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LONG-TERM CHANGES IN LAKESHORE VEGETATION ZONE IN HASUGAWARA REGION OF LAKE KASUMIGAURA

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SYNOPSIS

The long-term changes in a lakeshore vegetation zone were investigated by using an old map produced in 1883-84 and aerial photographs taken since 1947. The Hasugawara region of Lake Kasumigaura was used as an example. This area is a part of a river delta formed by the supply of sediment from former tributaries of the Sakura River under the action of obliquely incident waves. After constructing a floodway for the Sakura River, sediment supplies were completely exhausted, and the river deltas have gradually eroded owing to wave action. The major cause of the recession of the lakeshore vegetation zone is attributable to erosion as well as other factors already pointed out such as land reclamation from the lake and other factors. Detailed measurement of the bathymetry and grain size distribution of lakebed materials show that the lakeshore vegetation zone was eroded up to a depth of 0.7 m below the mean lake level with the recession of the shoreline.

INTRODUCTION

Lake Kasumigaura, with an area of 171 km^2 and a mean water depth of 4 m, is the second largest lake in Japan. In recent years, the lakeshore vegetation and sandy beaches of this lake have disappeared owing to various anthropogenic factors. Hirai (1), (2) produced a geographical map (Environmental map of Lake Kasumigaura) in which the distribution of low land along the lakeshore, the use of the land and lake in the coastal zone, anthropogenic changes to the land, and photographs showing typical lakeshore scenery were summarized. Hirai (3), (4), (5) concluded that anthropogenic factors such as the transformation of wetland into lotus ponds, fishing ports and aquacultural facilities, and sand mining from the lakebed have affected 45% of the lakeshore, resulting in damage to the habitat of lakeshore vegetation. Hirai (3), (4), (5) also showed that this damage is closely related to the large-scale reclamation of land from the lake, which was carried out from before World War II to the 1960s. The construction of a new river bank surrounding the lake is associated with the comprehensive development of the lake since the 1970s, and various anthropogenic changes related to the land such as land reclamation for new uses in recent years. Hirai (3), (4), (5) further argued that dredging in the navigation channels of fishing ports to ensure the safety of navigation and excess sand mining have affected the lakeshore environment. In addition to these factors, Uda et al. (6) examined the lakeshore changes due to longshore sand transport generated by wind waves on the basis of measured topographic changes of the lake, and investigated the long-term changes in the lakeshore by using past aerial photographs and old maps.

On the other hand, measures for protecting lakeshore vegetation have been taken, and beach nourishment with the aim of recovering lost sandy beaches has been carried out since 2000 in Lake Kasumigaura (Uda and coworkers (7), (8), (9)). Although lakeshore vegetation has disappeared in the Hasugawara region located at the bottom of the west bay (Tsuchiura-iri) of Lake Kasumigaura, as shown in Fig. 1, the exact cause of the disappearance of the lakeshore vegetation in this area has not yet been clarified, and only general explanations have been given for the causes. In this study, the long-term changes in the shoreline in the Hasugawara region are investigated by using old maps produced during 1883-84 and aerial photographs. Furthermore, a detailed bathymetric survey was carried out and samplings of the bed materials were taken to investigate the causes of the disappearance of the vegetation zone.

