國立臺灣大學生命科學院漁業科學研究所

碩士論文

Institute of Fisheries Science

College of Life Science

National Taiwan University

Master Thesis

利用衛星遙測技術研究近 40 年來棲地破壞對日本鰻資源量的影響

Study of the relationship between *Anguilla japonica* resource and habitat destruction by satellite remote sensing in the past 40 years

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中華民國 102 年 7 月

July 2013

致謝

此論文能夠順利完成，要感謝 韓玉山老師的悉心指導，不厭其煩一次又一次的指正論文上的缺失，也謝謝老師這兩年來提供許多的出差機會，讓我可以更了解鰻魚產業的現況，與產業有所接軌，這兩年真的受益良多；此外也要感謝 黃祥麟老師在衛星遙測技術上的指導與意見，讓這本論文可以順利完成。

承蒙國立臺灣海洋大學終身特聘教授 廖一久博士、國立台灣海洋大學環境生物與漁業科學學系 王佳惠博士、國立台灣海洋大學環境生物與漁業科學學系 黃祥麟博士，對於論文的細心審閱，並且給予寶貴的意見，使此論文更加的完善，對此由衷的感謝。

在實驗室這兩年中，感謝怡誠學長、岱倪學姊、明惠學姊、小陶學姊、給予實驗上寶貴的意見；感謝皖之學姊在我們肚子餓，給予我們點心讓我們可以放鬆許多；感謝敬華學姊這一年來教導我帶領我很快的進入狀況，讓我事半功倍。另外也要感謝我的同學阿梅、阿旗、阿元、邦又、敏睿、鳳媖不只是實驗上給予意見，也在閒暇的時候一起聚餐、放鬆、談心讓心靈上有所慰藉。也感謝實驗室碩一、碩二的學弟妹的鼓勵與實驗上的幫助。也要感謝父母的支持與關懷讓我可以放心的在這個領域上學習。

在台大漁科所這兩年的日子裡我學習許多，也了解產業目前的所面臨的困境，對此讓我有所使命感，希望在未來的日子裡可以貢獻所學，在鰻魚產業上能夠有所貢獻。

陳健澤 謹誌

中華民國 102 年 8 月

中文摘要

日本鰻是日本、韓國、台灣及中國重要養殖魚種，目前養殖業者的鰻苗完全仰賴漁民在河口捕撈。然而其資源量從 1970 年代以後急遽下降；且近年來因各國都市及工業不斷擴張，而使鰻魚的自然棲地受到嚴重的破壞。本研究擬探討從 1970 至 2010 年代，東亞四國日本鰻棲地改變的情形，與鰻魚長期資源量相互比較，觀察是否有所關聯性。

本研究實驗方法使用衛星遙測技術，將其應用在土地覆蓋之改變(Land Cover Change, LCC).衛星遙測技術是一項分析時間空間改變有效率的工具，它可以大範圍紀錄古今的地理樣貌，以提高效率以及精準度以利實驗分析。而本研究區域是從東亞四國中，各選定四條主要鰻苗捕撈河川，藉由 USGS 下載各河川衛星照片後，再由 Arc GIS 分析其棲地改變之情形。結果顯示，日本在 1970 至 2010 年代當中，河川天然棲地長度減少 21%，天然面積減少 27%，棲地品質指數(habitat quality index, HQI）減少 6%；韓國，天然棲地長度減少 46%，天然面積減少 57%，HQI 減少 29%；台灣，天然棲地長度減少 22%，天然面積減少 53%，HQI 減少 50%；中國，天然棲地長度減少 76%，天然面積減少 81%， HQI 減少 25%。在鰻苗長期資源量方面，日本官方平均年產量在 1970 年代為 80.6 噸，1990 年代為 35.9 噸，而近 5 年來為 6.6 噸，資源量在 1970 年代至現今減少 92%；而根據福隆當地漁民資料，1984~1995 年間，年平均總產量 334096 隻，而 2007~2013 年間，年平均總產量 14190 隻，資源量從 1970 年代至今減少達 96%。

結論而言，東亞地區在 1970 到 2010 年代，天然棲地總長度減少 47%，天然棲地總面積減少 81%，HQI 減少 25%。與鰻苗資源量官方統計減少 92%及福隆當地漁民統計減少 96%相互比較，鰻苗資源量應受到棲地破壞而減少。

關鍵字：棲地破壞、日本鰻、衛星遙測技術、東亞四國、鰻魚資源量

Abstract

The Japanese eel is an important aquaculture species in Japan, Korea, Taiwan and China. At present the only source of glass eels needed by fish farmers comes solely from the catches made by fishermen at river mouths. However eel stocks have been in rapid decline since the 1970s. Furthermore with urbanization and constant expansion of industrialization in various countries, the natural habitat of eels have been severely damaged. The aim of this study is to discuss the relationship between habitat changes in the four East Asian countries and the long-term eel stock size from the 1970s to the early 2010s.

The method of this study is using satellite remote sensing on land cover change (LCC). Satellite remote sensing is an efficient tool for analyzing temporal and spatial changes as it could record geographical features on a large geographical scales over times to enhance efficiency and accuracy to facilitate data analysis. Present study focus on four major eel-catching rivers in each of the four East Asian countries. Then satellite images of those rivers were downloaded from the USGS website and fed to ArcGIS to analyze the condition of habitat change in each of them.

The result of this study shows that in the period of 1970s~2010s in Japan, the length of natural habitats in the rivers decreased by 21%, loss of natural areas is 27%, and the habitat quality index, (HQI) decreased by 6%. In Korea, the length of natural habitats in the rivers decreased by 46%, the loss of natural areas is 57%, and the HQI decreased by 29%. In Taiwan, the length of natural habitats in the rivers decreased by 22%, the loss of natural areas is 53%, and the HQI decreased by 50%. In China, the length of natural habitats in the rivers decreased by 76%, the loss of natural areas is 81%, and the HQI decreased by 25%.

In terms of long-term glass eel stock sizes, Japanese official data shows 80.6 tons of annual production in the 1970s, 35.9 tons in the 1990s and in the recent 5 years it is 6.6 tons. The eel stock size decreases by 92% from the 1970s to the present day. According to local fisherman in Fulung, eel stock data in the period of 1984~1995, the mean annual catch of glass eels is 334096, however, in the period of 2007~2013, the total number of glass eels is 14190 on average per year and the stock size decreases by 96% from the 1970s to the present day.

In summary, in East Asia from the 1970s to the 2010s, the total length of natural habitats decreased by 47%, the loss of total natural habitats is 81%, and the HQI decreased by 25%. Compared with the official eel stock decrease of 92% in Japan, and local fisherman data of a decrease of 96% in Fulung, this shows eel stock size decline should be related to habitat loss.

Key words: habitat destruction, Japanese eel, satellite remote sensing, East Asia four countries, eel stock size

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Introduction

The catadromous eel (genus *Anguilla*) is an important aquaculture species in the East Asia. Due to the large-scale artificial production techniques of eel fry (glass eel) are unavailable; the fry source for eel aquaculture must be captured by fisherman in the estuaries. However, the natural stock of glass eel, especially the Japanese eel *Anguilla japonica*, European eel *A. Anguilla* and American eel *A. rostrata*, has been significantly decreasing for the last three decades owing to overfishing, habitat destruction, global climate change and other unknown factors (Tatsukawa, 2003; Dekker, 2003; Casselman, 2003). The decline of natural eel resources causes considerable impact on eel aquaculture industry in East Asia.

Around the world, there are 19 species of anguillid distributed in the coastal areas of North Atlantic Ocean, Indian Ocean and West Pacific Ocean (Aoyama, 2009). All *Anguilla* larvae are spawned in the tropical or subtropical ocean. After eggs hatching, the eel larvae with transparent and leaf-like body are called leptocephali, and they are transported by oceanic currents for several months to their growth habitats. When leptocephali grow to specific maximum size, they then metamorphose into glass eels when they drift near continental shelf (Miller, 2009). After metamorphosis, glass eel enter the estuaries, rivers or lakes and appear pigment on the body. They grow for several years and then become silver eel ready for seawater spawning migration. They migrate thousands of kilometers back to the birth place to spawn and then die (Tsukamoto, 2006).

However, there are many artificial buildings near the estuarine due to urbanization and industrialization during past few decades. Urban growth, particularly the movement of residential and commercial land use to rural areas at the periphery of metropolitan areas, has long been considered a sign of regional economic vitality. But, its benefits are increasingly balanced against ecosystem impacts, including degradation of air and water quality and loss of farmland and forests, and socioeconomic effects of economic disparities, social fragmentation and infrastructure costs (Squires, 2002; Fei, 2005).

For example, dams (Fig. 1a) may limit the upstream movement of eels such that eel numbers often decrease above dams (Goodwin, 1999; Machut, 2007) and increase immediately below dams (Wiley, 2004; Machutet, 2007). Consequently, barriers may influence stream community composition and population dynamics in upstream and downstream directions. Upstream of dams, decreased eel densities may influence stream fish communities by removing a native piscivore which could otherwise comprise over 25% of the total fish biomass in streams (Smith, 1955; Ogden, 1970). Freshwater mussel distributions may also be limited through restrictions of the fish host movements that are necessary for upstream dispersal of mussel glochidia

(Williams, 1993; Watters, 1996). Downstream of dams, increased eel densities may increase intraspecific competition and decrease per capita growth rates (Machut, 2007). Reduced access to headwater streams may also influence eel stock–recruitment dynamics by decreasing the production of female eels (Krueger, 1999).

The rapid expansion of coastal aquaculture (Fig. 1b) has serious environmental and socioeconomic consequences, which include large-scale removal of valuable coastal wetlands, land subsidence, acidification, salinization of groundwater and agricultural land, and subsequent loss of goods and services generated by natural resource systems (Chua, 1992).

Not only dam, aquaculture but also harbor (Fig. 1c), riverbank (Fig. 1d) which replace the mangrove and wetland by land reclamation were creating the eel habitat destruction. Land reclamation has been a common practice to produce valuable land in coastal areas. The impact of land reclamation on coastal environment and marine ecology is well recognized and widely studied. It has not been recognized yet that reclamation may change the regional ground water regime, which may in turn modify the coastal environment, flooding pattern, and stability of slopes and foundations (Jiao, 2001).

Land cover change (LCC) is caused by human disturbances and/or natural events (Wen, 2011). Human activities now affect most of the terrestrial biosphere and are increasing in intensity and extent (Jeremy, 2003). Ensuing habitat loss and degradation impair ecosystem function (Defries, 1999) and reduce the value of ecosystem services for humans (Daily, 1997), and natural events such as global warming, flooding, rivers dry up etc. LCC at different scales from local to global, especially quantitative analysis of LCC has been a main concern to scientists and researchers in the past century, particularly the past few decades around the world (Wen, 2011). However, traditional field ecological data do not translate readily to regional or global extents, and models derived purely from such local data are unlikely to predict the global consequences of human activities (Jeremy, 2003).

Monitoring land cover changes using multi-temporal remotely sensed data provides an accurate evaluation of human impact on the environment (Abdullah, 2012). Importantly, remotely sensed imagery provides an efficient means of obtaining information on temporal trends and spatial distribution of urban areas (Fei, 2005) near the estuary and river. The long-term data record obtained from Landsat satellites are a valuable resource for monitoring land use cover change (USGS, 2011). Accurate and up-to-date land use information is essential for environmental planning, understanding the impacts to terrestrial ecosystems (Wulder, 2007) and achieving sustainable development (Alphan, 2003).

For example, the study of Abdullah, (2012) is to investigate the extent of ship breaking activities in Bangladesh along the Sitakunda coast, various spatial and non-spatial data were obtained by remote sensing imagery. The other study "River pollution remediation monitored by optical and infrared high-resolution satellite images (Paolo, 2013) "were to use high resolution satellite images combined with a classical remote sensing methodology to monitor vegetation conditions along the Bormida River.

The hypothesis of this study focus on whether the artificial buildings like dam, harbor, aquaculture and riverbank cause the Japanese eel resource decline; thus this study use the technology of satellite remote sensing to find the relationship between *Anguilla japonica* resource and habitat destruction during the past 40 years.

Materials and methods

Study area

The main *Anguilla japonica* glass eel catching area is around East Asia countries, including Japan, Korea, Taiwan and China. Choosing Ten-ryu River (天龍川), Ohyodo River (大淀川), Ni-yodo River (仁淀川), and To-ne River (利根川) as Japan study area (Fig. 2) is according to the "日本養殖新聞", due to the four rivers is the main eel catching area in Japan. Choose Han River (漢江), Geum River (錦江), Yeongsan River (榮山江) and Nakdong River (洛東江) as the Korea (Fig. 3) study area due to Han River, Jin River Luo-Dung River are the top three rivers. Choosing Rung-Shan River as the Korea study area by news from the Korean who working in eels.

Take Danshui River (淡水河), Lanyang River (蘭陽溪), Zhuoshuei River (濁水溪) and Kaoping River (高屏溪) as study areas because of they are the main *Anguilla japonica* catching area of Taiwan (Fig.4).Take Minjiang River (閩江), Pearl River (珠江), Qiantang River (錢塘江) and Yangtze River (長江) as study areas due to they are the main Japanese eel catching area of China (Fig. 5).

Landscape image collection and processing

The main rivers of East Asia countries Taiwan, China, Korea and Japan are the major Japanese eel catching area. Historical Landsat data covering the rivers and estuaries of four countries were collected from USGS website (http://glovis.usgs.gov/) and the path/row were recorded on Table 1~4. Each Landsat image contained three color bands (R-red, G-green, B-blue) composited with ArcMap (ESRI, 2008) either RGB231 for MSS data (Landsat 1, 3) or RGB742 for TM/ETM+ data (Landsat 5, 7) to highlight the contrast between vegetative and urban landscape (Kerr, 2003; Merem, 2008; Castilla, 2009). All satellite images were first geo-referenced to clearly identifiable landmarks with ArcMap 9.3 (ESRI, 2008; Huang, 2013). When the images were processed, we calculate the habitat length, area and HQI by a tool called "Measure".

Remote sensing image classification

After processing the satellite images, this study classifies all river valleys under study into two parts, artificial buildings and natural habitats, and then calculates their percentage in length and area. Artificial buildings include 1. riverbanks 2. dams and the upper dam areas 3. aquaculture zones 4. harbors. The remaining area is regarded as a natural habitat. The boundary line of the river under study is restricted to the plane because it is the main habitat of Japanese eels. After measuring the length and area of the river, the area data was used to weight a value called HQI (habitat quality index). According to the study Kimura, (2012) when the artificial revetment rate in Japanese lakes is 100%, then the decreasing rate of fish catch is 25%; so this study refers to the data and makes the natural habitat data multiplied by 1 and the artificial building data multiplied by 0.75 based on the effect of riverbanks on eel stock abundance (Kimura, 2012). Furthermore, the dam, will stop the eel migrating to the upper stream, thus the upper dam valley by 0.

Eel resource data

The four countries official eel catch data was collected from 日本養殖新聞 during 1970s to 2010s and the original data was recorded on Table 5. We also collected the eel catch data form Fulung fisherman during 1980s to 2010s and the original data was recorded on Table 6.

Result

Remote sensing image

Japan:

1.Ten-ryu River (天龍川)

The length of the natural habitat of Ten-ryu River in the 1970s, the 1990s and the early 2010s is 27km, 27km and 27km respectively with the corresponding area of 8 km^2, 9 km^2 and 6 km^2; the HQI value in the 1970s, 1990s and 2010s is 8 km^2, 9 km^2 and 6 km^2 (Table 7A); the percentage of HQI in the 1970s~1990s, the 1990s~2010s and 1970s~2010s is 13% ,-33% and -25% (Table 7B).

Although there were many artificial buildings near the river in the past 40 years, in the 1970s, the 1990s and the early 2010s, there were many sandbanks in the middle of the river (Fig. 6 yellow frame). Therefore the eel habitat area did not decrease significantly and the data of this river shows no significance in the past 40 years. However, the habitat area still changed as the sandbank area is changed by climate factors like water quantity (Table 7).

Because the Scan Line Corrector (SLC) on Landsat-7 used to compensate the forward motion of the whisk-broom sensor malfunctioned on May 31, 2003, there is a problem with the images. As a result, the images acquired from Landsat-7 show data gaps that occupy about 22% of the entire scene (楊, 2009). Fortunately, this study is not affected by this problem and we can still calculate the habitat change values accurately.

2. Ohyodo River (大淀川)

The nature habitat length of Ohyodo River in 1970s, 1990s and 2010s is 35km, 30km and 30km, and the area is 7 km^2, 4 km^2 and 4 km^2; the HQI value in 1970s, 1990s and 2010s is 8 km^2, 7 km^2 and 7 km^2 (Table 8A); the percentage of HQI in 1970s~1990s, 1990s~2010s and 1970s~ 2010s is -10%, 0% and -10% (Table 8B).

There was no harbor near the estuary in the 1970s in this river,, but in the 1990s and the early 2010s, there was a harbor near the estuary (Fig. 7 yellow frame) – the main factor on habitat change in this river. However in the 1970s, not many artificial buildings were in the river. Yet in the 1990s and the early 2010s, more artificial buildings began to appear. Even so, there were no significant habitat changes between the 1990s and the early 2010s (Table 8).

3. Ni-yodo River (仁淀川)

The nature habitat length of Ni-yodo River in 1970s, 1990s and 2010s is 15km, 17km and 17km,and the area is 3 km^2, 3 km^2 and 3 km^2; the HQI value in 1970s, 1990s and 2010s is 3 km^2, 4 km^2 and 4 km^2 (Table 9A); the percentage of HQI in 1970s~1990s,1990s~2010s and 1970~ 2010 is 25%, 0% and 25% (Table 9B).

There is no obvious habitat change in the past 40 years in this river, but it is worth mentioning that in the 1970s, there was no tributary flowing to the river, but in the 1990s and the early 2010s, there was a tributary flowing to this river (Fig. 8). At first, we thought there was no tributary because of the drought season in the 1970s, so we checked the other same path/row remote sensing images of this area to make sure. We found there was really no tributary near the river. Therefore the total length and area in the 1990s and the early 2010s are higher and bigger than those of the 1970s because of the tributary. Indeed more and more artificial buildings begin to appear year by year (Table 9).

