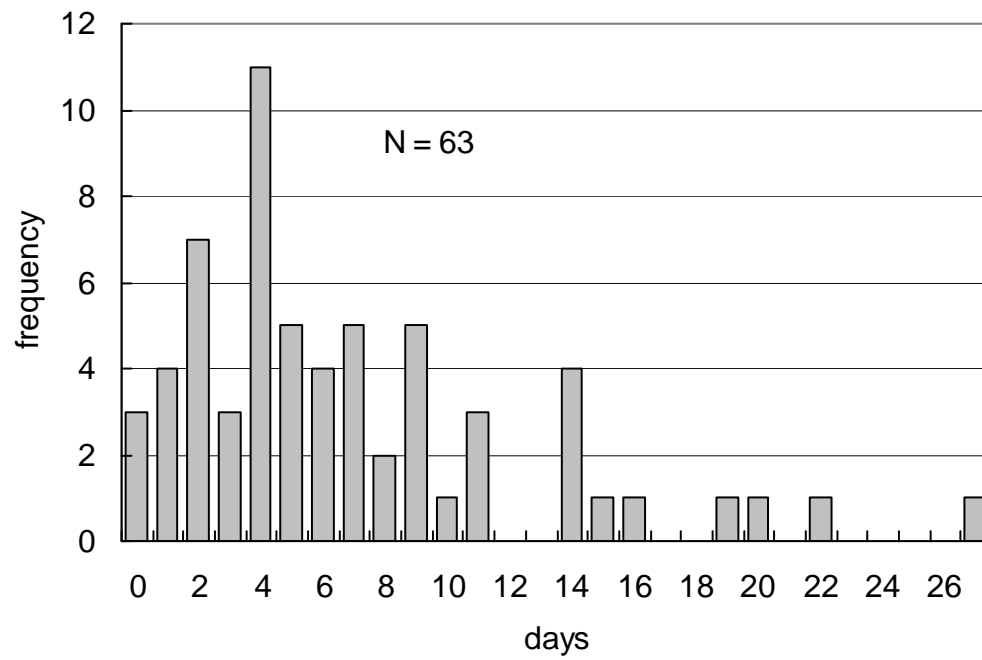Fig. 1 Matsushita *et. al*.
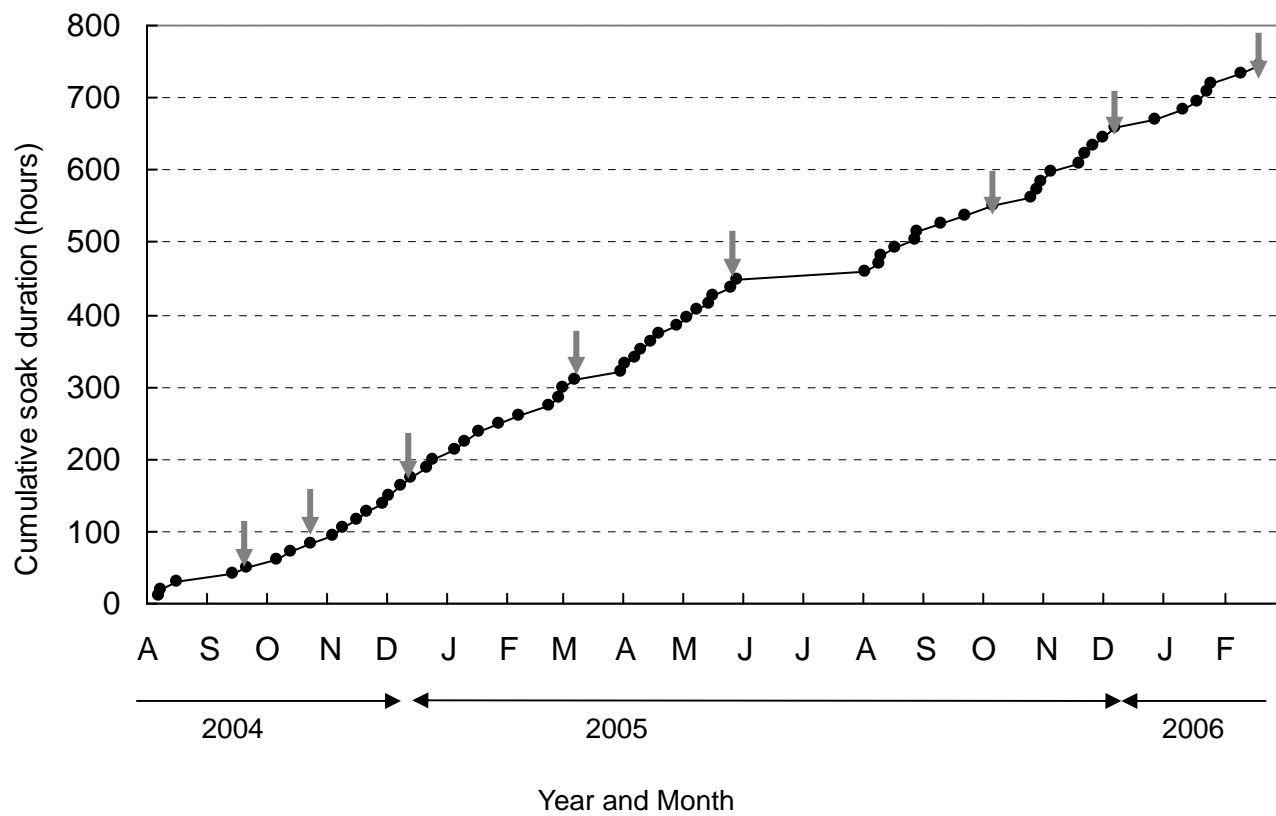