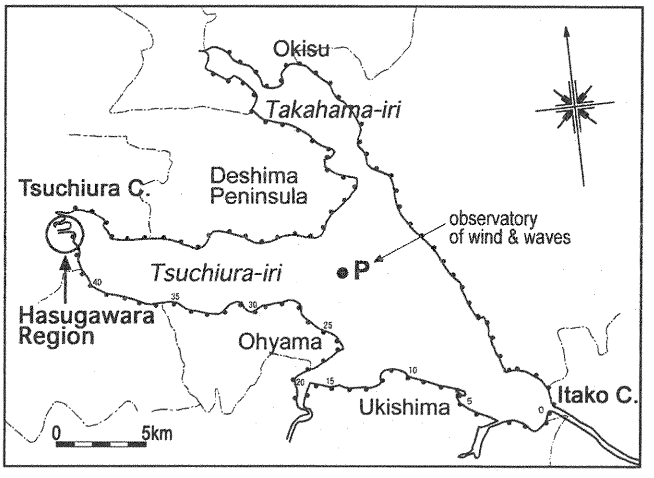

Fig. 1 Location of Hasugawara Region of Lake Kasumigaura

GENERAL CONDITIONS OF HASUGAWARA REGION

The Hasugawara region is located at the tip of the bay named Tsuchiura-iri, which has a slender shape in the east-west direction (Fig. 1), and therefore, the predominant direction of waves in this area is from the east. Figure 2 shows the probability distribution of the daily maximum wind velocity between 1978 and 2004 measured at the observatory located at the center of the lake (P in Fig. 1). The predominant wind directions at the observatory are north-northeast (NNE) and north (N). The frequencies of winds from SSE-SW and WNW are also relatively high, although less than those of wind from N and NNE. Note that the northerly wind is sheltered by Deshima Peninsula and has no relationship with the generation of wind waves in the Hasugawara region. Waves in the Hasugawara region are mainly generated by wind from directions ranging between E and SSE. Because the average direction of the normal to the shoreline in the Hasugawara region is N86°E, northward longshore sand transport is generated by wind waves from directions between E and SSE. When the mean daily maximum wind velocity in each direction is calculated from the observed data at the observatory in the center of the lake, the significant wave height in the Hasugawara region was predicted to be 0.27 m (wave period 2.4 s) by the formula proposed by Uda (10) given the fetch in the Hasugawara region and the daily maximum wind velocity.

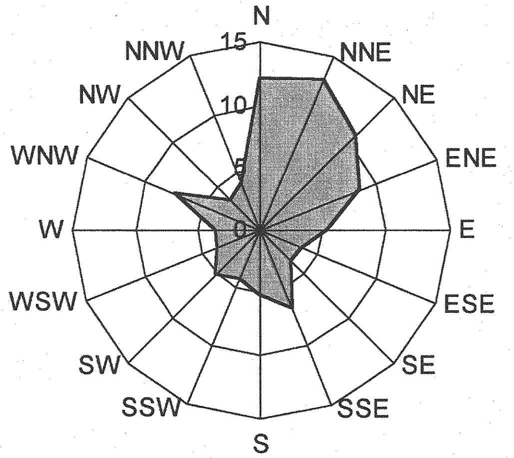

Fig. 2 Probability distribution of daily maximum wind velocity

LONG-TERM SHORELINE CHANGES

In the Hasugawara region, the lakeshore vegetation zone has markedly retreated in recent years, and protecting it is an important concern. To accomplish this, it is necessary for the long-term shoreline evolution of this region to be quantitatively investigated. In this study, an old map produced in 1883-84 by the Japanese Imperial Army and aerial photographs, taken in the past 50 years when many anthropogenic changes were being made to the lakeshore, were compared to study the evolution of the lake shoreline.

Figure 3(a) shows an old map produced in 1883-84, in which the condition of the past lakeshore before the anthropogenic changes is well preserved. The shoreline PQ extending east of the present Tsuchiura City area had a complicated configuration in those days, implying that the shoreline was covered with lakeshore vegetation such as *Phragmites australis*, because if it had been a sandy beach, a smoothly curved shoreline would have extended without irregular small projections. Similarly, the shoreline RS east of Ohmuro region in the southern part of the area which was examined was thought to have been covered with lakeshore vegetation because it had an uneven, complicated shoreline.

In contrast to these lakeshore conditions, a straight, smooth shoreline extends in Ohiwata region and the vicinity of the Hanamuro River mouth owing to the exposure to wind waves from the east or southeast, implying that these areas were comparatively unsuitable for the growth of lakeside vegetation. The Sakura River, which used to separate it into two tributaries near the river mouth, flowed into the lake immediately south of the present Tsuchiura City while forming a birdfoot river delta. This type of river delta is only formed when the rate of sediment supply from the river is much larger than that of longshore sand transport, which carries the supplied sediment away from the river mouth. Because the longshore component of wave energy flux near the Sakura River mouth is northward, the former river course of the Sakura

River is thought to have meandered northeastward against the action of waves incident from directions between E and SSE.