4. To-ne River (利根川)

The nature habitat length of To-ne River in 1970s, 1990s and 2010s is 240km, 225km and 175km, and the area is 227 km^2, 179 km^2 and 166 km^2; the HQI value in 1970s, 1990s and 2010s is 248 km^2, 237 km^2 and 233 km^2 (Table 10A); the percentage of HQI in 1970s~1990s, 1990s~2010s and 1970s~2010s is -5%, -2% and -6% (Table 10B).

More and more artificial buildings emerged year by year in this river in the past 40 years that caused the natural habitats to decrease year by year (Fig. 9). The data also shows this trend (Table 10).

Korea:

1. Han River (漢江)

The nature habitat length of Han River in 1970s, 1990s and 2010s is 150km, 123km and 89km, and the area is 188 km^2, 165 km^2 and 105 km^2; the HQI value in 1970s, 1990s and 2010s is 190km^2, 182km^2 and 166km^2 (Table 11A); the percentage of HQI in 1970s~1990s, 1990s~2010s and 1970s~2010s is -4%, -9% and -13% (Table 11B).

This study compares the two different parts of the river, the estuary and extended city area. In the 1970s and the 1990s there were no artificial buildings like harbors and aquaculture areas on the island near the river and the river estuary, but in the early 2010s there were many harbors and aquaculture areas on this island (Fig. 10 A-1, B-1 and C-1). The other part is the city extended significantly from the 1970s to the 2010s as this area is Korea's capital, Seoul (Fig. 10 A-2, B-2 and C-2). This trend is recorded in Table 11.

2. Geum River (錦江)

The nature habitat length of Geum River in 1970s, 1990s and 2010s is 55km, 46km and 23km, and the area is 54 km^2, 37 km^2 and 21 km^2; the HQI value in 1970s, 1990s and 2010s is 71km^2, 59km^2 and 56km^2 (Table 12A); the percentage of HQI in

1970s~1990s,1990s~2010s and 1970s~2010s is -18%, -6% and -22% (Table 12B).

There was no harbor near the estuary in the 1970s in this river (Fig. 11 A-1 black frame), but there was a harbor near the estuary in the 1990s and the 2010s (Fig. 11 B-1 and C-1 black frame). Besides, the harbor was built by land accretion due to the fact that the harbor built connected the estuary land and the outside island. So we calculated the total length of the river in the early 2010s and found that it is higher than in the 1970s and the 1990s because of harbor extension by land accretion (Table 12).

3. Yeongsan River (榮山江)

The nature habitat length of Yeongsan River in 1970s, 1990s and 2010s is 159km, 63km and 58km, and the area is 120 km^2, 28 km^2 and 14 km^2; the HQI value in 1970s, 1990s and 2010s is 120km^2,51$km^2$and 41km^2 (Table 13A); the percentage of HQI in 1970s~1990s, 1990s~2010 and 1970s~2010s is -58%, -19% and -66% (Table 13B).

There were plenty of natural and territorial waters in the 1970s in this river , however in the 1990s and the early 2010s, parts of the territorial waters were replaced by aquaculture areas, harbors and riverbanks (Fig.12 black frame), so the total area declined significantly in the past 40 years. Especially for the period from the 1970s to the 1990s, the HQI decreased by 66% (Table 13).

4. Nakdong River (洛東江)

The nature habitat length of Nakdong River in 1970s, 1990s and 2010s is 116km, 104km and 88km, and the area is 52 km^2, 45 km^2 and 38 km^2; the HQI value in 1970s, 1990s and 2010s is 53 km^2, 50 km^2 and 48 km^2 (Table 14A); the percentage of HQI in 1970s~1990s, 1990s~2010s and 1970s~ 2010s is -5%, -5% and -9% (Table 14B).

More and more artificial buildings emerged year by year in this river in the past 40 years that caused the natural habitats to decrease year by year as well (Fig. 13). The data also shows this trend (Table 14).

Taiwan:

1. Danshui River (淡水河)

The nature habitat length of Danshui River in 1970s, 1990s and 2010s is 103km, 64km and 60km, and the area is 55 km^2, 14 km^2 and 12 km^2; the HQI value in 1970s, 1990s and 2010s is 69km^2, 22km^2 and 22km^2 (Table 15A); the percentage of HQI in 1970s~1990, 1990s~2010s and 1970s~ 2010s is -69%, 1% and -69% (Table 15B).

There is a lake flowing to Danshui River in the 1970s (Fig. 14 A-2 black frame). But in the 1990s and the early 2010s (Fig. 14 B-2 and C-2 black frame), the lake shrunk due to land accretion leading to loss of natural habitats. Furthermore, this was a “winding” tributary flowing to the river (Fig. 14 A-2 black cycle), but in the 1990s and the early 2010s, the tributary became “straight” (Fig. 14 B-2 and C-2 black cycle) and this factor caused habitat loss and destruction between the period of the 1970s, the 1990s, and the 2010s.

We also discover a habitat change factor. In the 1970s there was no weir on this river (Fig. 14 A-1), but in the 1990s there were two weirs on the river (Fig. 14 B-1). In 2004, typhoon Aere destroyed one of the weirs, making the remote sensing images of the 2010s to show just one weir (Fig. 14 C-1) (台灣自來水公司). For this reason, the natural length and area value increased from the 1990s to the early 2010s. In the past 40 years, urbanization caused a 69% (Table 15) habitat loss because the river is near the capital of Taiwan (Fig. 14 A-2, B-2 and C-2).

2. Lanyang River (蘭陽溪)

The nature habitat length of Lanyang River in 1970s, 1990s and 2010s is 55km, 45km and 42km, and the area is 29 km^2, 30 km^2 and 15 km^2; the HQI value in 1970s, 1990s and 2010s is 29km^2, 31km^2 and 16km^2 (Table 16A); the percentage of HQI in 1970s~1990s,1990s~2010s and 1970s~2010s is 6%, -49% and -46% (Table 16B).

There were not many artificial buildings near or on the river in the 1970s, and the watercourse was extensive (Fig. 15 A-1). But in the 1990s and the early 2010s, there were more artificial buildings near or on the river, making the watercourse thinner (Fig.15 B-1 and C-1).

According to the data in Table 16 and Figure 24, the habitats change significantly.

Because in the period from the 1990s to the early 2010s, there were more land accretion on the river. For example, in the river estuary there was land accretion that caused habitat loss (Fig. 15 B-1 black cycle and Fig. 15 C-1 black cycle). In the other example, in one of the tributaries in the 1990s, there was more water quantity in this area. But in the early 2010s, the tributary disappeared (Fig. 15 B-1 black frame and Fig. 15 C-1 black frame).

3. Zhuoshuei River (濁水溪)

The nature habitat length of Zhuoshuei River in 1970s, 1990s and 2010s is 84km, 85km and 72km, and the area is 108 km^2, 69 km^2 and 52 km^2; the HQI value in 1970s, 1990s and 2010s is 108km^2, 69km^2 and 52km^2 (Table 17A); the percentage of HQI in 1970s~1990s,1990s~2010s and 1970s~2010s is -36%, -25% and -52% (Table 17B).

There were less natural and artificial structures near the estuarine area in the 1970s in this river (Fig. 16 A-1). But in the 1990s, there were many aquaculture zones near the estuarine area that caused habitat loss (Fig. 16 B-1). Disastrously, there was an industrial estate, The No. 6 Naphtha Cracker Complex (Mailiao) of Formosa Petrochemical Corp (Fig. 16 C-1), near the coast and it not only caused habitat loss, but also released industrial sewage to the water, leading to serious damage of the estuarine area.

In addition, in the 1970s and the 1990s (Fig. 16 A-2 B-2), there was no dam on the river. But in the early 2010s there was a weir, Chi-Chi (Yao, 2009) on the upstream of Zhuoshuei River that made the river lose about 13km of habitat length (Fig. 16 C-2 black frame) (Table 17).

4. Kaoping River (高屏溪)

The nature habitat length of Kaoping River in 1970s, 1990s and 2010s is 92km, 93km and 85km, and the area is 81 km^2, 45 km^2 and 50 km^2; the HQI value in 1970s, 1990s and 2010s is 81km^2, 46km^2 and 54km^2 (Table 18A); the percentage of HQI in 1970s~1990s,1990s~2010s and 1970s~ 2010s is -44%, 17% and -34% (Table 18B).

More and more artificial buildings emerged year by year in this river in the past 40 years. But from the 1990s to the early 2010s, the total habitat length decreased by 3km while the habitat area change is an increase of 9km (Fig. 17). The explanation for this is that during the 20 years, there were many artificial buildings near the river that caused the percentage of habitat length to decrease. However the sandbanks in the river changed tremendously in this period and caused the percentage of habitat area to increase (Table 18).

China:

1. Minjiang River (閩江)

The natural habitat length of Minjiang River in the 1970s, the 1990s and the early 2010s is 92km, 79km and 31km, and the area is 86 km^2, 83 km^2 and 47 km^2; the HQI value in 1970s, 1990s and 2010s is 87km^2, 91km^2 and 94km^2 (Table 19A); the percentage of HQI in 1970s~1990s, 1990s~2010s and 1970s~2010s is 5%, 3% and 9% (Table 19B).

Urbanization and habitat loss increased year by year in the past 40 years in this river (Table 19). But the data shows the total length of the river became shorter and the total area became larger because there was a tributary in the 1970s and the 1990s (Fig. 18 A-1 and B-1 black frame). It is a natural, winding tributary with many sandbanks. But in the early 2010s, the tributary became straight with fewer sandbanks, and there were many artificial structures near the riverside (Fig. 18 C-1 black frame). For this reason, the total area increased from the 1990s to the early 2010s but the total length decreased.

2. Pearl River (珠江)

The nature habitat length of Pearl River in 1970s, 1990s and 2010s is 242km, 218km and 108km, and the area is 1208 km^2, 557 km^2 and 86 km^2; the HQI value in 1970s, 1990s and 2010s is 1209km^2, 986km^2 and 772km^2 (Table 20A); the percentage of HQI in1970s~1990s, 1990s~2010s and 1970s~2010s is -18%,-22% and -32% (Table 20B).

In this river, there are two data changes worth discussing. One is the total length became longer and the other one is the total area became smaller over the past 40 years. In the 1970s, the area faced less artificial destruction to the environment (Fig. 19A black frame), but in the 1990s (Fig. 19B black frame), land accretion area increased. In the early 2010s, the situation had become more serious (Fig. 19C black frame). So the total length became longer due to increased accretion area and the total area became smaller because of the same factor (Table 20).

3. Qiantang River (錢塘江)

The nature habitat length of Qiantang River in 1970s, 1990s and 2010s is 224km, 170km and 8km, and the area is 7124 km^2, 5129 km^2 and 1727 km^2; the HQI value in 1970s, 1990s and 2010s is 7124km^2, 6336km^2 and 5363km^2 (Table 21A); the percentage of HQI in 1970s~1990s, 1990s~2010s and 1970s~ 2010s is -11%, -15% and -25% (Table 21B).

In this river, the habitats saw a loss year by year in the past 40 years. In the 1970s there were fewer damages to the environment (Fig. 20A); but until the 1990s there were many artificial structures near the riverside (Fig. 20B) and until the early 2010s the situation has become more severe than the 1990s (Fig. 21 C) (Table 21).

4. Yangtze River (長江)

The nature habitat length of Yangtze River in 1970s, 1990s and 2010s is 523km, 286km and 113km, and the area is 3199 km^2, 1637 km^2 and 291 km^2; the HQI value in 1970s, 1990s and 2010s is 3798km^2, 3399km^2 and 2928km^2 (Table 22A); the percentage of HQI in 1970s~1990s, 1990s~2010s and 1970s~2010s is -11%, -14% and -23% (Table 22B).

The habitat loss was also year by year in the past 40 years in this river. What is worth mentioning is the total area (Table 22) from the 1990s to the early 2010s decreased significantly due to the fact that in the 1970s and the 1990s there was not much land accretion in the lake, Kao-Yu (Fig. 21 A and B yellow frame). But in the early 2010s there were many artificial structures in the lake, making the area smaller (Fig. 21 C yellow frame). Therefore the data shows the total area decreased tremendously during the period of the 1990s to the early 2010s.

This study shows a bar chart of the four rivers of Japan, Korea, Taiwan and China in the 1970s, the 1990s and the early 2010s in Figures 22~25. This study also shows a bar chart of the four East Asian countries in the 1970s, the 1990s and the early 2010s in Figure 26.

Eel resource data

According to the "日本養殖新聞" glass eel catch data of East Asian four countries, Japan, the mean annual glass eel catch in 1970s,1990s and 2010s is 80.6 tons, 35.9 tons and 6.6 tons, respectively (Table 23A), and the percentage of the eel catch value change in 1970s~1990s, 1990s~2010s and 1970s~2010s is -56%, -81% and -92% (Table 23B).

Taiwan, the eel resource in 1990s and 2010s is 14.9 tons and 3.1 tons (Table 24A), and the percentage of the eel catch amount change in 1990s~2010s is -79% (Table 24B).

Korea, the eel resource in 1990s and 2010s 8.7 tons and 3.4 tons (Table 25A), and the percentage of the eel resource value change in 1990s~2010s is -60% (Table 25B).

China, the eel resource in 1980s, 1990s and 2010s is 43.2 tons, 36.7 tons and 38.6 tons (Table 26A), and the percentage of the eel resource value change in 1980s~1990s, 1990s~2010s and 1980s~2010s is -15%, 5% and -11% (Table 26B). This study also made bar charts of each sites (Fig. 27~30).

As to local fisherman data in Fulung, this study lists data from 1984 to 1995, and 2007 to 2013 without data available from 1996 to 2006. The mean annual catch of glass eels in the period from 1984 to 1995 is 334096 eels per year, and in the period from 2007 to 2013 is 14190 per year (Table 27A). The percentage of eel catch change value over this period, (1984~1995)~(2007~2013) is -96% (Table 27B). This study makes a run chart in Figure 31.

Discussion

Eel catch data

This study uses eel stock data of the four countries of Japan, Korea, Taiwan and China from "日本養殖新聞". All the eel stock data shows a decreasing trend (Fig. 27~30). However, it is worth mentioning that in 1978 China had a policy called "The reform and opening-up policy" and the policy covered aquaculture (中投顧問 2010). It meant the Chinese government wanted to develop the industry of aquaculture. Therefore prior to 1978, there were not many cultured eels. But after the policy was implemented, eel stock increased because many fishermen started to culture eels, causing the requirement of glass eels to increase. Therefore the data of eel catch in China shows no significant change.

This study refers to eel catch data in Japan as East Asian eel stock, because the Japanese have been culturing eel for a long time, and their government demanded strict records of the data, leading to complete data recording of the eel stocks in the past 40 years, more importantly, according to Han, (2010), the population structures of anguillid eels have long been considered panmictic. This is because sexually mature stocks migrate and spawn in a single site, and their larvae are passively transported back to their growth habitats by oceanic currents with a long larval duration, making population genetic structuring quite impossible (Schmidt, 1925; Tsukamoto, 1992; Avise, 1994; Tesch, 2003; Aoyama, 2009). Therefore, the Japanese eel should be considered as a single management unit for conservation (Han, 2010). Thus for this reason, Japanese catch data can reflect the whole East Asian eel stock change. Generally speaking, eel stocks decreased heavily during the period according to the official eel stock data.

Habitat quality index, HQI

There are many factors affecting the habitat, for example, riverbanks will cause eel habitat destruction, dams will cut off the river and cause habitat loss, land accretion will cause habitat loss too, thus, those factors appertain to water quantity. Furthermore, the DO, PH, salinity, or other pollutions, and so on, appertain to the water quality. In this study, we discuss the water "quantity" because the analytical methods used in analyzing Landsat images in this study just show LCC and cannot reflect the water quality.

The long term habitat change in East Asia

As a whole, in the past 40 years, Japanese natural habitats decreased not as serious as those of the other East Asian countries. The percentage of HQI is -6%

(Table 28) (Fig. 22). As the Japanese government enacted a conscientious and careful law about river management, and there are many professionals on environmental conservation, furthermore, their people have a good concept of environmental protection (曾). But the rate of habitat change in the other countries is higher because their governments did not enact effective laws and instilled in their people the newest concepts of environmental protection; For Korea, the percentage of HQI is -29% (Table 29) (Fig. 23); For Taiwan, the percentage of HQI is -50% (Table 30) (Fig. 24); For China, the percentage of HQI is -25% (Table 31) (Fig. 25) and the total HQI of East Asia is -25% (Table 32) (Fig. 26)

Even though there were different decrease rates in the rivers of each country, as a catadromous species Japanese eels would be transported to East Asian regions by ocean currents after hatching (Miller, 2009). As such, the four countries of East Asia is the mean habitat of the Japanese eel, because Japanese eel is a single panmictic population of in East Asia thus (Han, 2010), if somewhere habitat loss or destruction in East Asia, it will decrease the eel resource of whole East Asia.

Habitat destruction

The International Union for Conversation of Nature and Natural Resources (IUCN) takes "habitat destruction" as the biggest reason for reducing biodiversity in the last decade in the Red List of endangered species. The Red List shows 86% of birds and mammals, 90% of freshwater fish as well as more than 30% of marine life are directly affected by habitat destruction (NTNU). Therefore habitat destruction is an important factor of organism resources.

In many tourist attractions like Jamaica, Dubai, Palau, etc (Chen, 2013), people prefer to live the hotel witch near the coastline for ocean view and marine aqua activities; and since time immemorial, the local resident live near the river for the water or the other daily life. Human activities may cause dramatic changes to landscapes, coastal line, and river habitat change (Wen, 2011).

Wetlands are the most productive natural environment, which gave birth to countless species of aquatic, and is a very important link between terrestrial and aquatic ecosystems, thus when people develop the wetlands by land accretion and then it will cause the biodiversity decrease heavily (池), furthermore, people build many riverbanks or revetments for flood defense, but it cause almost disappearance of the supply of the detritus as food for the fish larvae and juveniles. These environment changes are irreversible and permanently transform the native habitats and ecosystems (Huang, 2013).

