チリ共和国チロエ島におけるチリウニLoxechinus albusの移植

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Tsukuba Business-Academia Cooperation Support Center, Agriculture, Forestry and Fisheries Research Council Secretariat
Transplantation of the Sea Urchin *Loxechinus albus* in Chiloé Island, Chile

Sohei KINO

**Abstract:** In order to understand methods to effectively utilize the resource of the Chilean sea urchin, *Loxechinus albus*, a transplantation experiment was carried out during 6 months from August 1988 to February 1989 in Chiloé Island, Chile. One thousand adults at 58.6 mm in mean test diameter showing mal-developed gonads in Linao which was depauperate in algae were transplanted to an experimental area of 400 m² in Hueihue which was rich in algae. The gonad index improved from 8.5 to 13.7 two months after transplantation. The recovery rate of transplanted *L. albus* after 6 months was 83.0% (90.4% including sampled individuals). The movement range of this species was very narrow. In Linao, *L. albus* barely gathered to algae put in a net bag; the numbers that gathered were 2–10, 15–20 individuals in 4–8–15–21 days after providing algae, respectively.

**Key words:** *Loxechinus albus*; Transplantation; Gonadal improvement; Movement

Some countermeasures have been taken for the propagation of sea urchins, such as artificial bank creation, transplantation, and the release of juveniles through seed production. Among them, transplantation is used to enhance the commercial value of sea urchin gonads. In Japan, the transplantation of sea urchins to other waters for the quantitative improvement of the gonad has been implemented for *Anthocidaris crassispina* (Nakamura and Yoshinaga 1962), *Strongylocentrotus intermedius* (Kawamura 1965; Tomita et al. 1986), and *S. nudus* (Kawamura 1963; Akimoto 1976; Yoshida and Ebina 1998). Additionally, the transplantation of *Hemicentrotus pulcherrimus* yielded favorable results in an artificially created bank involving the installation of rocks (Taki and Higashida 1964). Also, in the Mediterranean, the transplantation of *Paracentrotus lividus* led to favorable gonadal improvement (San Martin 2004). In the Chilean sea urchin *Loxechinus albus*, studies on propagation are available, such as on seed production (Guisado and Castilla 1987; Zamora and Stotz 1994; Cárcamo 2004), releasing (Stotz et al. 1992), and culture (Bückle et al. 1977a, 1977b); however, there is no study on transplantation. Although Chiloé Island was one of the main fishing banks of *L. albus* (Barahona et al. 2003; Stotz 2004), there were some places where *L. albus* showed mal-developed gonads. These sea urchins were not targeted of the catch in the eastern coastal waters of Chiloé Island. In this study, a transplantation experiment involving *L. albus* showing mal-developed gonads was carried out in the eastern coastal waters of Chiloé Island to investigate its utility and effectiveness. Additionally, movement related to the recapturing of transplanted sea urchins was discussed.

**Materials and Methods**

**Sea urchins**

Figure 1 shows the experimental sites. At the collection site in Linao, numerous *L. albus* were present. Algae as a source of food for them were scarce. The sea bottom was a rock bed, and the accumulation of sand or non-geniculate
coralline algae was also noted in some places. Here, *L. albus*, ranging on the rock bed or field of non-geniculate coralline algae, showed mal-developed gonads, their test could be easily cut with scissors, they showed fine spines, weak adherence, and had an overall body color of darkish red. Sea urchins with mal-developed gonads were also distributed in Teupa or Yaldad in the southern part of Chiloé Island (Kino and Agatsuma 2007), where algae hardly grew and drift algae were not found or in places where tidal drift was poor and mud segmentation occurred, even if there were algae.

On the other hand, at the transplantation site in Hueihue, few *L. albus* and abundant algae were found. The sea bottom type was big stones or pebbles, and sand accumulation was present in some parts. Here, *L. albus* had well-developed gonads, a thick test, thick spines, showed strong adherence, and had an overall body color of bright red.