Figure 3(b) shows an aerial photograph taken in 2003 of the same area as that in Fig. 3(a). The lakeshore shoreline has markedly changed in 120 years. Although Ishida village, located east of Tsuchiura City, has remained as it was, the wetland near the lakeshore has changed into rice and lotus fields surrounded by dikes. The biggest change that can be observed in the vicinity of Tsuchiura City; the current course of the present Sakura River was excavated between the former north and south tributaries of the Sakura River, and these tributaries have been entirely reclaimed. Furthermore, the shoreline, which used to have many, small projections between PQ and RS, has changes to a straight form because of the construction of the river dikes. Although Kasumigaura Park appears to have been built to protrude into the lake, this is impact because a new course for the Bizen River was excavated on the north side of the park, and because sand mining was carried out on the south side of the park, leaving this area isolated.

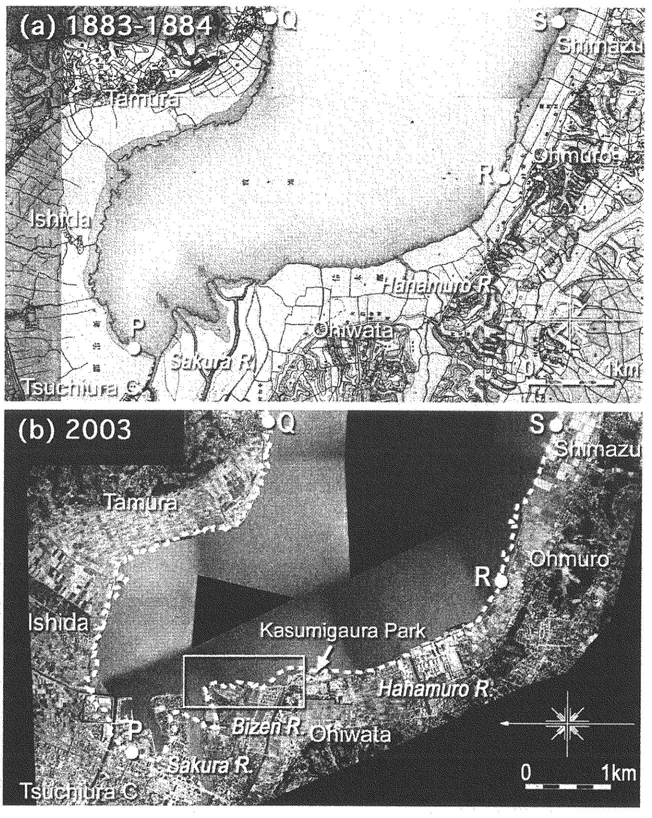

Fig. 3 Old map produced in 1883-1884 and aerial photograph taken in 2003

The shoreline changes in the Hasugawara region were investigated in detail in the rectangular area, shown in Fig. 3(b), by using aerial photographs. Figure 4(a) shows the old map produced in 1883-84. In those days, this area was a wetland, and the north and south streams of the south tributary of the Sakura River, which significantly meandered, flowed into the lake, forming birdfoot river deltas. In 1962, a new channel of the present Sakura River was excavated, the south stream of the former southern tributary was entirely reclaimed and a dike was built in this location (Fig. 4(b)). However, part of the original delta topography remained in the shallow zone offshore of the mouth of the north stream of the former southern tributary despite a new channel for the Bizen River having been excavated. Thus, the shape of the present shoreline had been formed by 1962. In an infrared imagery taken in 1972 (Fig. 4(c)), lakeshore vegetation can be clearly observed; a wide vegetation zone extended in front of the river dikes in the Hasugawara region. By 1985 a fishing port and Kasumigaura Park had been built on the right bank of the Sakura River mouth and on the southern side of the Bizen River, respectively (Fig. 4(d)), although there were no significant changes to the shoreline were observed in 1985 in other areas. By 1992, the lakeshore vegetation zone of Hasugawara region had greatly narrowed and Hasugawara fishing port had been constructed, as shown in Fig. 4(e). By 2003, the vegetation zone of Hasugawara region had further narrowed, and the shoreline on the left side of the Bizen River had markedly retreated because of sand mining (Fig. 4(f)).