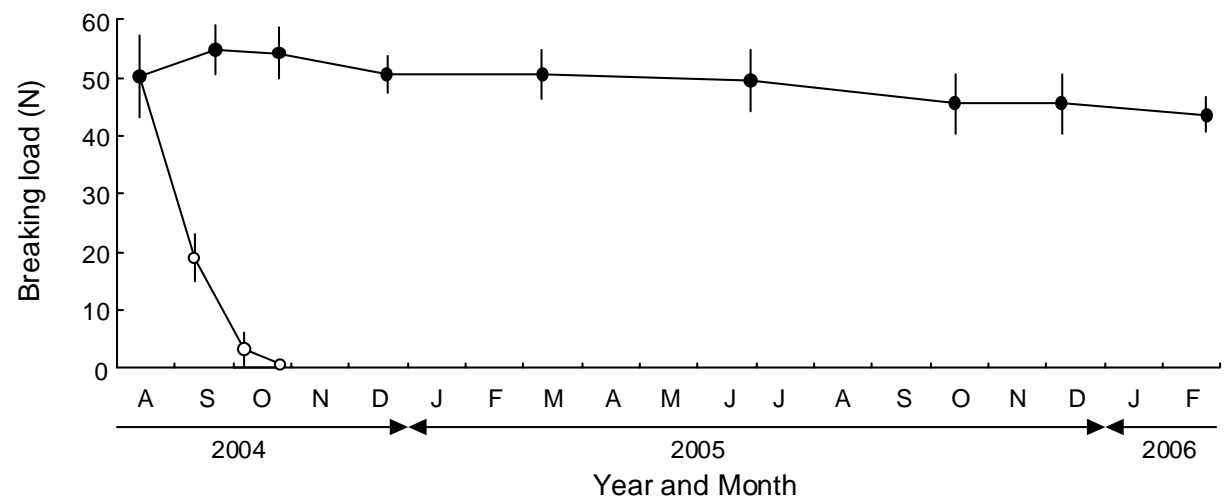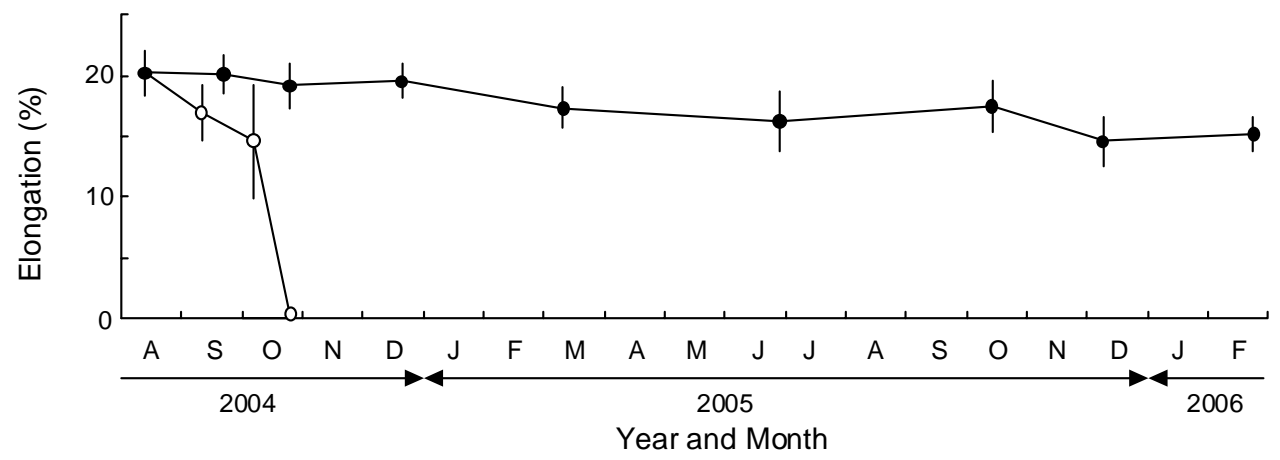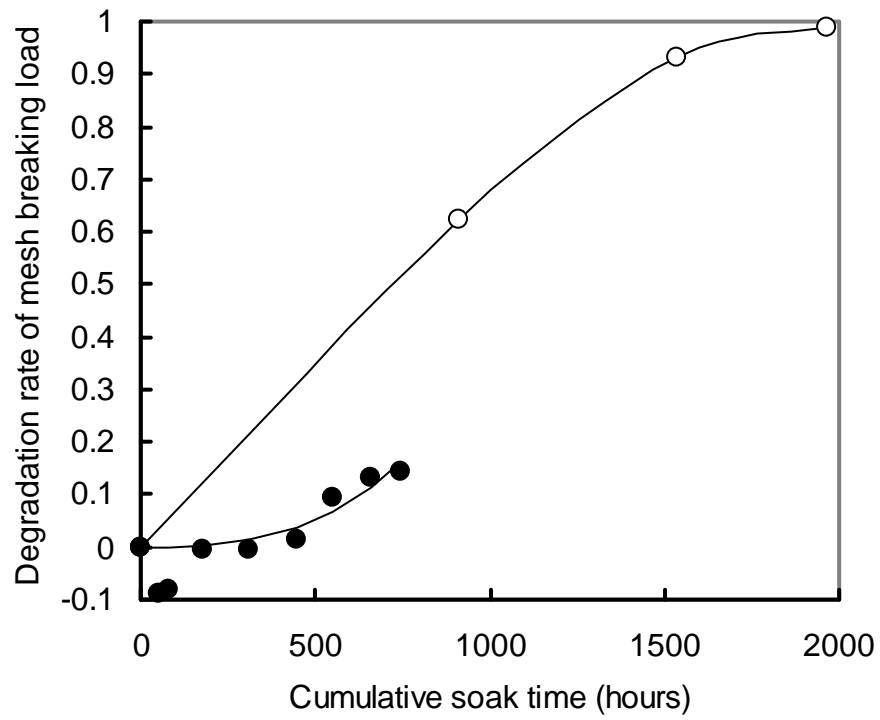Fig. 2 Matsushita *et. al*.

Fig. 3 Matsushita *et. al*.

Fig. 4 Matsushita *et. al*.

Fig. 5 Matsushita *et. al*.

Fig. 6 Matsushita *et. al*.