Hereinafter, *L. albus* is defined as follows:

**L-La**: *L. albus* with mal-developed gonads in Linao (indigenous to Linao)

**H-La**: *L. albus* with well-developed gonads in Hueihue (indigenous to Hueihue)

**T-La**: L-La transplanted to Hueihue

Firstly, before carrying out transplantation, a 20-m square quadrat made with 10-mm diameter rope and 40-kg sand bags set at the corners was placed on the sea bottom at a 5-m depth on August 8, 1988 in Hueihue. Then, all H-La (10 individuals) were removed from inside the quadrat by scuba diving. The density of H-La calculated based on individuals removed from the quadrat (400 m²) was <0.1 individuals/m². Secondly, the density of L-La was investigated by 10 random samplings using a 1-m square frame, and calculated as 19.4 individuals/m². Then L-La were collected on August 10 in Linao. One thousand individuals of 58.6 mm in mean test diameter (mean body weight: 72.9 g) were collected in 30 minutes by scuba diving employing 2 divers. Collected L-La were put in two 100-liter polycarbonate tanks covered with wet newspaper without adding any seawater, and were transported to Hueihue by boat. Finally, L-La were released together within an area of 1 x 2 m at the center of the quadrat by a diver.

The conditions at the time of transplantation were as follows: collected L-La were kept in air for 21-38 minutes until release, the air temperature was 10.0 °C, the seawater temperature was 10.7 °C in Linao and 10.8 °C in Hueihue, the weather was cloudy, and there was no wind. The experiment lasted until February 10, 1989 for 6 months.

**Measurement and observation**

The following investigations were carried out during the transplantation experiment:

**Oceanographic observation**: The seawater temperature and salinity at the surface (0 m) in Hueihue were measured weekly using an electronic thermo-salinometer (KENT/EIL 5005).

**Gonad index (GI)**: Thirty individuals of L-La were measured every month in Linao for 7 months, and every 2 months for T-La for a total of 6 months. The test diameter, body weight, and gonad weight of every specimen were measured using a varnier caliper and an electronic balance with an accuracy of 0.1 mm and 0.1 g, respectively. The gonad index was calculated by (Gonad weight/Body weight) x 100.

**Algal standing crop**: Algae were collected every month within a 1 m² area nearby the collection and transplantation sites in Linao for 7 months and Hueihue for 6 months, respectively, and the wet weight (g wet wt/m²) was calculated.
**Recovery number:** All T-La in and around the transplantation quadrat were recovered by scuba diving, and then counted 6 months after transplantation.

**Movement:** Movement of T-La was observed in the quadrat in Hueihue, and the aggregation behavior of L-La was observed in Linao on placing Ulva sp. and Macrocystis pyrifera in a net bag taking photos with a waterproof camera (Nikonos V, UW-Nikkor 20 mm/F2.8, and Nikonos speed-light SB-103) after 1, 2, 4, 8, 15, 21, and 35 days. Additionally, near the site of observing aggregation behavior, the approximate distance moved by a specific individual with characteristic white spine tips was also measured at the time of the diving above-mentioned by tracing for one month without touching it.

**Results**

**Gonad index and algal standing crop**

Figure 2 shows the seawater temperature and salinity change at the surface (0 m) during the transplantation experiment in Hueihue. The seawater temperature increased gradually, ranging between 10.4 and 15.5 °C, and the salinity ranged between 32.2 and 34.2 with small fluctuations. Figure 3 shows the GI change of L-La and T-La, and the change in the algal standing crop in Linao nearby the collection point of L-La, and in Hueihue nearby the transplantation quadrat. Although the initial GI of T-La was 8.5 in August, it increased to 13.7 two months after transplantation in Hueihue. The GI change due to transplantation was prominent; however, at and after 4 months (December), the GI ranged around 10. The GI of T-La was always greater than that of L-La during this experiment. The GI of L-La was always <9 from August to January, while a small increase was observed from February–March, synchronized with the growth of algae in Linao.