The other kind of habitat destruction, dam or weir, for example, the Atlantic sturgeon depends on channel habitats for all life stages and on healthy freshwater habitats for reproduction; such biological needs are in direct conflict with human activities, such as dredging and dam construction, which alter habitats or reduce water quality (Secor, 2000). And the other example, the anadromous members of shad, herring, and menhaden are threatened by the addition of dams, which can prevent them from reaching their spawning grounds. If positioned in key locations, water withdrawal facilities—such as reservoir intakes—may pose a threat to freshwater spawners in terms of egg and larval losses (Amanda, 2009).

The Japanese eel is a catadromous species, it will migrate into rivers for growth, but when there are artificial buildings such as dams on the river, they will block the river channel and the eel can-not migrate successfully (曾等, 2012). Furthermore, many artificial buildings like harbors, aquaculture areas and riverbanks built by land accretion or replacement of original natural habitats may cause eels to have less food sources. For this we know habitat loss could cause eel stocks to decrease.

The other factors of eel resource decline

Except the habitat loss, there are other three main factors affecting the eel resource, pollution, climate change and overfishing. Water quality changes associated with increased levels of nutrients, sediments, and contaminants. For example, nutrient loading leads to algal blooms, which can decrease the concentration of dissolved oxygen (DO) in the water. Low DO can reduce the amount of suitable habitat for fish and can impair fish growth and reproduction; and the factor, low DO, may effect eel too (Amanda, 2009). Otherwise, the effects of persistent pollutants combined with the eel's unusual life cycle may cause the decline in the eel population in northern Europe in recent decades (Larsson, 1991); the other example, when the eel expose in the contaminated environment, the strongly polluted eels detoxify less efficiently, have a lower condition and might be less successful spawner (Feunteun, 2002).

About the climate change, global warming has affected the stability of the hence produced shifts in plankton communities and food web structures. Two potential sources of nutrition have been proposed for eel larvae; dissolved organic matter (DOM) and particulate organic matter (POM) in the form of zooplankton fecal pellets and larvacean houses (Otake, 1993; Mochioka, 1996; Pfeiler, 1999). Marine snow has also been proposed as a potential source of nutrition (Knights, 2003); those primary production has been considered to be a good proxy for leptocephali food (Bardonnet, 2005). Thus, recruitment declines in Japanese eel may also have been due to starvation–advection problems (Karl, 2001; Knights, 2003).

There is also a factor about the climate change, the ENSO, Kimura (2001) showed a certain synchrony between *Anguilla japonica* recruitment and salinity fronts driven by ENSO in the Japanese eel spawning area; Kim (2007) also demonstrated that the changing oceanic conditions associated with climate change have resulted in decreased recruitment of Japanese eel.

The factor of eel resource decline worth to be discussed is overfishing. Tzeng (1986) indicated that Japanese eel elvers have been overfishing for aquaculture in Asian countries, thus the eel population is obviously decreased. Furthermore, Knight, (2003) has also inferred that Japanese eel populations (and escapement of pre-spawning silver eels) have been affected by overfishing.

The annual catch of glass eel in the 1970s in Japan about 80.6 tons and 334096 individual in Fulung in the period 1984~1995 on average; after that time, the catch cleared showed a decrease although it was fluctuating. Annual catches in some local fishing areas showed nearly synchronous fluctuations. This fluctuation may be caused in part by oceanic current conditions (Kimura, 2001). On the other hand, the average catch in Japan in the past 5 years were 6.6 tons and in Fulung in the period 2006~2013 is 14190 eels; this value was only 8% of the average catch in Japan in 1970s and was only 4% in Fulung in the period 2006~2013. It may be very difficult to explain this rate of decline for about 30 years by only dynamic oceanic environmental conditions (Tatsukawa, 2003). Because of some river fishermen have expressed concern that the decline in catch might be caused by overfishing of glass eels year by year. Furthermore, previous literature assumed that water pollution might have affected the survival of glass eels too.

Although many factors affect eel stocks, unfortunately, it is difficult to separate these potential factors. Thus we could not identify the main factor or the percentage of each factors contributing to eel resource decline (Tzeng, 2004).

Conclusion

This study has demonstrated that the HQI of East Asia declines 25%. However, the eel resource changes in Japan and Fulung of Taiwan are -92% and -96%, respectively. Thus, although the habitat destruction should contribute to eel resource decline to some extent, other factors such as water pollution, overfishing, and climate change may also be important factors for the decreasing of the eel resource.

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biodivctr/upload/article/006.htm.

台灣自來水公司. http://www.water.gov.tw/

a

(From Google Website)

b

(From Google Website)

c

(From Google Website)

d

Fig. 1 The artificial buildings of habitat destruction dam (a), aquaculture zone (b), harbor r(c), riverbank (d).

Fig.2 The four main rivers catching eel area in Japan; Ten-ryu River (天龍川), Ohyodo River (大淀川), Ni-yodo River (仁淀川), and To-ne River (利根川)

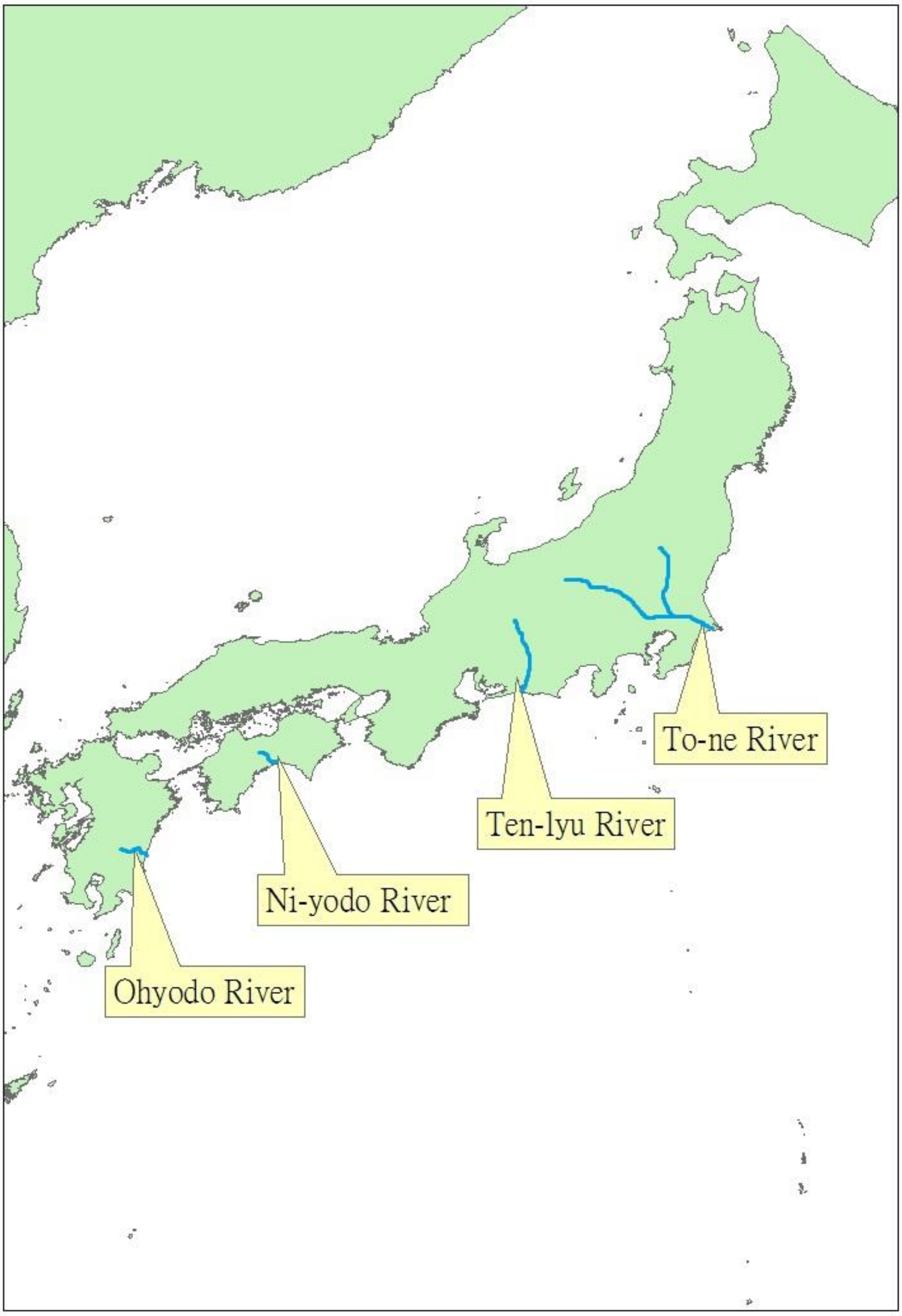


Fig.2 The four main rivers catching eel area in Japan; Ten-ryu River (天龍川), Ohyodo River (大淀川), Ni-yodo River (仁淀川), and To-ne River (利根川)

Fig.3 The four main rivers catching eel area in Korea; Han River (漢江), Geum River (錦江), Yeongsan River (榮山江) and Nakdong River (洛東江)

Fig.4 The four main rivers catching eel area in Taiwan; Danshui River (淡水河),

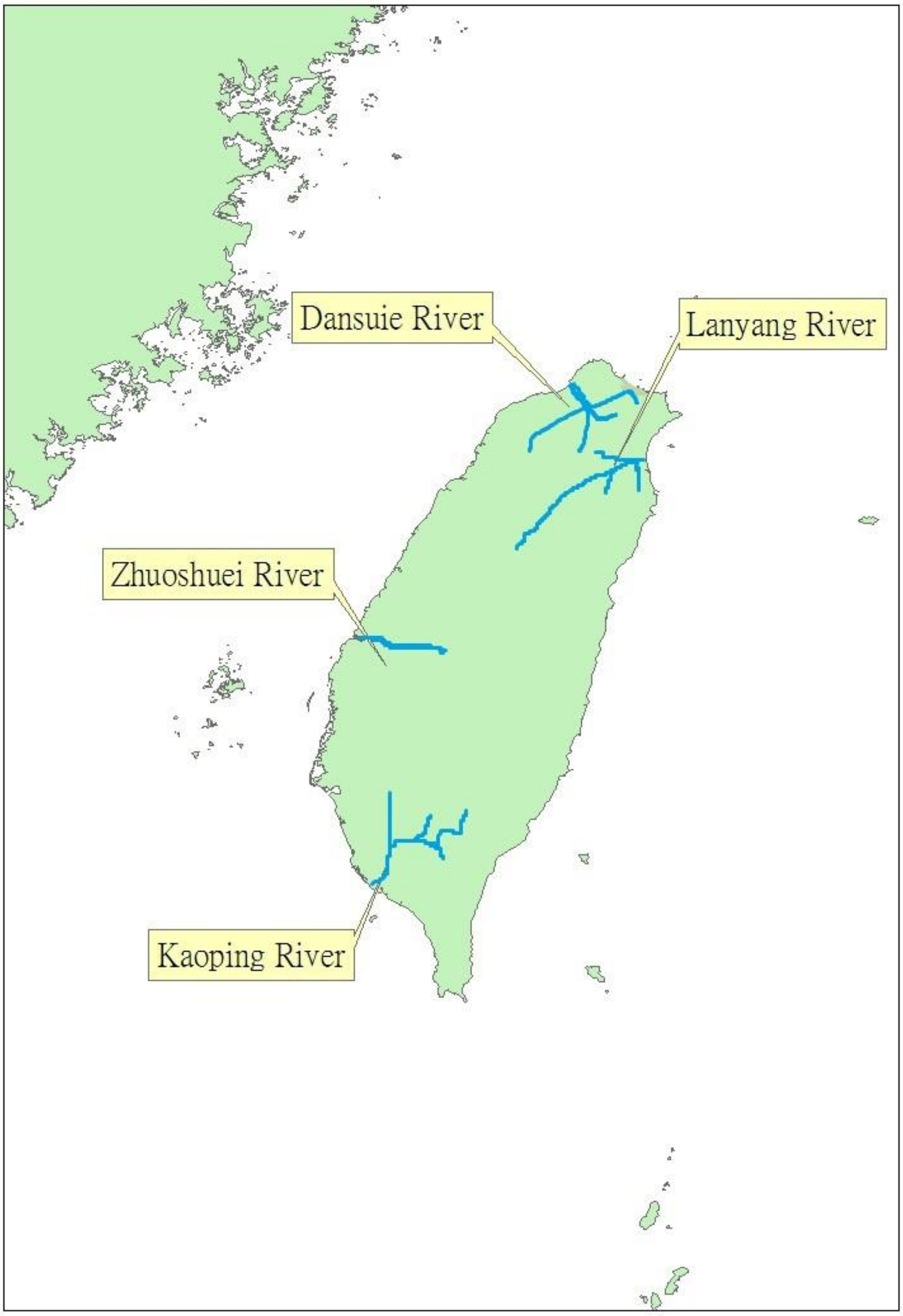
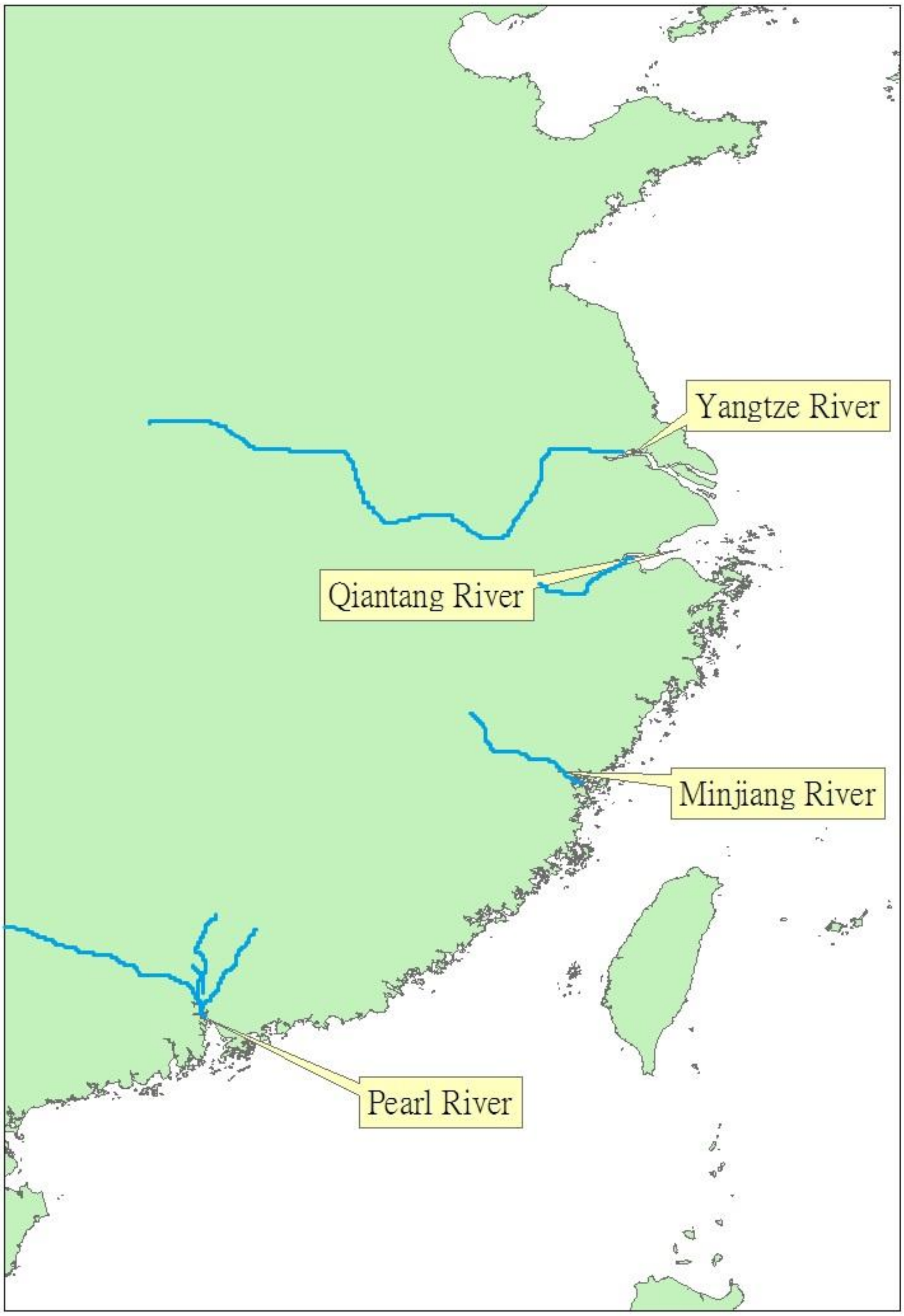


Fig.4 The four main rivers catching eel area in Taiwan; Danshui River (淡水河), Lanyang River (蘭陽溪), Zhuoshuei River (濁水溪) and Kaoping River (高屏溪)

Fig.5 The four main rivers catching eel area in China; Minjiang River (閩江), Pearl River (珠江), Qiantang River (錢塘江) and Yangtze River (長江)