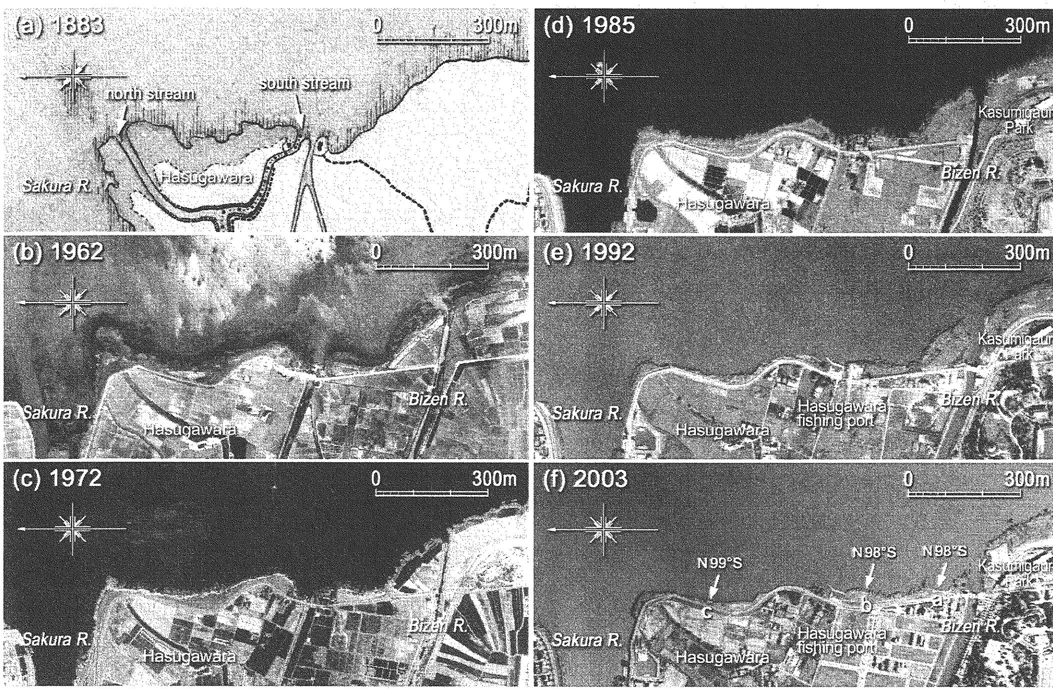

Fig. 4 Shoreline evolution on the basis of old map produced in 1883-1884 and aerial photographs

Fig. 5 Condition of pocket beach *a* in Hasugawara region

In Fig. 4(f), small pocket beaches labeled *a*, *b* and *c* can be seen. For example, Fig. 5 shows a photograph depicting the condition of pocket beach *a*, which was taken looking northwards. A vegetation zone of *Phragmites australis* exists at the north end of the pocket beach, forming a solid boundary preventing northward longshore sand transport. Thus, pocket beach *a* is a statically stable beach. Similarly, pocket beaches *b* and *c* are also statically stable because both of their ends are separated by lakeshore vegetation. Taking the conditions of the pocket beaches into account, the direction normal to the shoreline at the center of the pocket beaches is drawn, which gives a wave direction of approximately N98°S, as shown in Fig. 4(f). This wave direction is considered to be approximately equivalent to the predominant wave direction in the Hasugawara region, and the oblique wave incidence to the mean shoreline is the cause of the northward longshore sand transport in the Hasugawara region.