The algal standing crop in Hueihue was abundant in August and September, when only Ulva sp. was found. Especially, in September, its quantity was 1534 g wet wt/m². However, they were washed away due to poor weather conditions in October. Consequently, the standing crop decreased to 63 g wet wt/m². Then, Ulva sp. grew gradually, with the quantity reaching the same level as in August to December, at approximately 800 g wet wt/m². It did not disappear until February. On the other hand, in Linao, only dimensionless algal growth was observed.

*Fig. 2. Changes in the seawater temperature and salinity at the surface (0 m) in Hueihue during the transplantation experiment.*

*Fig. 3. Changes in the gonad indices of L-La (native *Lorechinus albus* in Linao) and T-La (transplanted *L. albus* to Hueihue), and alteration in the algal standing crop in Linao and Hueihue. Asterisk: no data in Hueihue.*
was found from August to November. After December, Ulva sp. and M. pyrifera showed new growth, and after January, the algal standing crop in Linao reached the same level as in Hueihue, with approximately 300 and 500 g wet wt/m² in January and February, respectively. Drift algae were not observed between August and November in Linao.

Recovery number

Table 1 summarizes the transplantation experiment. A total of 830 individuals of T-La were recaptured; its breakdown was 796 individuals (inside the quadrat within a 5-m radius from the center), 15 individuals (the remainder of the quadrat), and 19 individuals outside the quadrat (a 5-m distance from the quadrat). One dead individual was found at the center of the quadrat. No broken sea urchin tests indicating possible predation were found. Since 40 and 34 individuals were sampled for measurement in October and December, respectively, the recovery rate was calculated as 83.0% (90.4% including sampled individuals). T-La showed no change in their external morphology and they were easy to distinguish from H-La due to their body color, spine color, and fragility of the test. Additionally, T-La showed a stronger adherence than L-La, as more force was needed to remove them from stones or rocks compared with L-La.

Movement

Movement of L. albus was observed both in Hueihue and Linao. Six months after transplantation in Hueihue, out of 830 individuals recaptured, 796 (96%) remained within a 5-m radius from the center of the quadrat. Another 15 individuals moved between 5 and 10 m, and the remaining 19 individuals were outside the quadrat, moving 15 m from the center of the quadrat. Figure 4 shows the aggregation of L-La in Linao. The numbers of individuals that aggregated toward the algae in the net bag were 0, 1, 2, 10, 15, 20, and 20 in 1, 2, 4, 8, 15, 21, and 35 days, respectively. Although many L. albus were observed around the net bag in the figure, the number of individuals that aggregated toward the algae in the net bag was low at one month. Moreover, it was observed that L. albus around the net bag also moved inch by inch. One L. albus that showed the distinct characteristic of white-colored spine tips in Linao moved only 1.6 m in one month.

Discussion

Gonad index and algal standing crop

In this study, L. albus with mal-developed gonads were collected in Linao, an urchin barren, and then transplanted to Hueihue, with abundant algae, to investigate whether they would show gonadal enhancement. The GI of L-La barely increased, remaining below 10 at all times, however, that of T-La increased to 13.7

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Table 1. Summary of the transplantation experiment for *L. albus* in the 400 m² transplantation quadrat in Hueihue from August 1988 to February 1989 (H-La: native *L. albus* in Hueihue, L-La: native *L. albus* in Linao, T-La: transplanted *L. albus* to Hueihue)

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<td>5</td>
<td>15</td>
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<tr>
<td>Transplanted number (L-La, TD 58.6 mm, BW 72.9 g)</td>
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<td></td>
<td>1000</td>
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<tr>
<td>Sampled number of T-La for measurement</td>
<td>40</td>
<td>34</td>
<td></td>
<td>74</td>
<td></td>
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<tr>
<td>Recaptured number of T-La</td>
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<td></td>
<td>830</td>
<td>830</td>
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<tr>
<td>(inside the quadrat within a 5-m radius from the center)</td>
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<td></td>
<td>(796)</td>
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<tr>
<td>(the remainder of the quadrat, &gt;5 m from the center)</td>
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<td></td>
<td>(15)</td>
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<tr>
<td>(outside the quadrat at a 5-m distance)</td>
<td></td>
<td></td>
<td>(19)</td>
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<tr>
<td>Number of dead T-La</td>
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* found at the center of the quadrat.
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Fig. 4. Aggregation of _Loecheinus albus_ around _Ulva_ sp. and _Macrocystis pyrifera_ in a net bag in Linao. The number plates show the days after positioning the net bag.