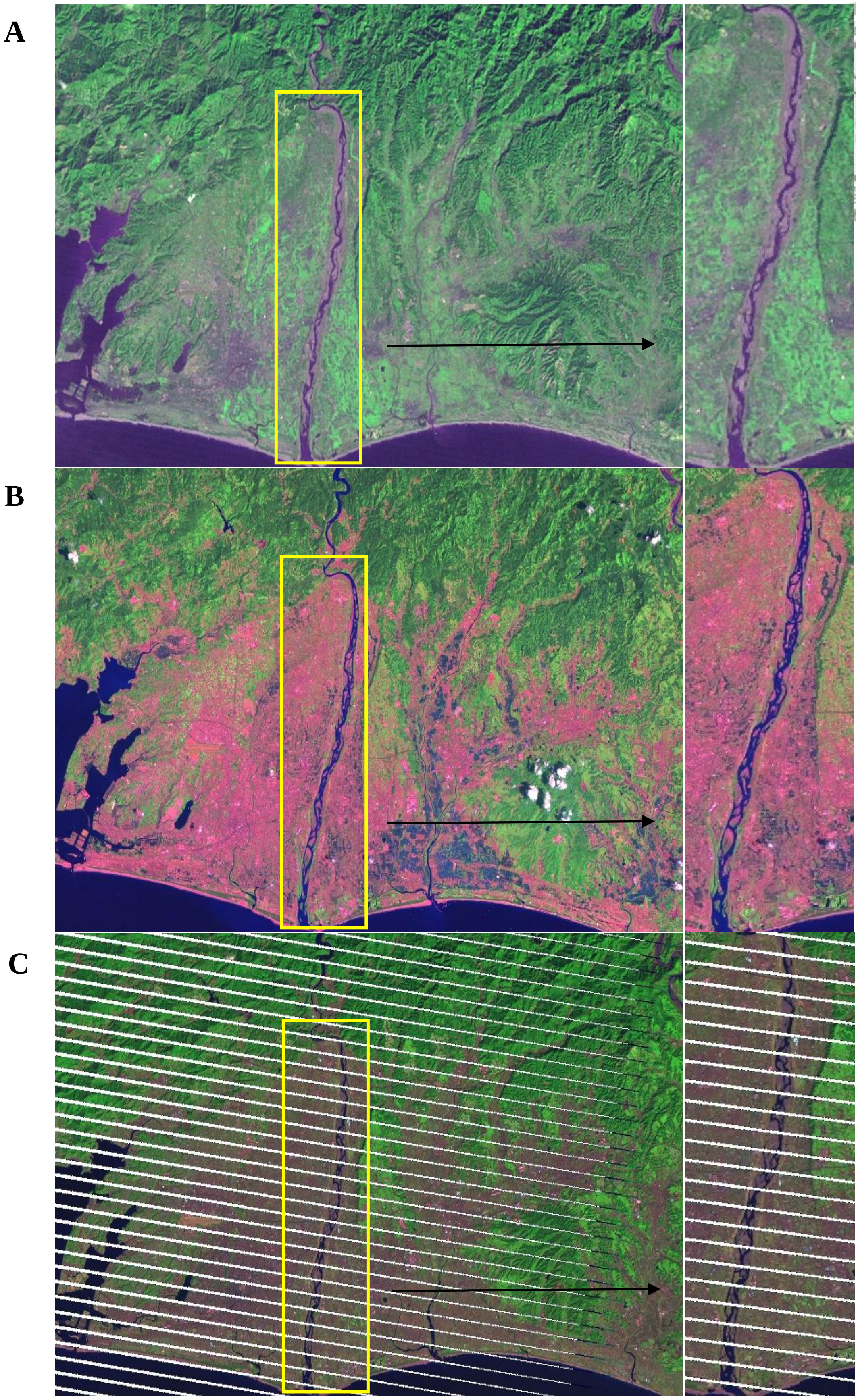


Fig.6 The Ten-lyu River (天龍川) of Japan 1970s(A) 1990s(B) 2010s(C)

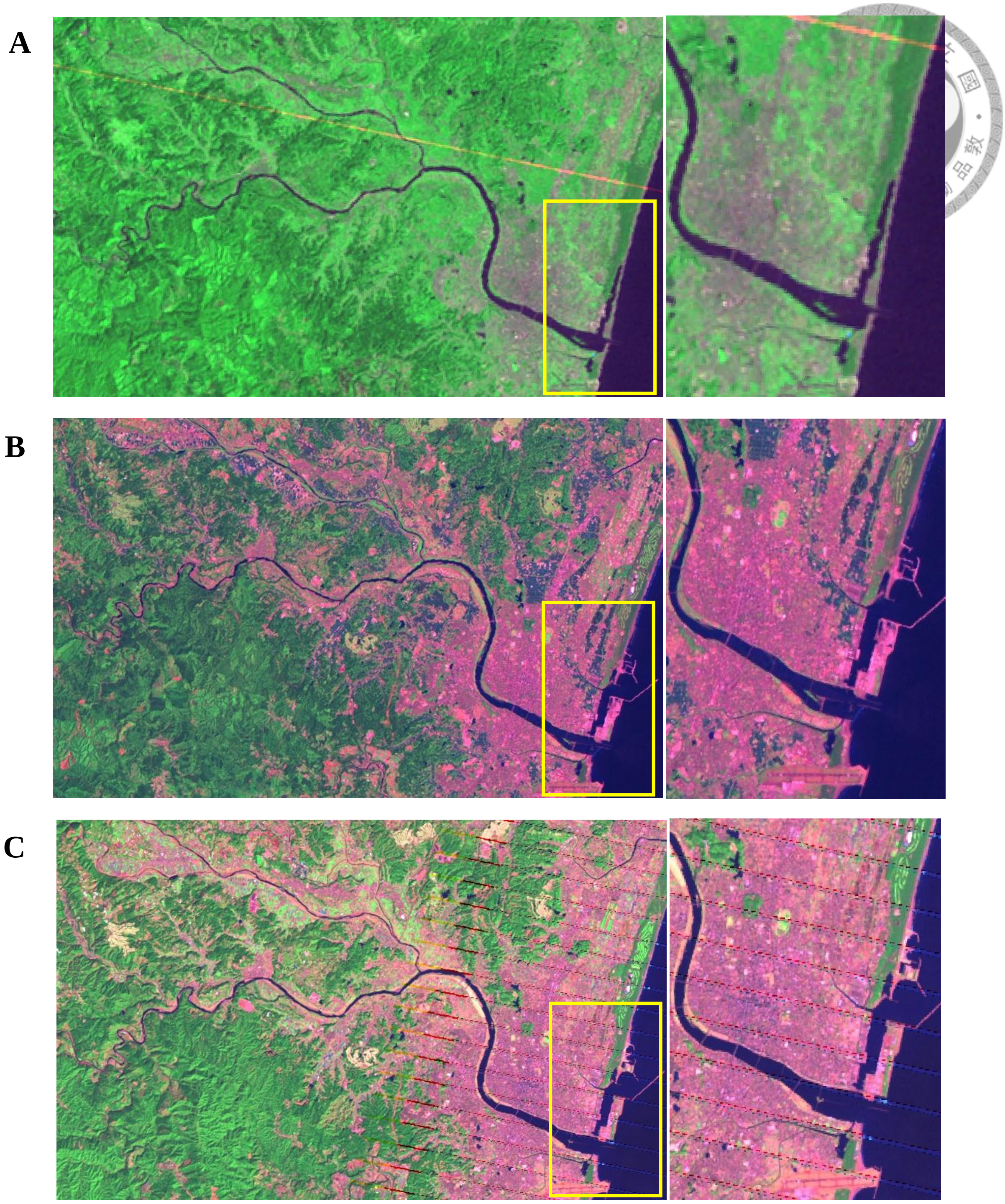


Fig.7 The Ohyodo River (大淀川) of Japan 1970s(A) 1990s(B) 2010s(C)

A

B

C

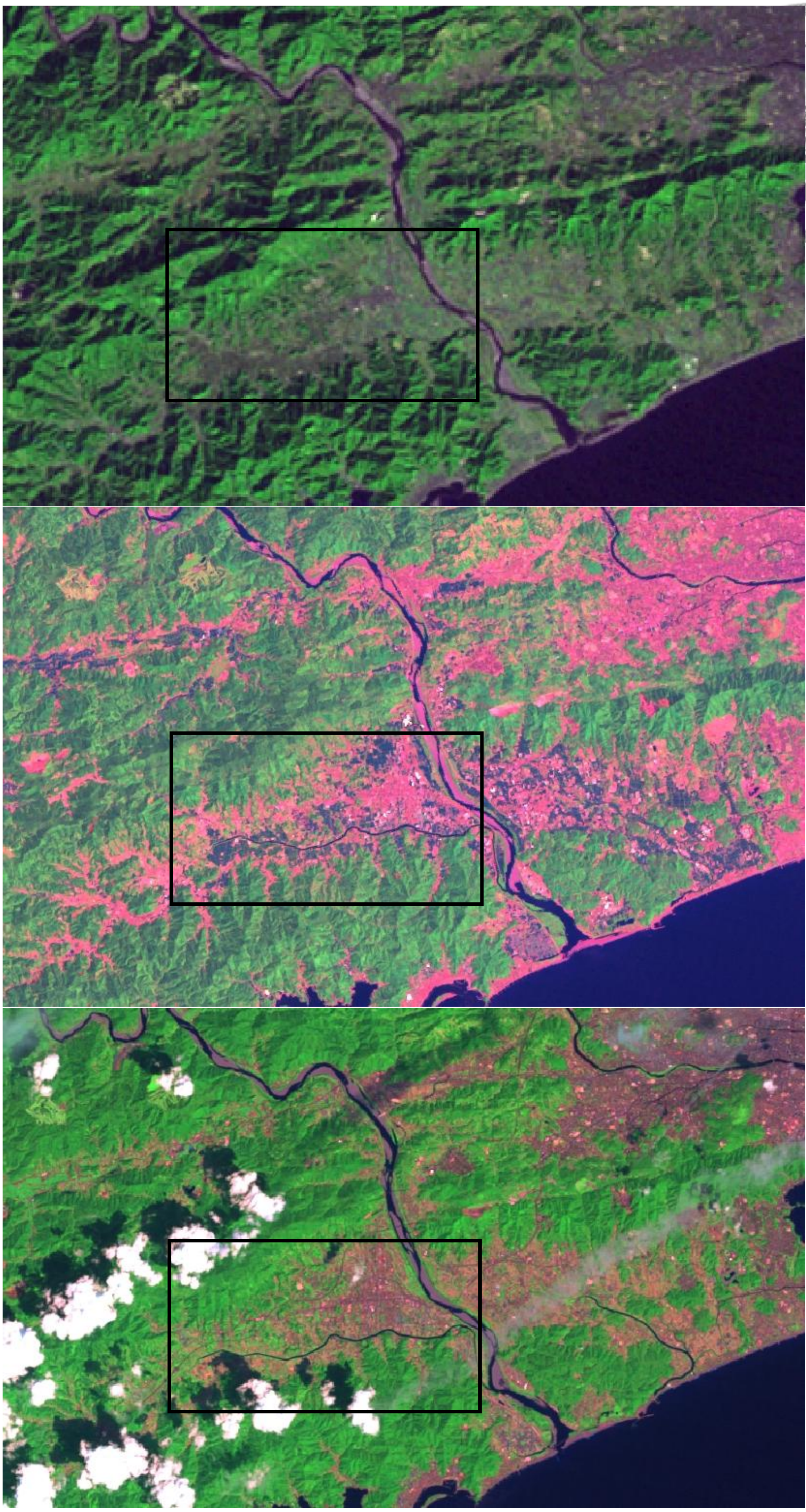


Fig.8 The Ni-yodo River (仁淀川) of Japan 1970s(A) 1990s(B) 2010s(C)

A

B

C

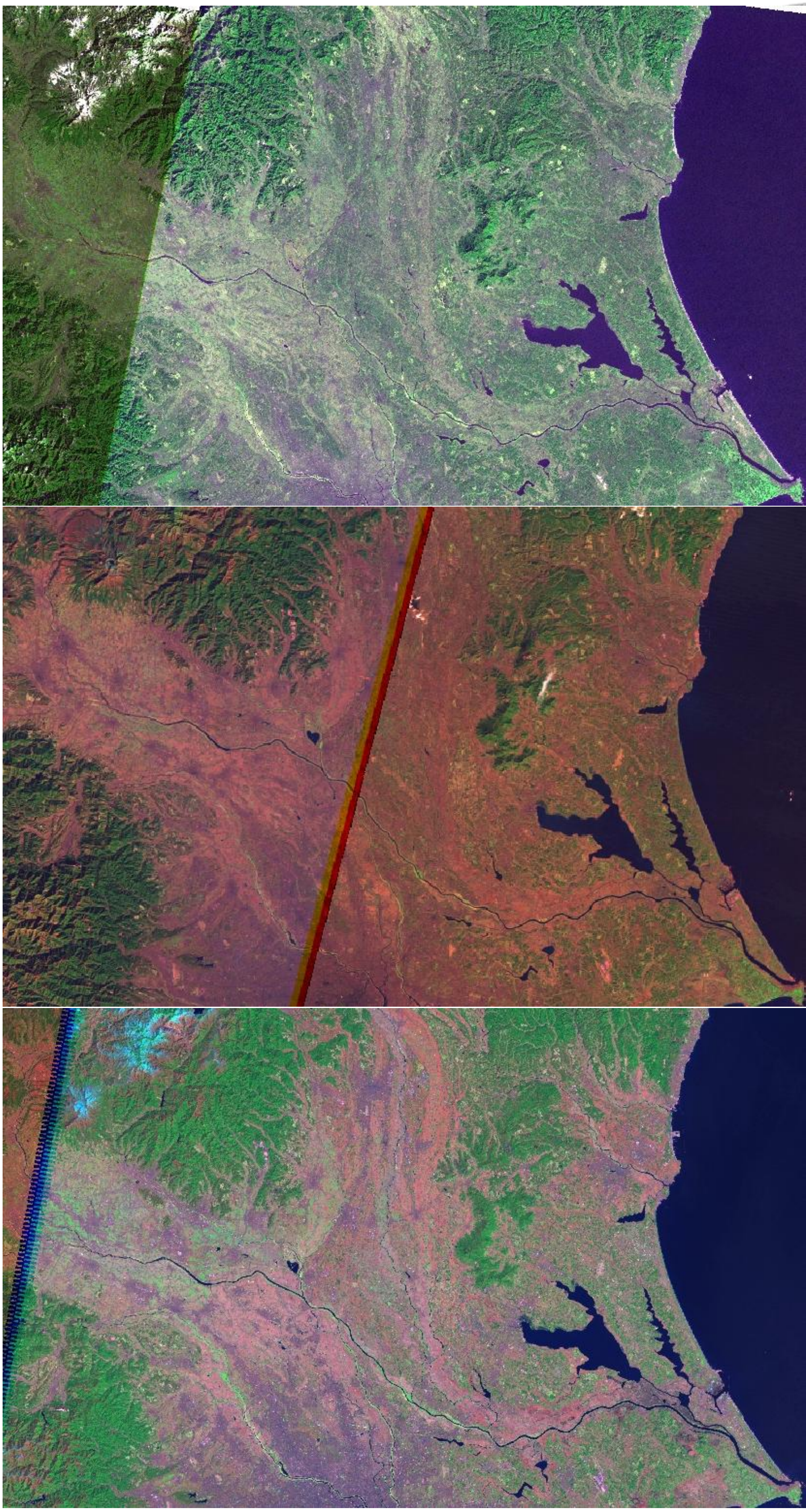


Fig.9 The To-ne River (利根川) of Japan 1970s(A) 1990s(B) 2010s(C)

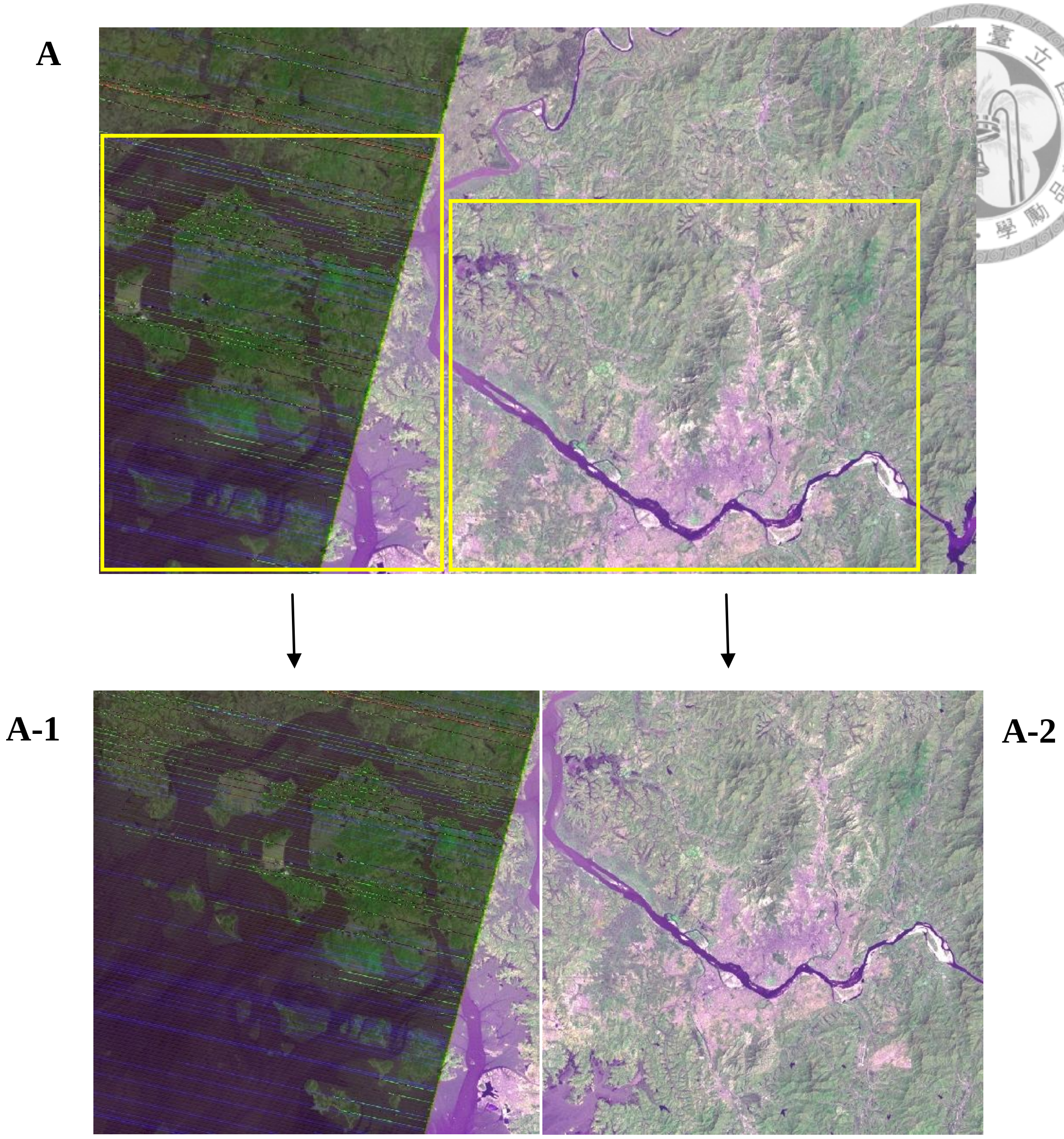


Fig.10 The Han River (漢江) of Korea 1970s(A)