RECESSION OF VEGETATION ZONE AND LAKEBED TOPOGRAPHY

Figure 6 shows the change in the marginal line of the lakeshore vegetation zone between 1985 and 2003. The vegetation zone retreated by as much as 100 m on the left bank of the Bizen River and 60 m in the Hasugawara region. The recession on the left bank of the Bizen River was triggered by dredging. Significant recession of the vegetation zone occurred in the zone between Hasugawara fishing port and the Sakura River mouth, although no shoreline changes could be seen south of Hasugawara fishing port.

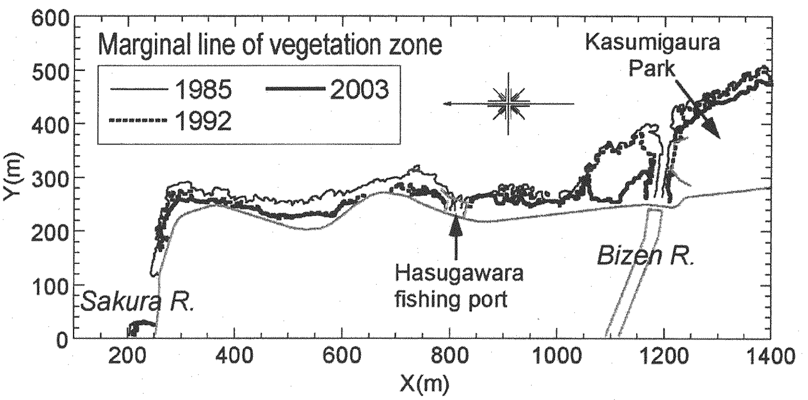

Fig. 6 Changes in lakeshore vegetation zone in Hasugawara region

The change in the vegetation zone between 1985, when there was a wide vegetation zone in the Hasugawara region, and 2003 is summarized by Fig. 7, on which the lakebed topography measured in 2002 and 2006 is superimposed. The white dotted line in Fig. 7 shows the marginal line of the vegetation zone in 1985, the lakebed topography surrounded by the black dashed line was measured in October 2006 and the rest of the lake was measured in March 2002.

Offshore of Kasumigaura Park, a steep slope exists extending from Y.P. 0.2 m to -0.8 m, in strong contrast to the terrace topography in the zone shallower than 0.2 m, where Y.P. is the abbreviation of Yedogawa Peil (-0.84 m below the mean sea level in Tokyo Bay). Although a narrow channel that had been dredged to a level of Y.P. -1 m extends offshore of the Bizen River mouth, the protruding contours offshore of Kasumigaura Park smoothly extend to the north of this channel. There was a wide lakeshore vegetation zone on the landward side of this shallow area in 1985, but this vegetation zone had retreated by up to 100 m by 2003. Except for the area that was seriously affected by the impact of the anthropogenic changes offshore of the Bizen River mouth, the location of the offshore marginal line of the lakeshore vegetation is in good agreement with the location of the contour line of Y.P. 0.4 m at present. The same feature can be found near Hasugawara fishing port and Hasugawara region in the north part of the study area. Therefore, the depth of closure h_c above which topographic changes due to waves occur, is approximately equal to Y.P. 0.4 m (mean water depth 0.7 m) in this area. Furthermore, although the southern stream of the former south tributary flowed into the lake near Hasugawara fishing port, the protruding topography corresponding to the abandoned river mouth delta has been left intact offshore of this fishing port except for the narrow navigation channel.