(1.6 times the initial GI) two months after transplantation in October in Hueihue. The average GI in October 1986 in Hueihue was 13.8 (Kino and Agatsuma 2007), suggesting that the GI of T-La reached the average value in Hueihue in this period. Additionally, as no drift algae were observed between August and November in Linao, the GI of L-La did not increase. In the period of August–December, there was a marked difference in the algal standing crop between Linao and Hueihue (Fig. 3), and algal abundance was involved in gonadal development over a short period.

Transplanted _S. intermedius_, in 2 months, show a rate of gonadal development more than 5 times that of un-transplanted ones from the end of April (Kawamura 1965). Equally, transplanted _S. nudus_ show GI improvement from 4.43 to 12.16 in 5 months (Yoshida and Ebina 1998) and from 4.3 to 15.2 in 2 months (Kawamura 1963). Transplanted _Paracentrotus lividus_ of 30–50 mm in test diameter show a significant improvement in the GI from 1.12 to 4.12 six months after transplantation (San Martin 2004). On the other hand, the GI of _S. nudus_ from trophically poor coralline flats increases from 6.5 to 13.4 in 20 days and to 17.5 in 2 months by rearing with excess kelp (_Laminaria religiosa_), reaching the minimum level for commercial landing (Agatsuma 1999). However, in Linao, although algae began to grow in December and sufficient algae were found in February and March, the GI increase was very small. This suggested that the algal standing crop did not always reflect the increase in the GI, because this period coincided with the minimum GI period after the spawning season (Kino and Agatsuma 2007). Agatsuma (1999) also commented that it is preferable to transplant _S. nudus_ 2 months before maturation and the spawning season. Therefore, the GI of T-La also did not increase after December and showed almost the same value as that of L-La. In other words, if it is necessary to perform effective transplantation in a short time, it should be implemented a few months before the maximum GI period (just before spawning). If transplantation is carried out after the spawning...
season, it is likely that it will take about 1 year before having commercial value. Although it is thought that transplantation markedly stresses sea urchins due to their collection and transport, considering these unfavorable conditions, this period in August (austral winter) seemed advantageous because it was low-temperature season (Fig. 2).

The GI of T-La increased to 13.7 in October, and then it decreased to 10.3 in December. Although this period coincided with the spawning season of this species in Huelhue (Kino and Agatsuma 2007), the spawning of T-La was not confirmed. Assuming that they spawned, this means that the spawning population increased as a result of the transplantation of L. albus which showed no capacity to spawn; transplantation is also useful as one of the propagation methods for this species.

It is necessary to understand the algal requirements of sea urchins on actual transplantation; however, the algal consumption of T-La was not investigated in this study. At sizes of 70 and 40 mm in test diameter, L. albus consumes 230 g/month of M. pyrifera and 38 g/month of Lessonia nigrescens, respectively (Bückle et al. 1977b). The body weights are ca. 160 g (70 mm) and ca. 30 g (40 mm), respectively (Bückle et al. 1977a), and the daily rate of algal consumption can be calculated as 4.8 and 4.2% of the body weight, respectively. Consequently, the algal standing crop in an area transplanted into should be more than 5% of the total weight of sea urchins transplanted every day. Algal growth or algal supply as drift algae should be greater than the amount grazed by sea urchins.