B

B-1

B-2

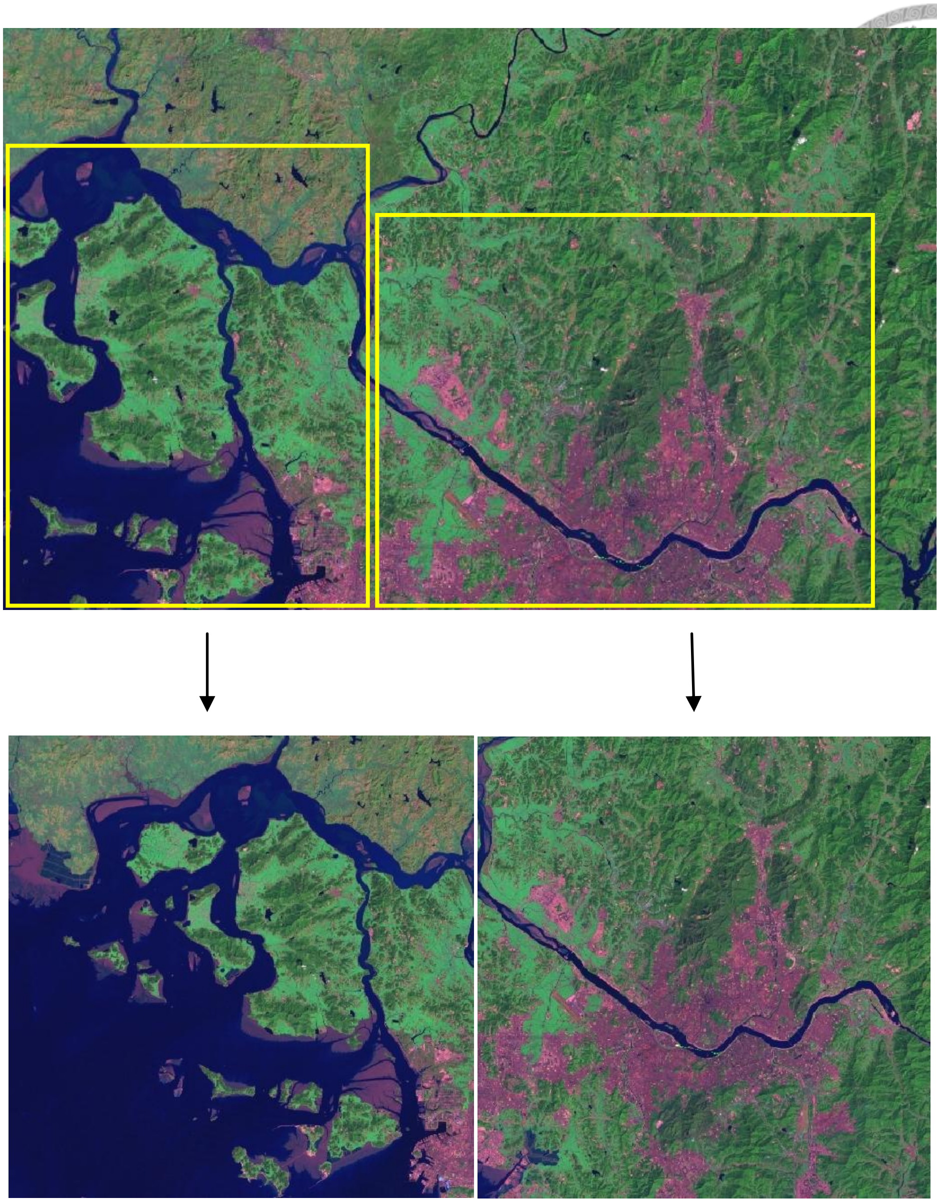


Fig.10 The Han River (漢江) of Korea 1990s(B)

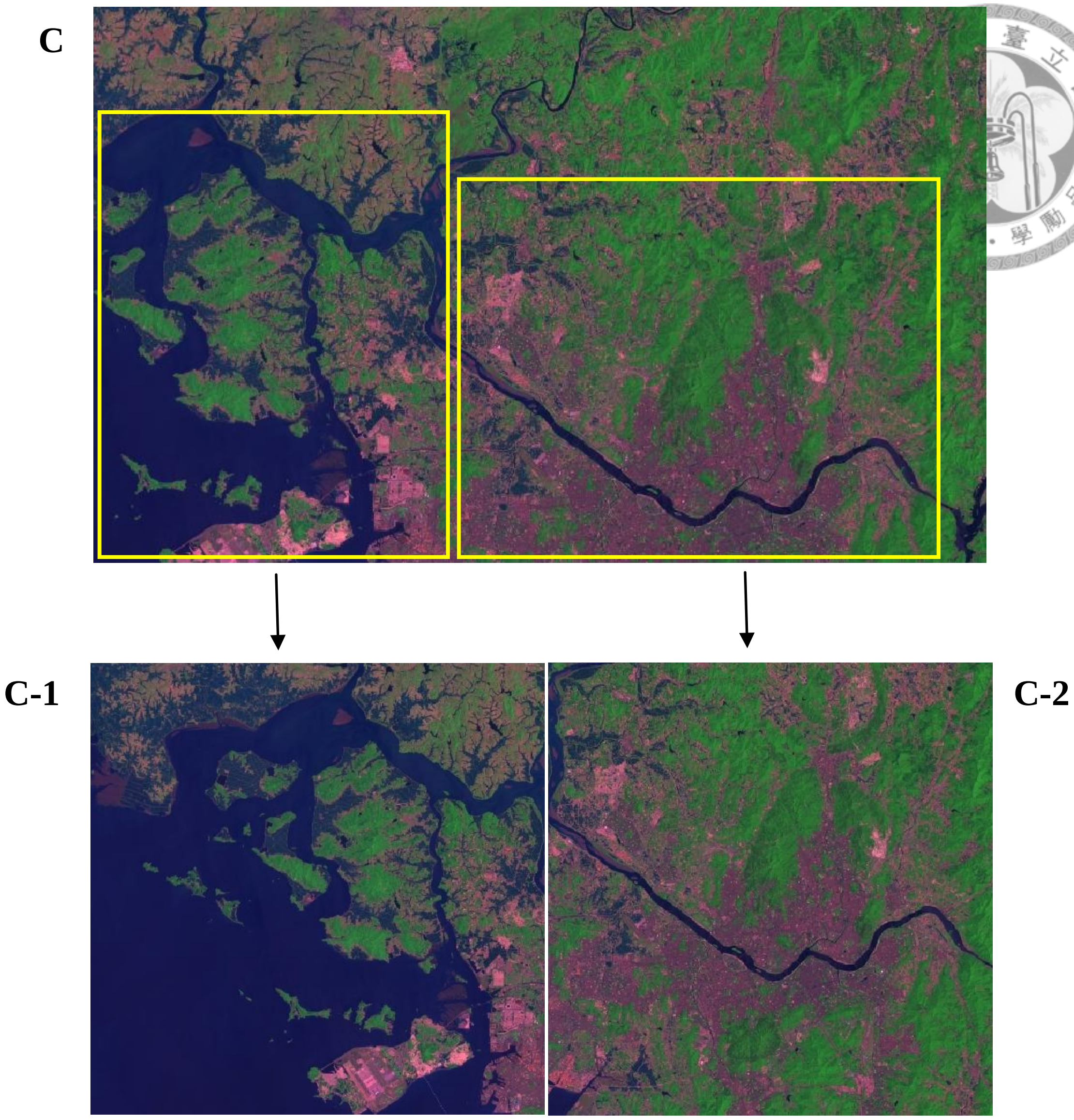


Fig.10 The Han River (漢江) of Korea 2010s(C)

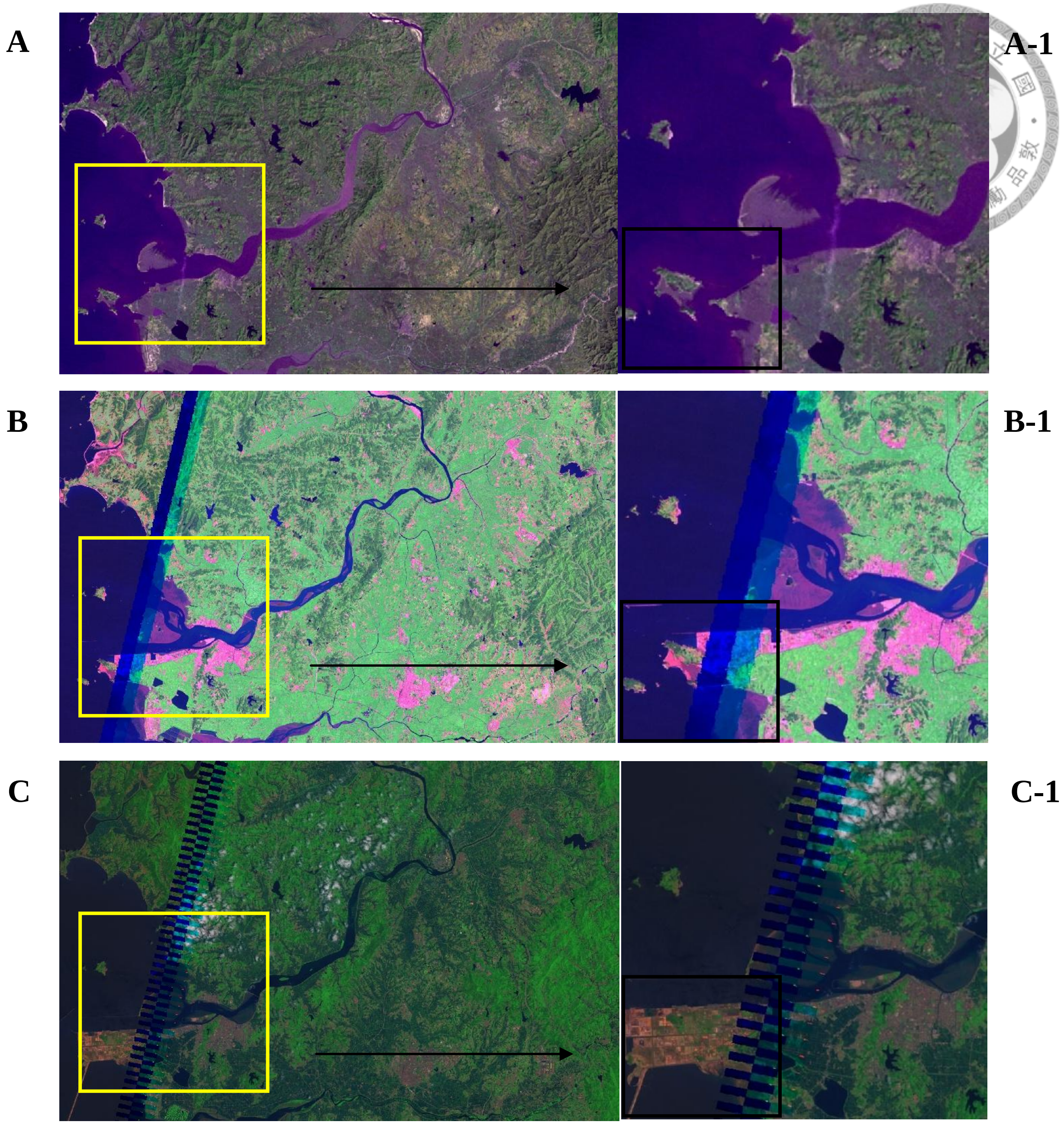


Fig.11 The Geum River (錦江) of Korea 1970s(A) 1990s(B) 2010s(C)

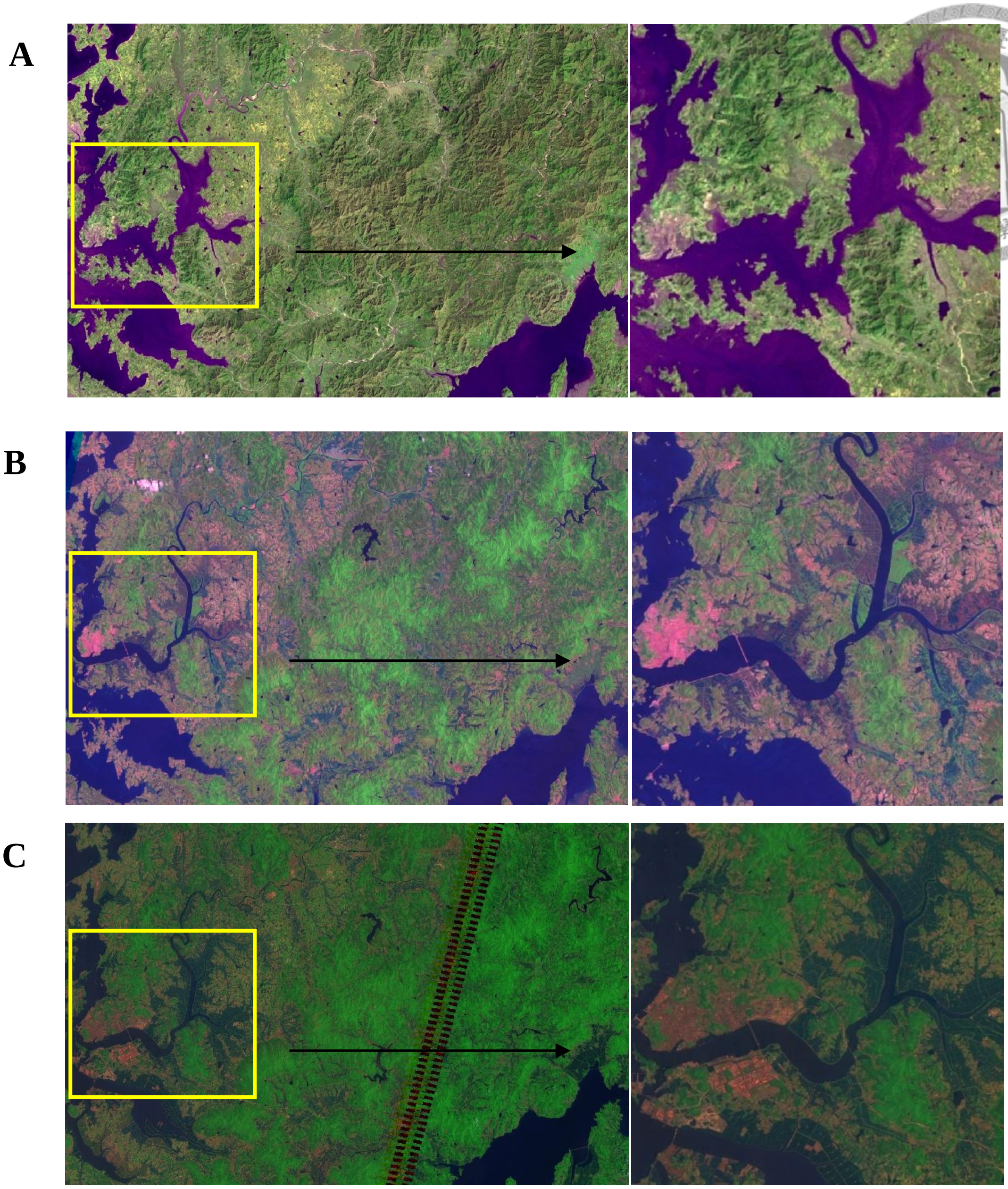


Fig.12 The Yeongsan River (榮山江) of Korea 1970s(A) 1990s(B) 2010s(C)

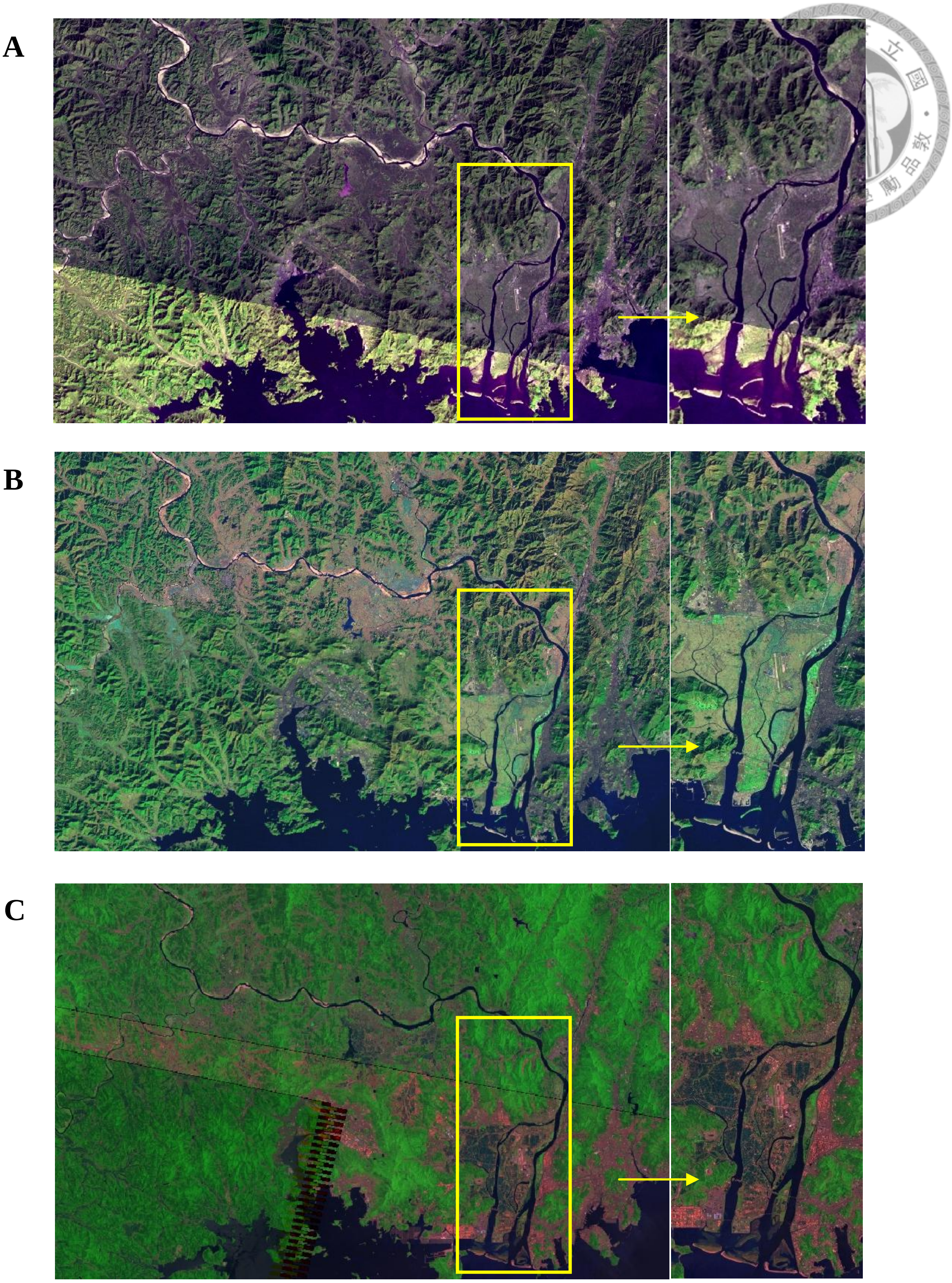


Fig.13 The Nakdong River (洛東江) of Korea 1970s(A) 1990s(B) 2010s(C)