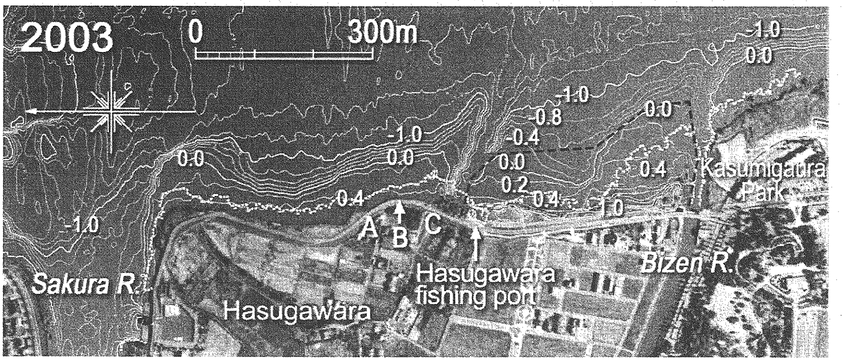

Fig. 7 Distribution of lakeshore vegetation zone and lakebed topography in Hasugawara region

Around the north stream of the former south tributary, the seabed topography changes markedly with respect to the contour line of Y.P. 0 m with a steep slope offshore, and a lakebed terrace with a gentle slope extends in the zone shallower than the depth of Y.P. 0m; thus, the past river delta topography is well preserved on the lakebed. The north slope of this river delta is as steep as 1/8 and the slope extends to the present stream of the Sakura River. Near the former Sakura River mouth, northward longshore sand transport prevails because of the relationship between the shoreline configuration and the direction of the predominant waves from N98°S, resulting in the formation of a river delta of an asymmetrical shape with a projection to the north. In the south part of the river delta, a lakebed terrace was formed near the depth of closure h_c under the action of waves, and eroded sand was transported northward and deposited, resulting in the formation of a steep slope near the north end. In addition, since 1983 the seaward marginal line of the vegetation zone has retreated in parallel near the mouth of the north stream of the former south tributary and along the concave shoreline in the Hasugawara Region. Taking the predominance of northward longshore sand transport into account, Hasugawara fishing port breakwater serves as a solid boundary. The fluvial sediment supply has been completely exhausted at the mouth of the north stream of the former south tributary, and sand supply by the northward sand transport, which was originally supplied from the south stream of the former south tributary, has also been exhausted. Thus, the area north of Hasugawara fishing port was thought to have eroded, resulting in the recession of the lakeshore vegetation zone.

In general, lakeshore vegetation is likely to become locally eroded owing to the direct action of waves reflected from a seawall near the boundary between the seawall and the vegetation zone (Uda et al. (6)). In the Hasugawara region, the seawall is directly exposed to waves between points A and C, as shown in Fig. 7. Setting point B as the location protruding furthest eastward, incident waves from N98°S are reflected along the seawall between points A and B, and propagate northward, thus causing the recession of the lakeshore vegetation. Figure 8 shows the condition of the lakeshore in the vicinity of point A; here, the vegetation zone has rapidly receded because of the action of waves reflected from the seawall.

Fig. 8 Eroded vegetation zone next to seawall in Hasugawara region near point A

DETAILED ANALYSIS OF LAKESHORE CHANGES

Figure 9 shows the detailed bathymetry of the area studied measured along 22 transects at 20 m intervals in October 2006, covering a longshore distance of 420 m. In the vicinity of transect No. 1 next to the Bizen River mouth, a vegetation zone with dense growth of *Phragmites australis* protrudes. A wetland exists behind the central part of this protrusion, and the elevation of the surrounding area is relatively high. Between transects No. 4 and No. 6 north of the vegetation zone, a narrow pocket beach with a longshore length of 40 m exists, and offshore of this pocket beach, a flat offshore lakebed extends. The width of this offshore flat lakebed rapidly narrows in a northward direction, and an embayment with a steep slope approaches the shoreline north of transect No. 9.