Recovery and movement

Numbers of transplanted P. lividus of 30–50 mm in test diameter decrease by 7.7% (mainly predation by fish) after about 1 month, and their recovery rate is 60% after 6 months (San Martin 2004). The recovery rate of transplanted L. albus (58.6 mm in mean test diameter) in this study was high, at more than 80% (90.4% including sampled individuals) after 6 months. Since the activity of predators rises due to the gradual increase in the seawater temperature (Fig. 2), predation may occur. As for predators of L. albus, brachyurans and asteroid have been reported in Chiloé Island waters (Kino 2009); however, evidence of predation such as the presence of broken tests was not found in the transplantation quadrat except for one dead individual. Thus, it is thought that a low risk of predation is one of the reasons for the high recovery rate. Another reason is their locomotory behavior. In kelp forests, Strongylocentrotus franciscanus hardly moves compared with individuals outside the forest depending on the presence of food (Mattison et al. 1977), and the movement of S. droebachiiensis increases after reaching >15 mm in test diameter (Dumont et al. 2004). A difference is found in their locomotory behavior depending on the environment around them, size, or species. The movement range of L. albus is narrow, and individuals do not forage far for food (Dayton 1985). Some results of this study also support this. T-La hardly moved from the point of release, and 80% of them remained within a 5-m radius of the release point after 6 months. Although the maximum moving distance was 15 m in that period, individuals that moved this distance totaled less than 2% of T-La. Transplanted S. nudus hardly moves after 166 days (Akimoto 1976), or moves approximately 20 m in 2 weeks (Kawamura 1963). Transplanted S. intermedius also hardy moves; however, some individuals move more than 70 m (Kawamura 1965). In the case of released juvenile S. intermedius (20 mm in test diameter), it moves approximately 20 m from the release point if seeded in an adequate place (Monma et al. 1992). In this study, it was confirmed that the distance moved by one L. albus was 1.6 m in one month in Linao. Individuals hardly moved for foraging; only 20 individuals gathered around algae put on the sea bottom in one month. In coralline flats like Linao, it is suggested that low energy caused by a lack of food further reduces movement. On the other hand, however, S. nudus, in coralline flats gather in a short period around brown algae (L. religiosa) put on a rocky sea bottom in south-west Hokkaido, Japan; approximately 200 individuals gather after 24 hours (Fujita 1987). Consequently, it can be
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concluded that confined locomotory behavior is a characteristic of *L. albus*.

**Condition of transplantation**

A negative correlation is noted between algal quantities and the density of sea urchins such as *Evechinus chloroticus* (Ayling 1981), *L. albus* (Dayton 1985), *S. nudus* (Agatsuma et al. 1997), *S. intermedius* on juvenile release (Sakai et al. 2004), and *Heliocidaris erythrogramma* (Valentine and Johnson 2005). The state of the sea bottom grazed by sea urchins is called “Coralline flat” (Ayling 1981), “Urchin barren” (Coyer et al. 1993), “Isoyake” (Fuji 1999), and so on. It is believed that the heavy grazing of algae by sea urchins is one of the triggers of algal disappearance. In fact, it was proven that coralline flats are maintained by high-level foraging activity of the Japanese sea urchin *S. nudus* on the Japan sea coast of Hokkaido (Agatsuma et al. 1997).

Many coralline flat areas were seen in eastern coastal waters of Chiloé Island, and the sea bottom comprised pebbles covered with non-geniculate coralline algae (Kino 2009); Linao was an urchin barren zone showing a high density of sea urchins and absence of algal growth. However, even *L. albus* in a zone where no algae grew showed well-developed gonads in many cases. This means that *L. albus* utilizes drift algae; the intestine was filled with algae even when no algae grew around them. Consequently, in coralline flats, it is impossible for the gonads to develop unless drift algae exist. Thus, in coralline flats with the absence of drift algae such as Linao, *L. albus* shows mal-developed gonads throughout the year. In this study, the GI of *L. albus* with mal-developed gonads clearly improved on increasing the algal standing crop, but, as aforementioned, when sea urchins move little to forage for algae despite the existence of algal growth, or drift algae are not available, gonadal development is poor. The daily rate of algal consumption of *L. albus* was ca. 5%, as previously mentioned. Therefore, in the case of carrying out an actual transplantation, this behavior should be considered, and it is necessary to discuss the extent of the transplantation area, total weight of sea urchins, and algal standing crop including drift algae. However, sites influenced by freshwater are inappropriate for transplantation even if there are abundant algae, because mass mortality occurs (Kawamura 1965). Although the transplantation site salinity was stable during the experiment showing favorable conditions in this study, we should also pay attention to environmental factors other than algal food.