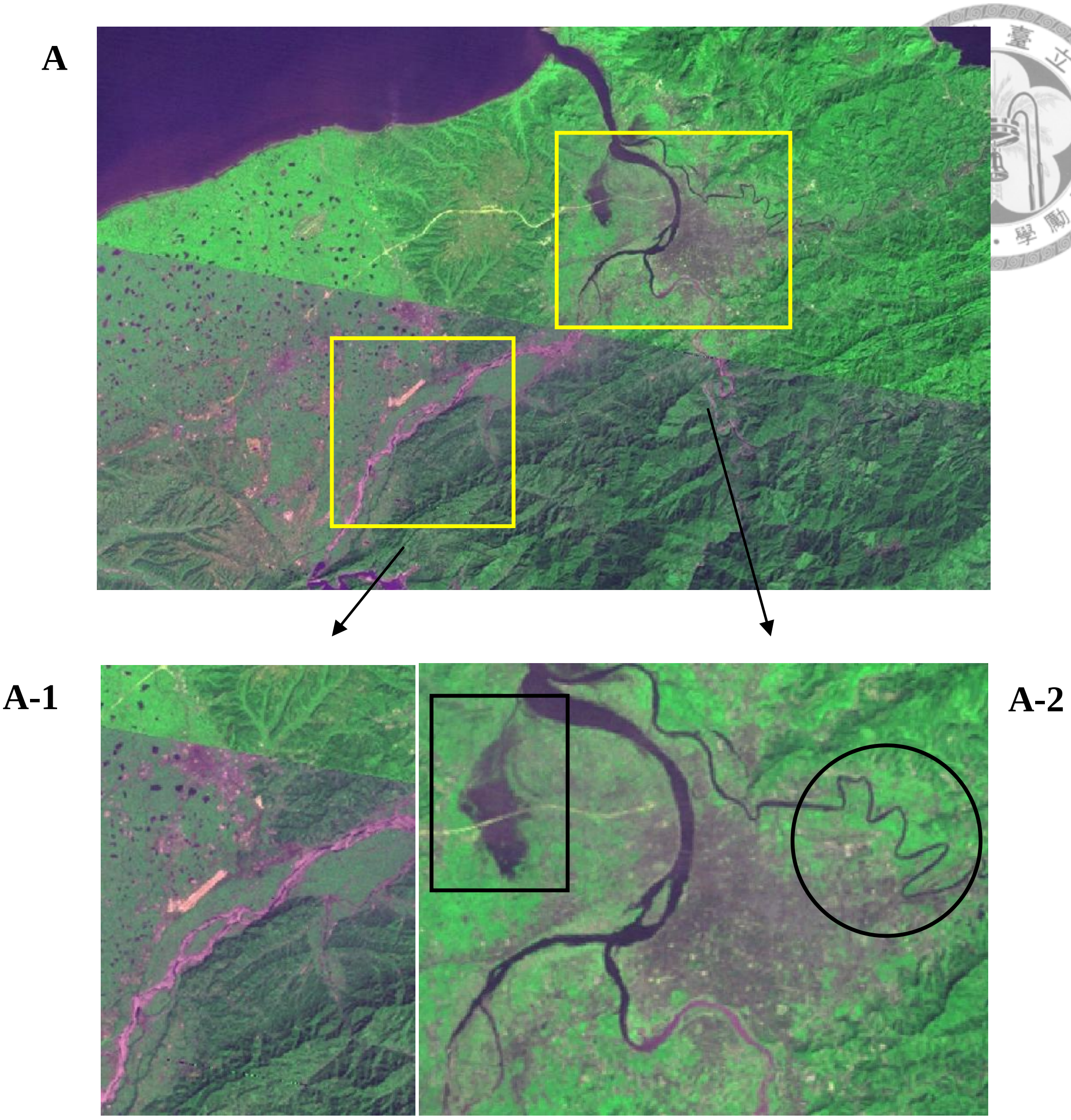


Fig.14 The Dansuie River (淡水河) of Taiwan 1970s(A)

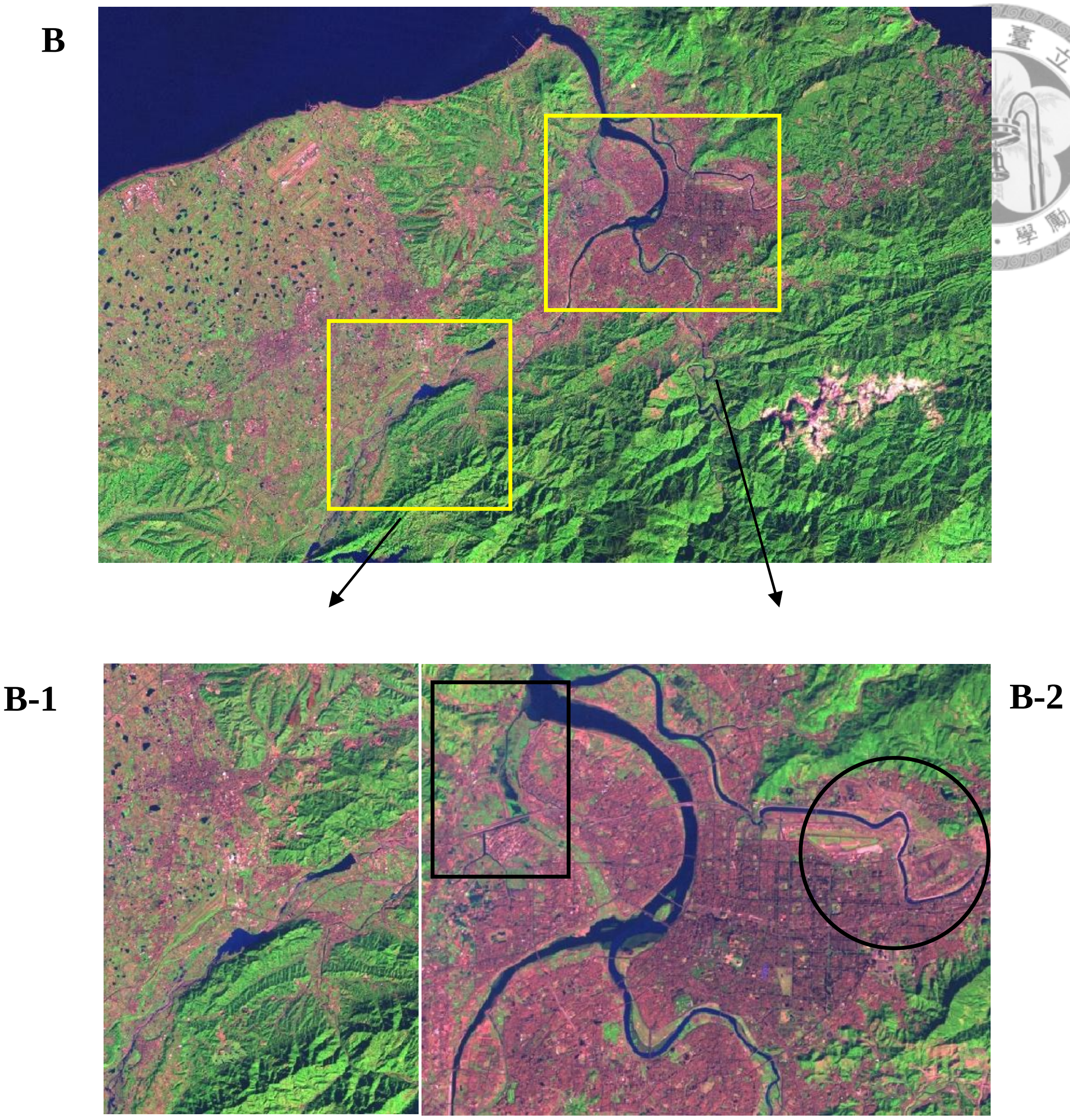


Fig.14 The Dansuie River (淡水河) of Taiwan 1990s(B)

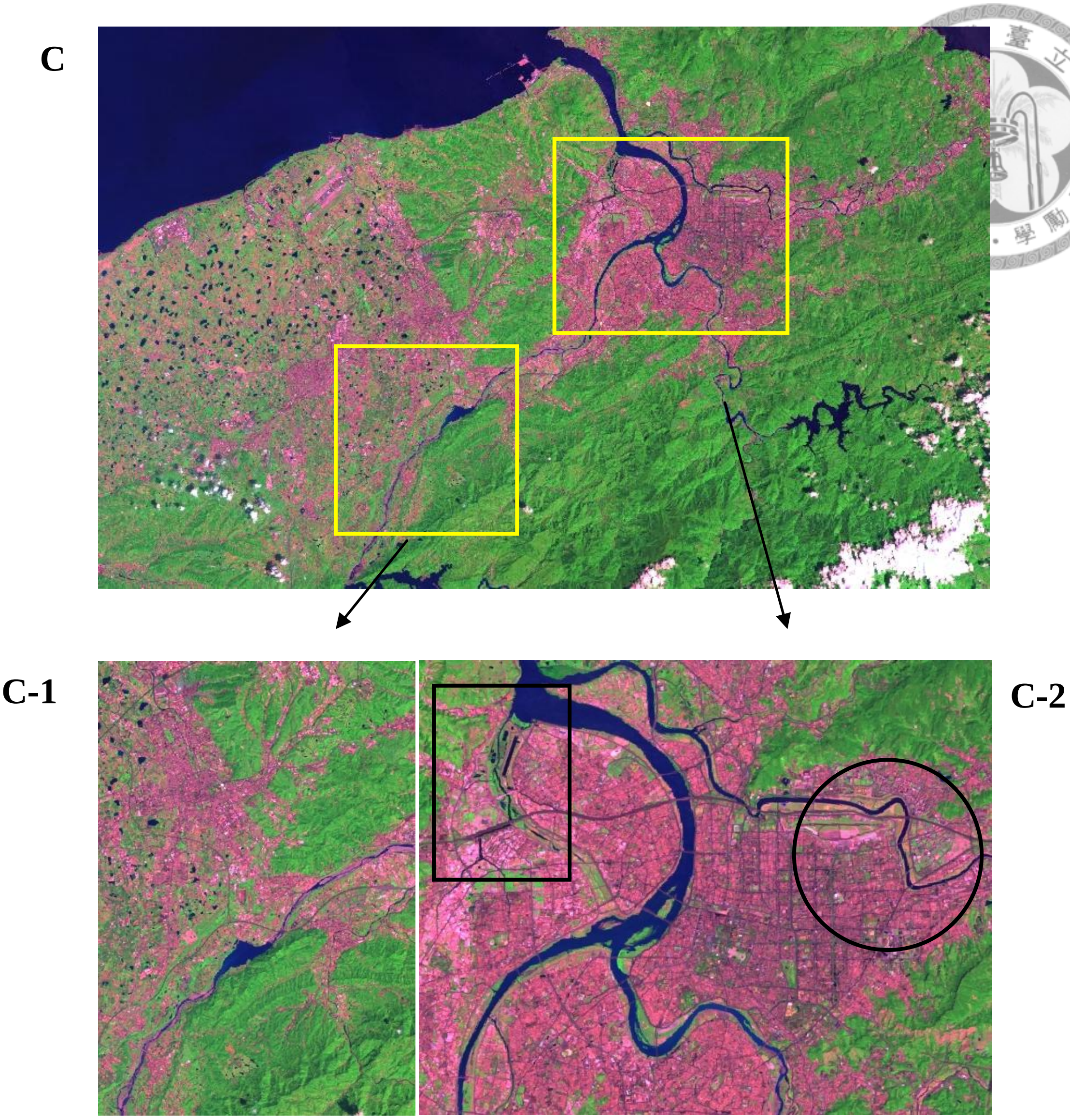


Fig.14 The Dansuie River (淡水河) of Taiwan 2010s(C)

A

A-1

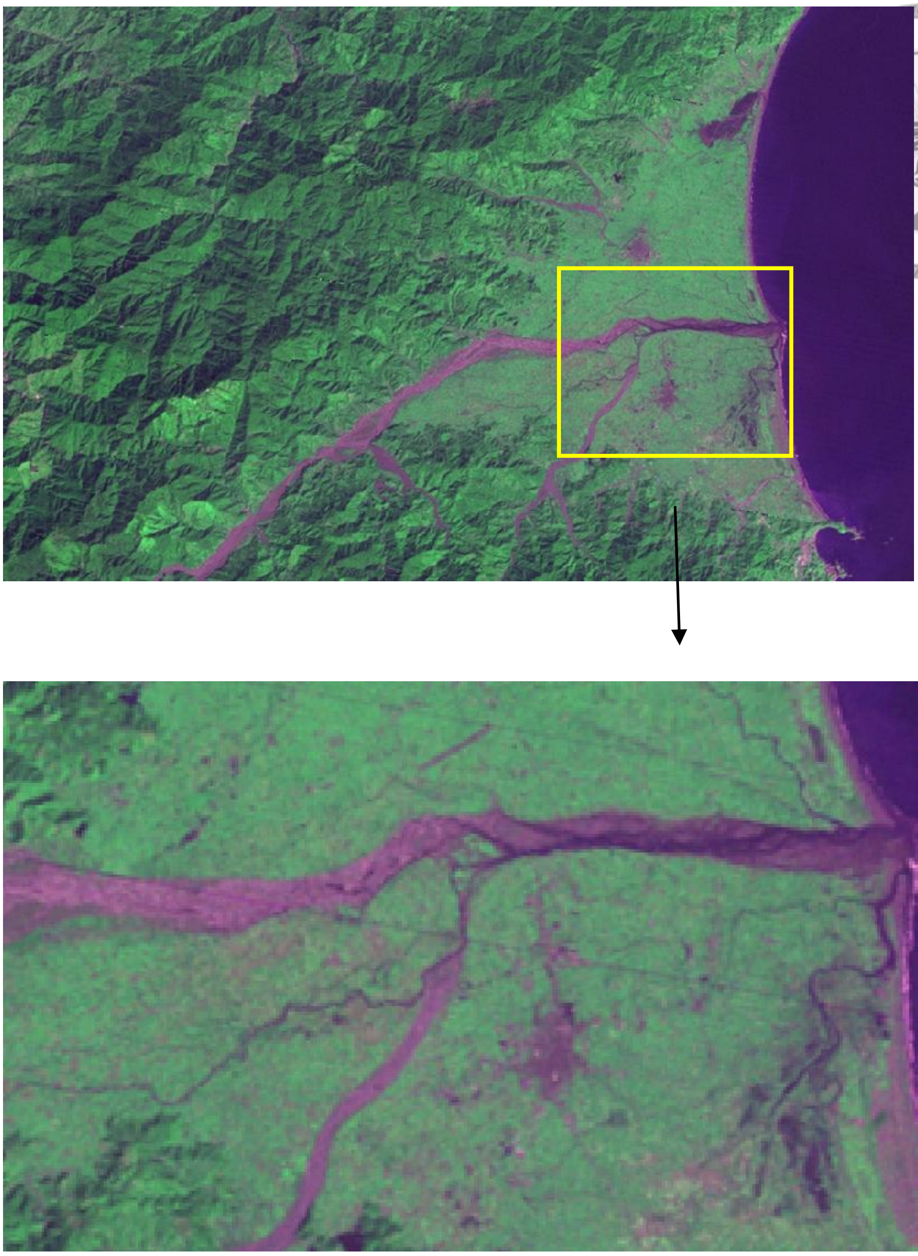


Fig.15 The Lanyang River (蘭陽溪) of Taiwan 1970s(A)