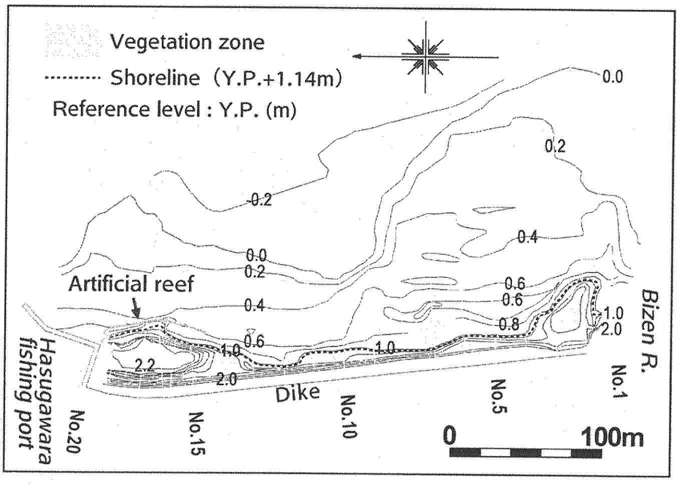

Fig. 9 Detailed lakebed topography in Hasugawara region

Figure 10 illustrates the longitudinal profile along transect No. 5. The foreshore slope is 1/13, the bed elevation of the beach is as shallow as Y.P. 0.5 m at a point 20 m offshore of the shoreline and a flat bed extends offshore. The depth distribution of the median diameter d_{50} along transect No. 5 is shown in Fig. 11; d_{50} is as coarse as 0.7 mm near the shoreline, corresponding to the steep foreshore slope, whereas it is as fine as 0.3 mm in the zone deeper than Y.P. 0.8 m. Point D, where the grain size markedly changes, is shown in the longitudinal profile in Fig. 10; it is also located where the slope changes between the foreshore slope and the flat offshore bed. The critical depth where the grain size decreases from the coarse grain size near the shoreline to the fine grain size with increasing depth, where the grain size approaches approximately 0.2 mm in the offshore zone, is approximately equal to the depth of closure h_c (Uda (10)). Therefore, h_c is Y.P. 0.5 m (mean water depth=0.6 m) as shown in Fig. 11. This depth is approximately equal to the critical depth of Y.P. 0.4 m obtained from the depth of the offshore marginal line of the receded vegetation zone.