As a candidate transplantation site, a former bank of *L. albus* is better, because it will have a sufficient provision of algae and is an adequate natural habitat for this species. Banks were reported in which the density of *L. albus* was more than 20 individuals/m² (Piedra Lile, Chiloé Island, X region) and more than 60 individuals/m² (Canal Leucayec, Guaiotecas, XI region) (Barahona et al. 2003). In Laitec (Chiloé Island, X region), where *L. albus* distributed in groups like patches on the pebble sea bottom, a density above 80 individuals/m² in each patch of *L. albus* was observed (Kino 2009). Consequently, it is suggested that *L. albus* can be transplanted at a high density considering the algal standing crop and environment of these sites where banks had previously formed.

Recently, the fishery of *L. albus* shifted further south of Chiloé Island, as the darkish-colored gonads of bigger individuals has been associated with poor quality (Barahona et al. 2003). A difference in the gonad color (yellow-brown) depending on the habitat has reported for *A. crassispina* (Yasuda et al. 1982). In both *S. intermedius* and *S. nudus*, individuals inhabiting a deeper sea bottom show mal-developed gonads because of a lack of algae (Osaki and Kawamata 1991). Additionally, *S. nudus* ranging at deeper sites (>15 m) shows mal-developed and dark-colored gonads commercially selected against, showing a correlation between the GI and quantity of brown algae (Kirihara and Yamauchi 2004). Although the gonadal quality was not investigated in this study, since the gonad color has a relationship with food, age, and the natural habitat (Matsui 1966), we need to explore transplantation methods to increase the commercial yield of *L. albus*. On the other hand, *S. intermedius* shows a non-synchronized
reproductive cycle when the transplantation of adults and release of juveniles are carried out in geographically separated areas differing from their original habitat (Tomita et al. 1986), and from their spawners’ habitat (Agatsuma et al. 1994), respectively. Therefore, for the propagation of resources, transplantation sites should also be determined considering this phenomenon of change in the reproductive cycle.

In this study, the effectiveness and possibility of *L. albus* transplantation were shown. Since the transplantation experiment was carried out only from August to February for 6 months, and the other months were not targeted, the time period after transportation was short, and number transplanted was also small. The minimum fishing legal size is 70 mm in test diameter (Stotz 2004), and a few years are needed before recapturing when small individuals are transplanted. Consequently, it is necessary to obtain more information on the adequate size, period, and method for actual mass transportation. Rogers-Bennett (2007) commented that transplantation may be more effective for gonadal enhancement than artificial seed production. Further studies are needed to investigate not only the improvement of gonad size but also the quality from the viewpoints of resource propagation and fishery of this species.

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**References**


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チリ共和国チロエ島におけるチリウニ *Loxechinus albus* の移植

城野草平

チリウニ *Loxechinus albus* 資源の有効利用のため、1988年8月から1989年2月にかけて6ヶ月間の移植試験をチリ共和国チロエ島で実施した。海藻に乏しいLinaoに生息する生殖腺の発達が悪いチリウニ1000個体（平均殻径58.6mm）を海藻が豊富なHuehueに設置した400m²の試験区に移植した。移植後2ヶ月で生殖腺指数が8.5から13.7に改善した。移植後6ヶ月の回収率は83%（サンプリング個体を含めると90.4%）であった。チリウニの移動範囲は狭かった。Linaoではチリウニはネットに収容した海藻にあまり集まらず、その数は海藻設置4, 8, 15, 21日後にそれぞれ2, 10, 15, 20個体であった。