B

B-1

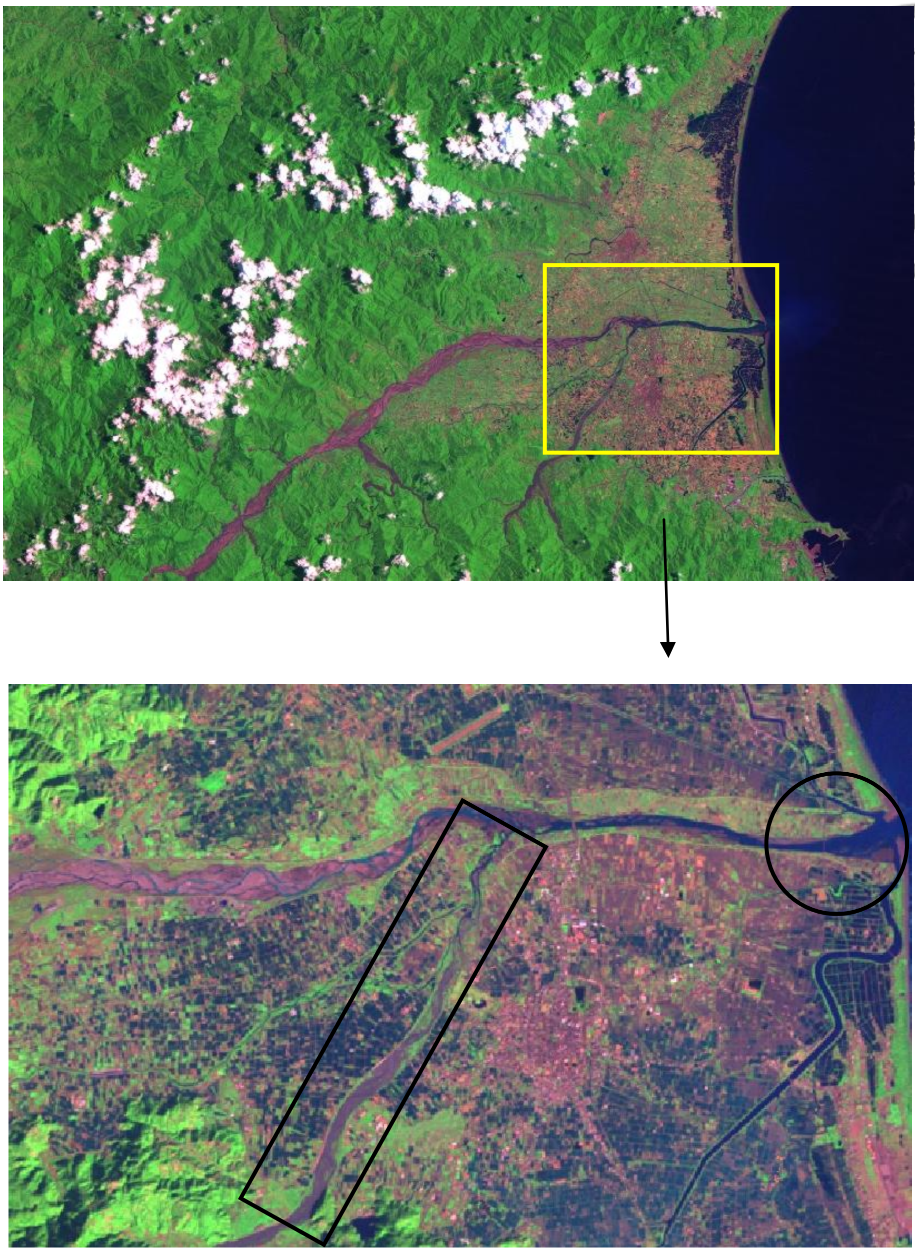


Fig.15 The Lanyang River (蘭陽溪) of Taiwan 1990s(B)

C

C-1

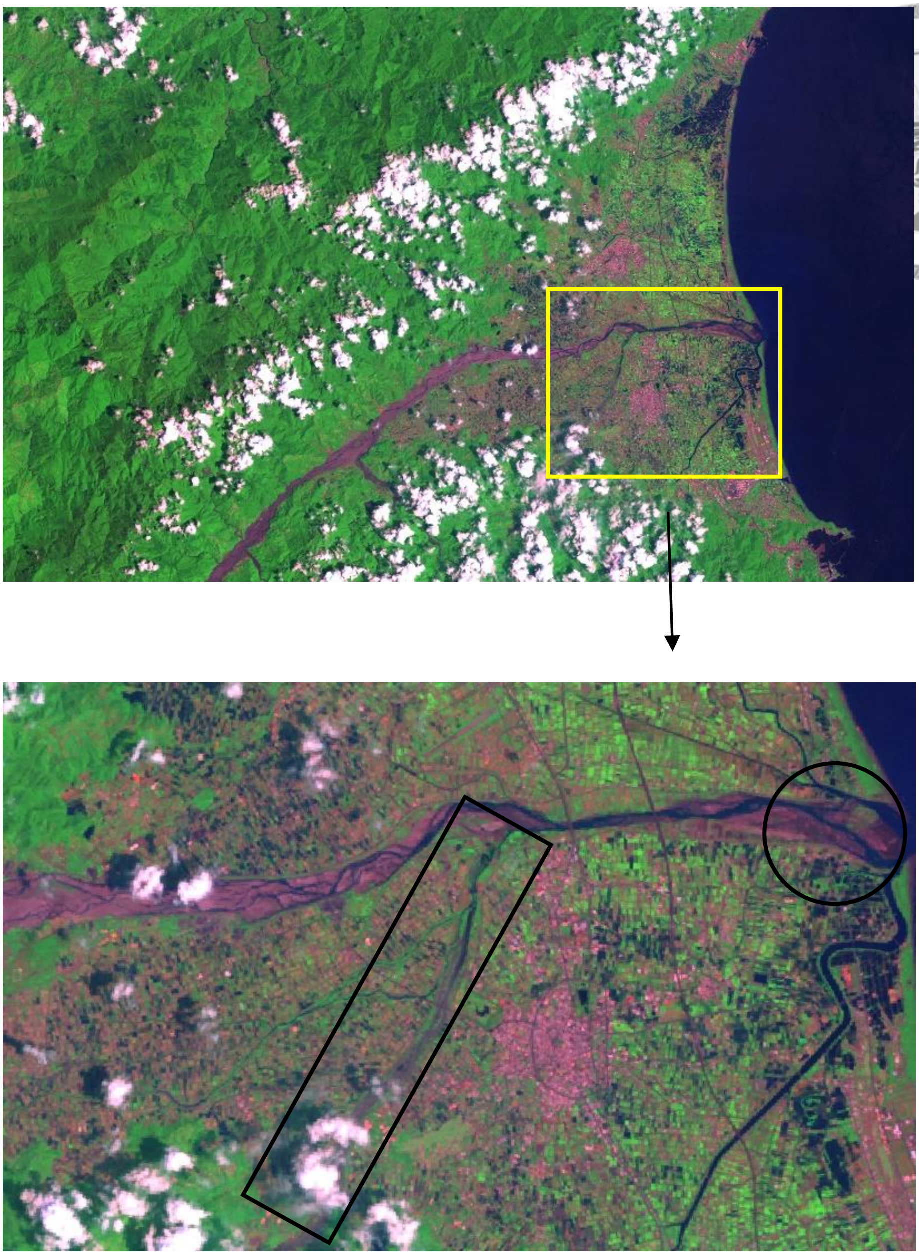


Fig.15 The Lanyang River (蘭陽溪) of Taiwan 2010s(C)

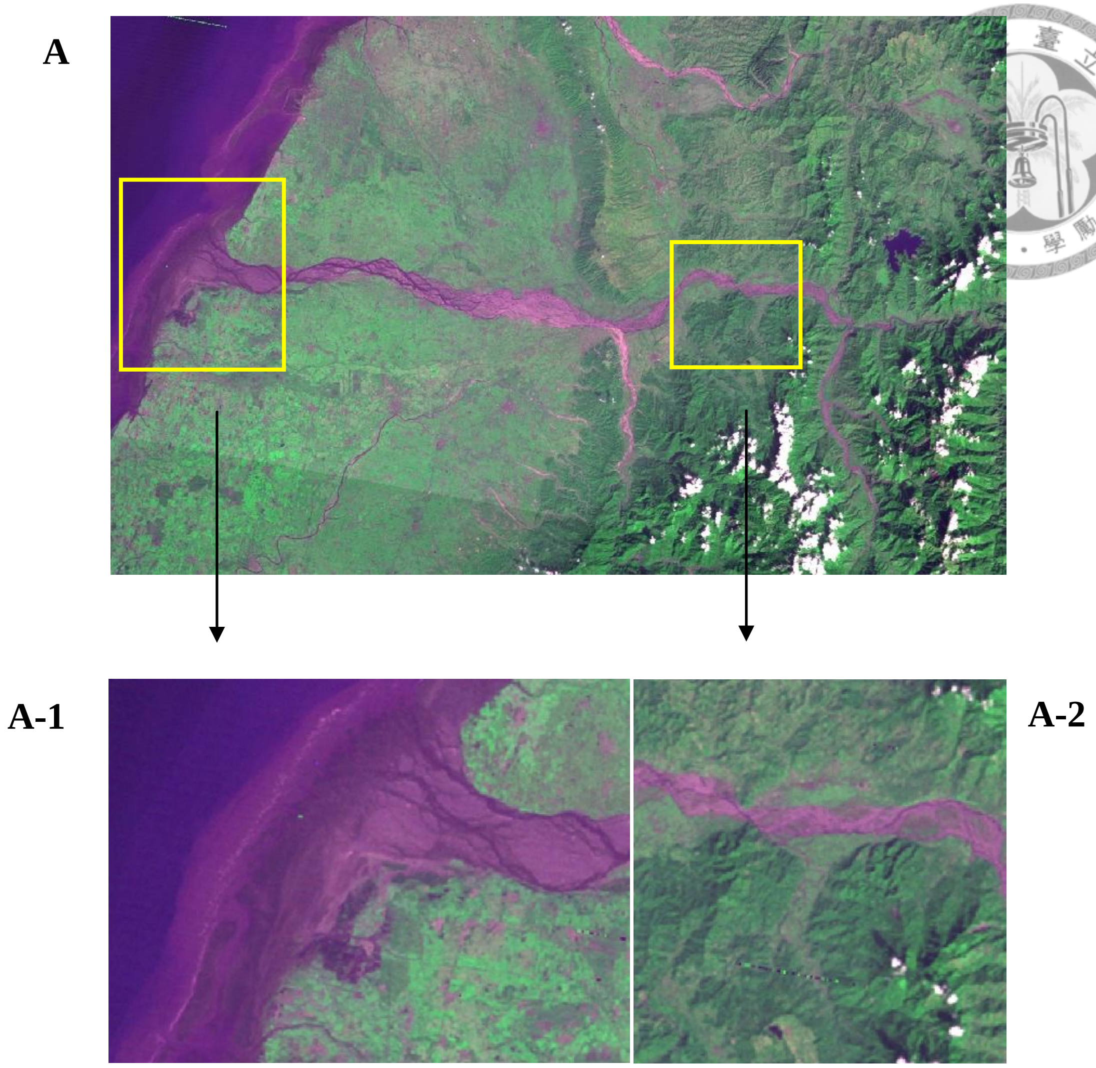


Fig.16 The Zhuoshuei River (濁水溪) of Taiwan 1970s(A)

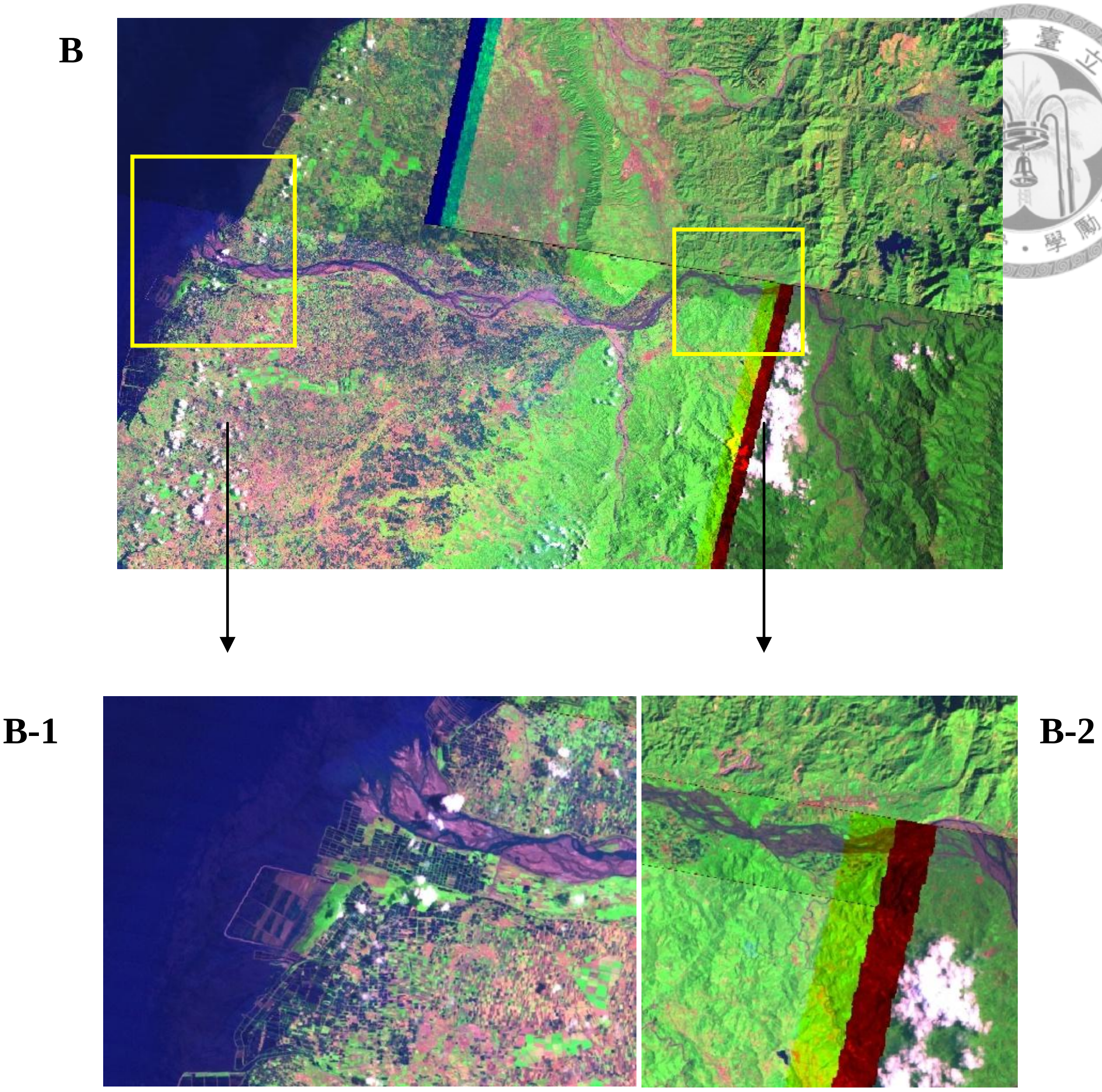


Fig.16 The Zhuoshuei River (濁水溪) of Taiwan 1990s(B)

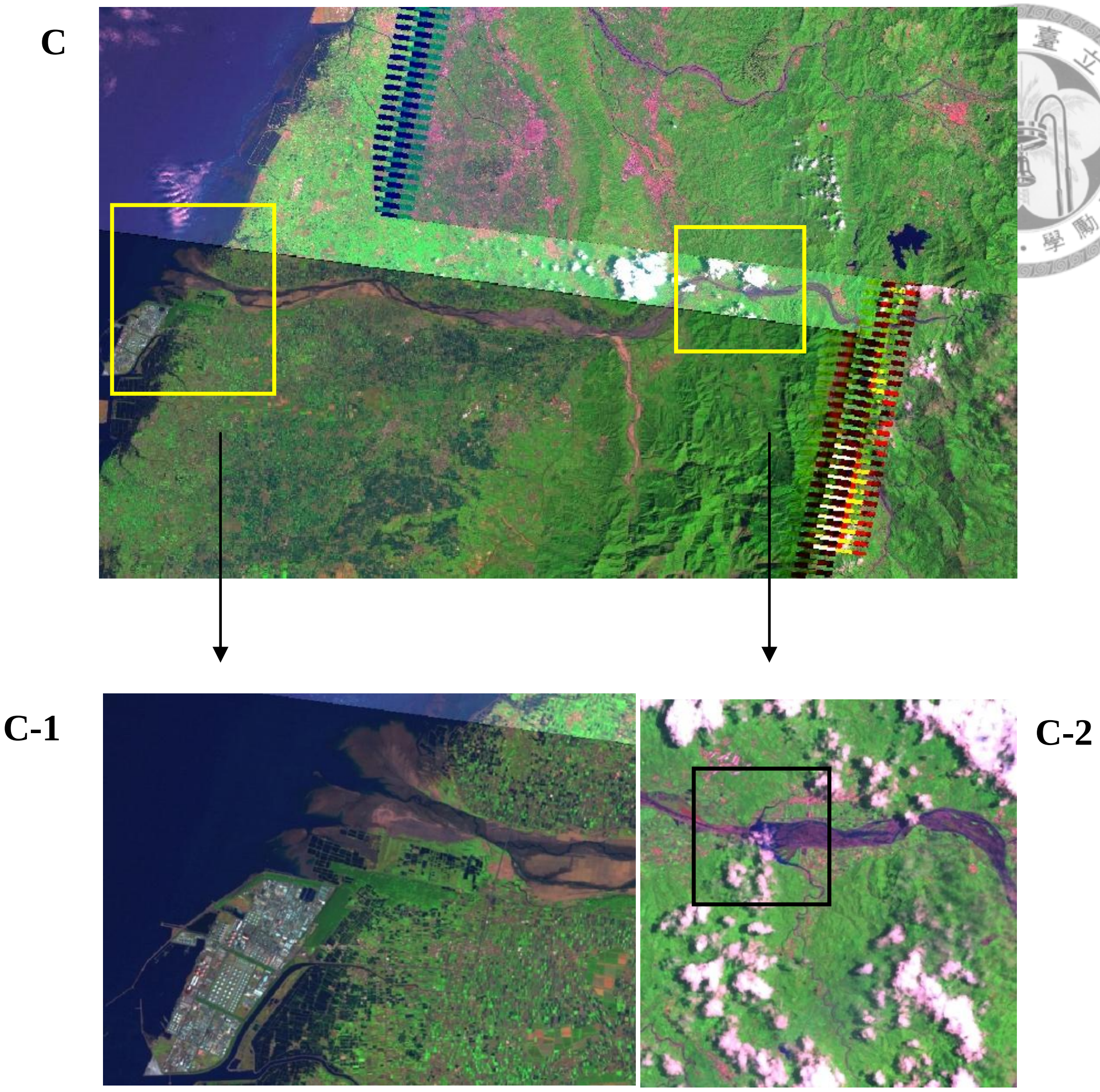


Fig.16 The Zhuoshuei River (濁水溪) of Taiwan 2010s(C)