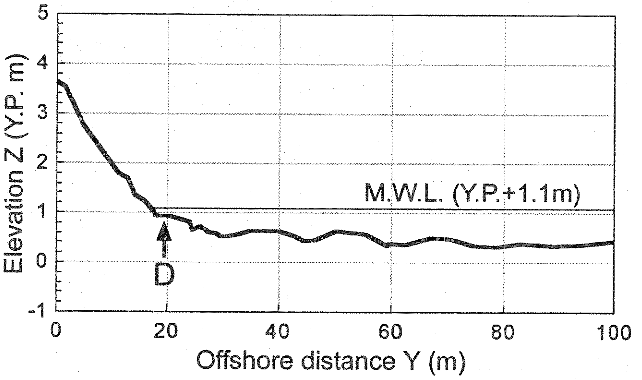

Fig. 10 Longitudinal profile along transect No. 5

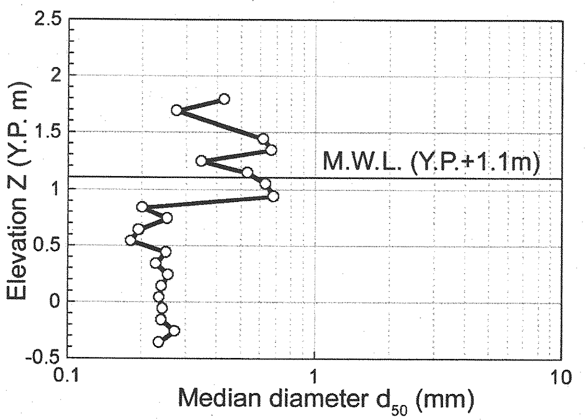

Fig. 11 Depth distribution of median diameter d_{50} along transect No. 5

EFFECT OF ARTIFICIAL REEF FOR PROTECTING VEGETATION ZONE

Urgent measures for protecting the lakeshore vegetation of Lake Kasumigaura have been taken since 2000. In this project an artificial reef was used as a breakwater to reduce the impact of wind waves (Uda et al. (7)). This method was also applied in the Hasugawara region; an artificial reef was built by using stones to protect the offshore marginal line of the lakeshore vegetation at transect No. 17, located at the north end of the area studied area shown in Fig. 9. Although the artificial reef, with a crown height very close to the mean water level, was built immediately offshore of the shoreline, as shown in Figs. 12 and 13, a channel with a depth of 0.3 m below the mean water level of the lake (Y.P. 0.8 m) immediately formed shoreward of the artificial reef. Since the shoreward flow is generated by wave overtopping over the artificial reef, the channel along the reef is thought to have formed by the actions of both local scouring by wave overtopping and the flow returning through the channel to outside the reef to satisfy the mass continuity. This means that when an artificial reef is used as a wave-dissipating facility to protect the lakeshore, a channel with several meters width should be built. This structure is effective in protecting the lakeshore vegetation without damaging lakeshore views because it is mostly submerged.

Fig. 12 Stone-made artificial reef for protecting lakeshore vegetation in Hasugawara region

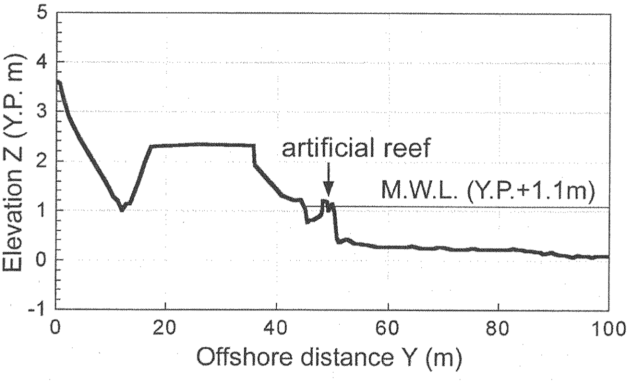

Fig. 13 Longitudinal profile along transect No. 17 crossing artificial reef

CONCLUSIONS

On the basis of an old map produced in 1883-84 and aerial photographs taken since 1947, the long-term changes in a lakeshore vegetation zone were investigated. The Hasugawara region in Lake Kasumigaura was used as an example. In the Hasugawara region, birdfoot river deltas had formed by 1883-1884 due to the deposition of sediment in the lake, which was supplied from the north and south streams of the former south tributary of the Sakura River. However, the sediment supply from the former streams was exhausted because of the construction of a floodway, and thus the erosion of the river deltas of the north and south streams began. This lakeshore change was similar to that which occurred at the former north and south streams of the Yasu River in Lake Biwa after the construction of the floodway (Uda et al. (11)).

The predominant wave direction in the area studied is N98°E, which is the direction normal to the stable shoreline at the center of the small pocket beach in the Hasugawara Region, and under the wave incidence, northward longshore sand transport prevails in the region. Accordingly, although sediment supplied from the south stream of the former south tributary of the Sakura River had also been transported by this northward longshore sand transport, it was also exhausted because of the construction of a floodway, resulting in erosion in the Hasugawara Region. As a result, the seawall was exposed to waves, and waves reflected from the seawall were obliquely incident to the lakeshore vegetation zone, accelerating the disappearance of the vegetation zone.

In conclusion, the exhaustion of sediment supplied from the river is also thought to be one of the causes of the disappearance of lakeshore vegetation in the vicinity of the former Sakura River mouth, along with land reclamation, the construction of river dikes and other causes reported in previous studies (Hirai (5)).

As shown in the present study, the causes of the shoreline recession and disappearance of the vegetation zone are closely related to the long-term topographic changes of lakes. Thus, a study of long-term topographic changes over an extensive area is also important as well as a detailed investigation of the condition of the present lakeshore. Furthermore, as one of the methods of dissipating incident waves to protect lakeshore vegetation without affecting lakeshore views is to build an artificial reef which is considered to be an effective method. When applying this method, it is necessary to build a channel to drain the water that overtops the reef.

ACKNOWLEDGMENTS

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APPENDIX-NOTATION

The following symbols are used in this paper:

Y.P. =Yedogawa Peil (-0.84 m below the mean sea level in Tokyo Bay)

h_c =depth of closure

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