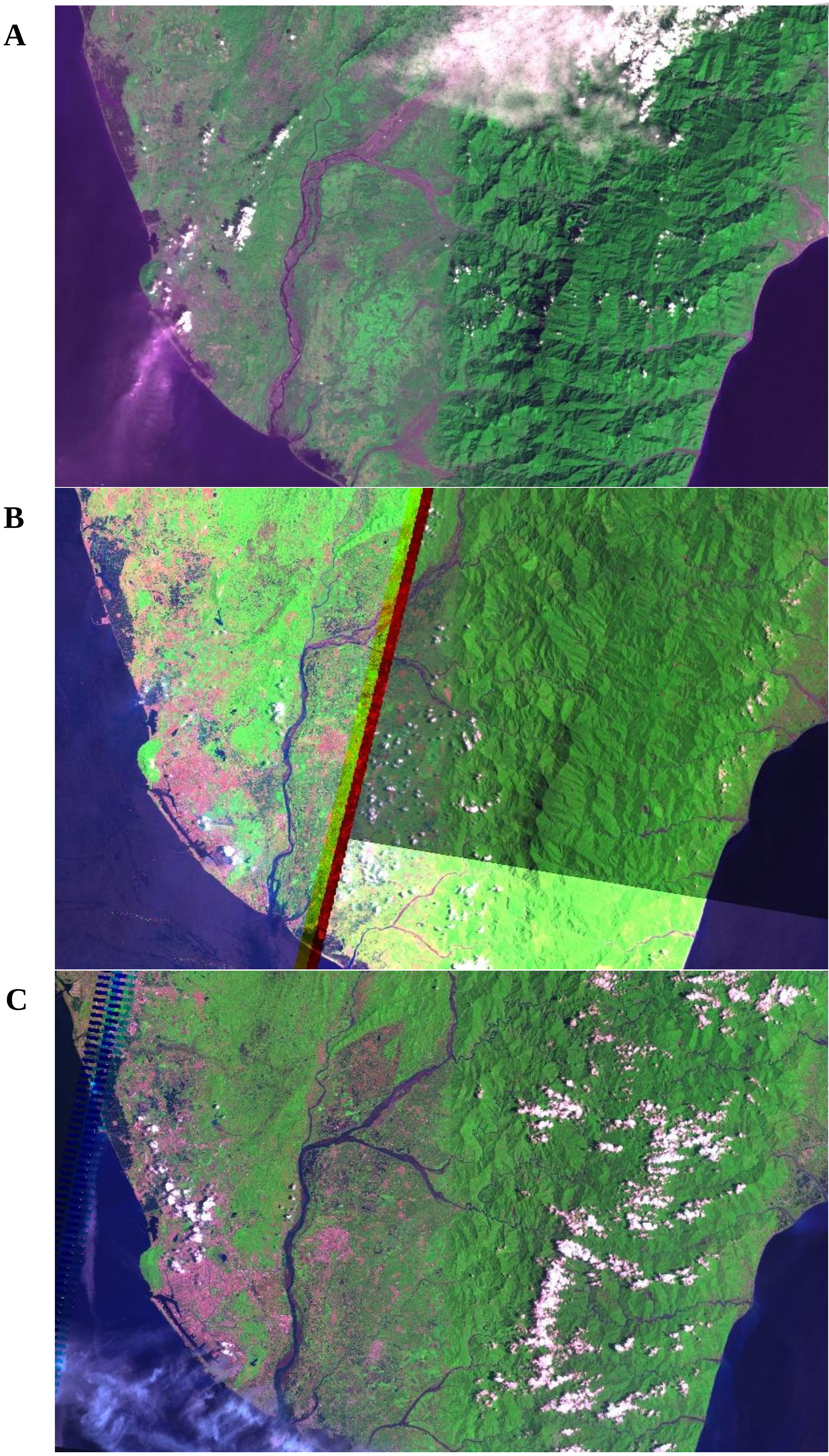
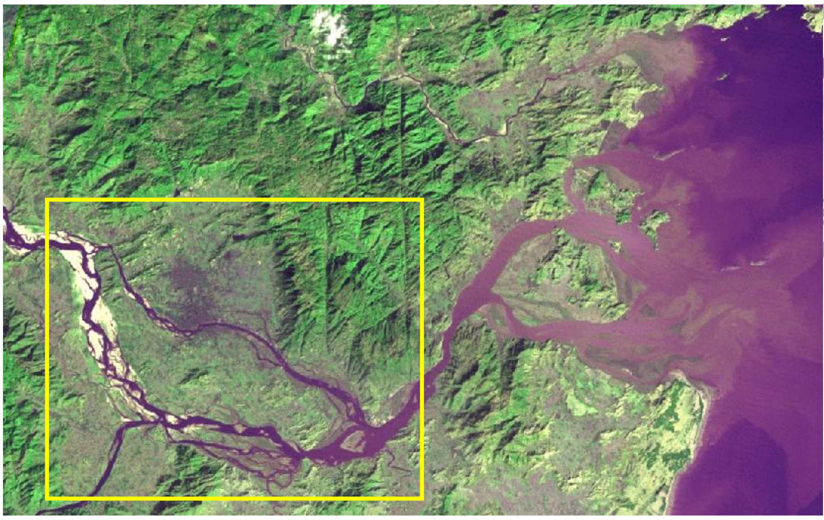


Fig.17The Kaoping River (高屏溪) of Taiwan 1970s(A) 1990s(B) 2010s(C)

A



A-1

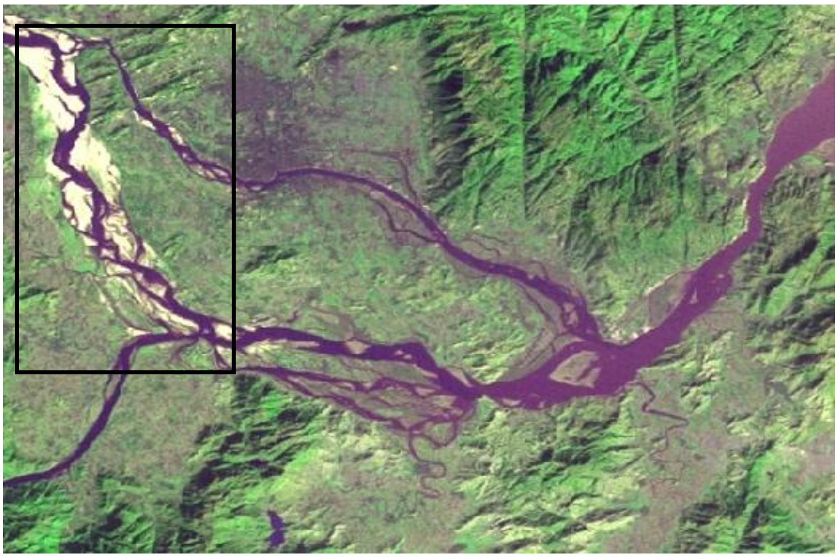


Fig.18 The Minjiang River (閩江) of China 1970s

B

B-1

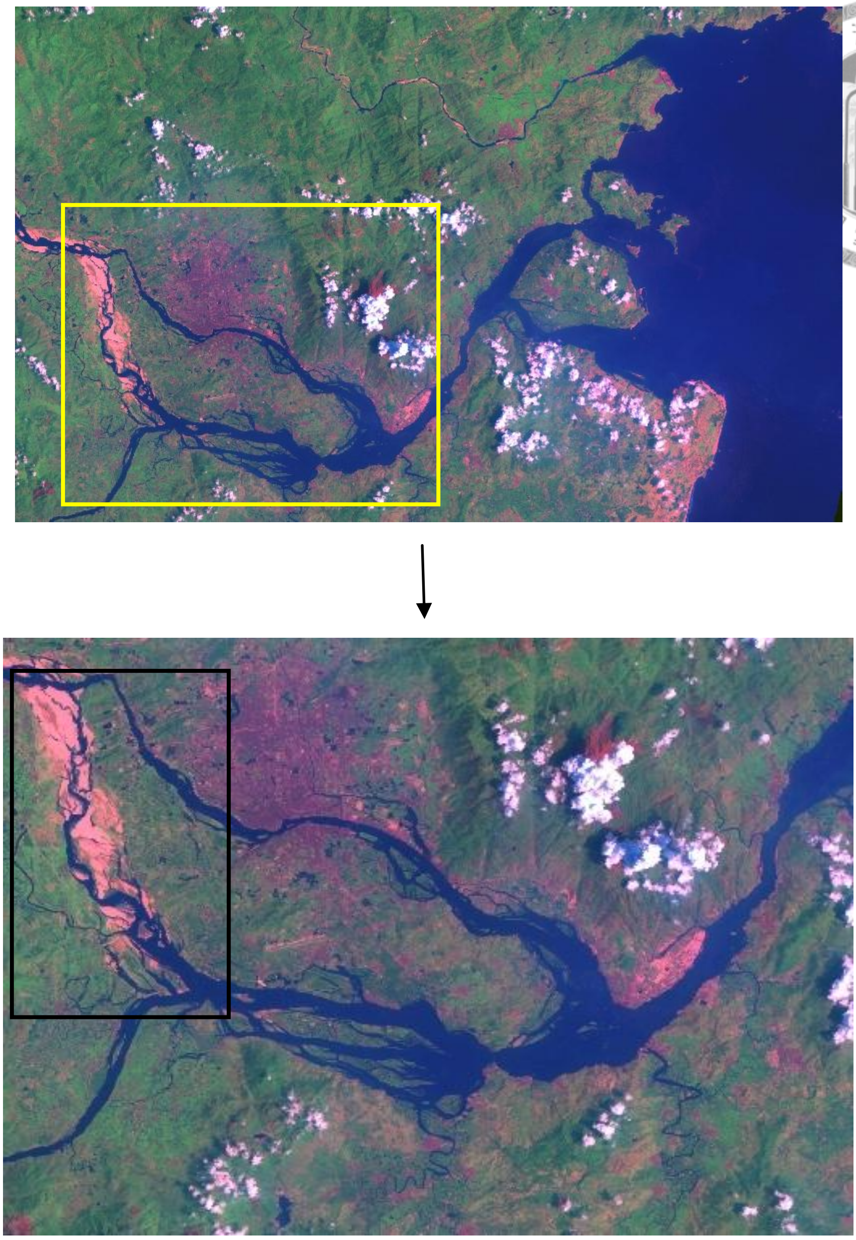
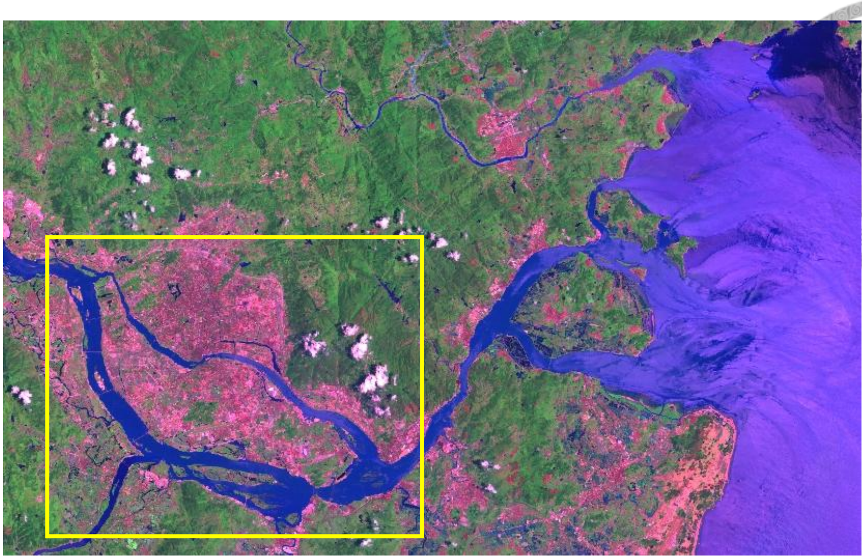


Fig.18 The Minjiang River (閩江) of China 1990s(B)

C



C-1

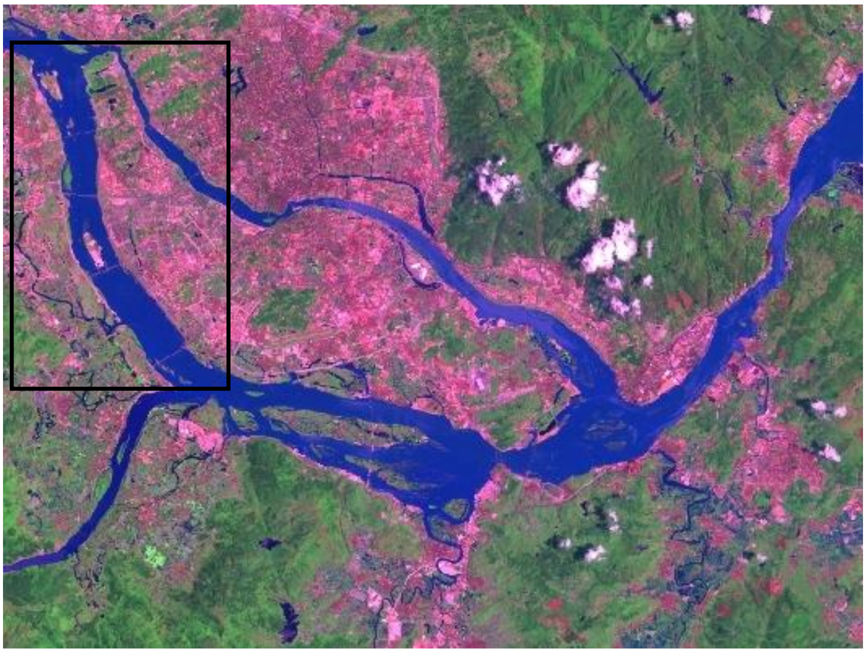


Fig.18 The Minjiang River (閩江) of China 2010s(C)

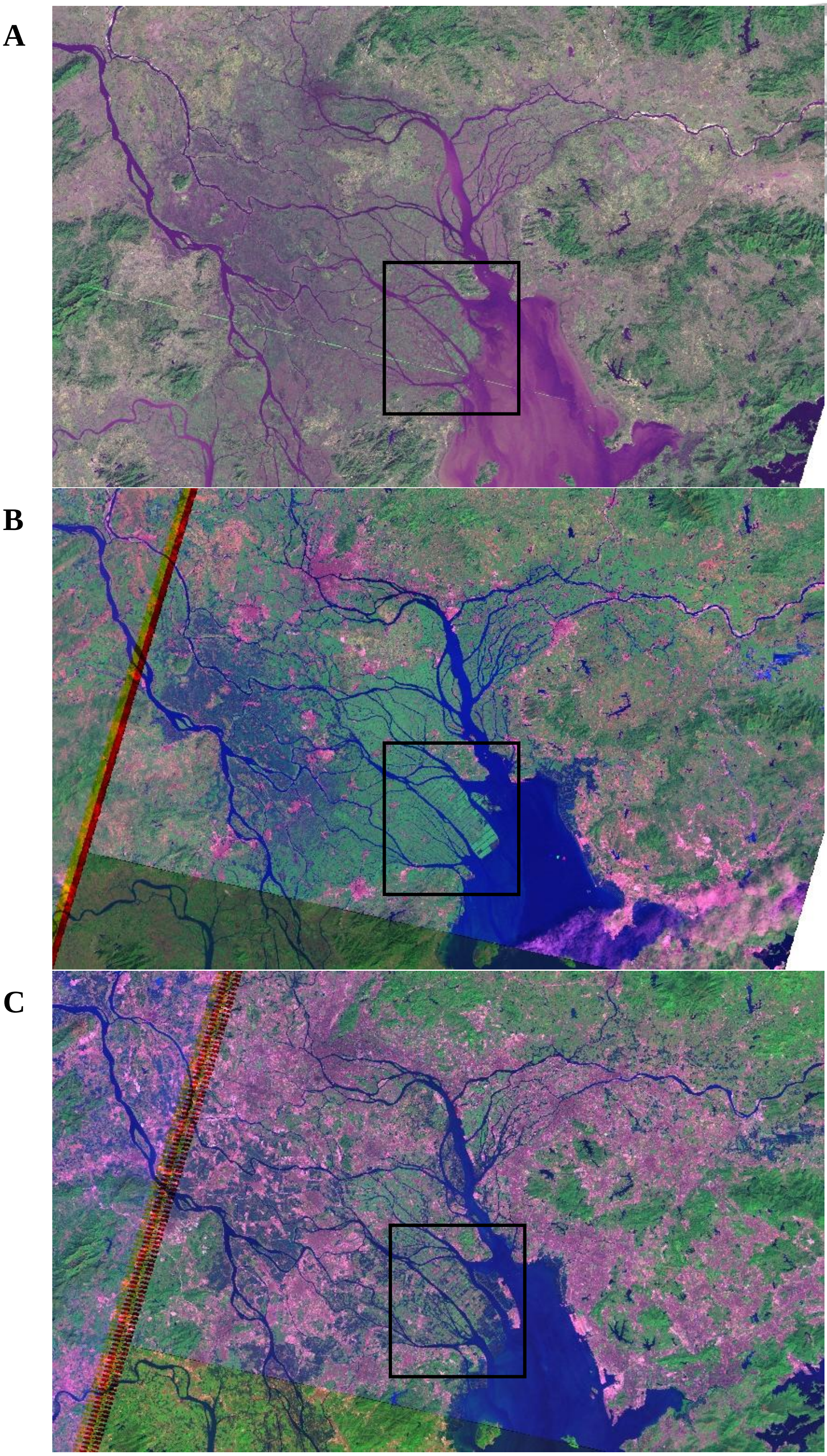


Fig.19 The Pearl River (珠江) of China 1970s(A) 1990s(B) 2010s(C)

A

B

C

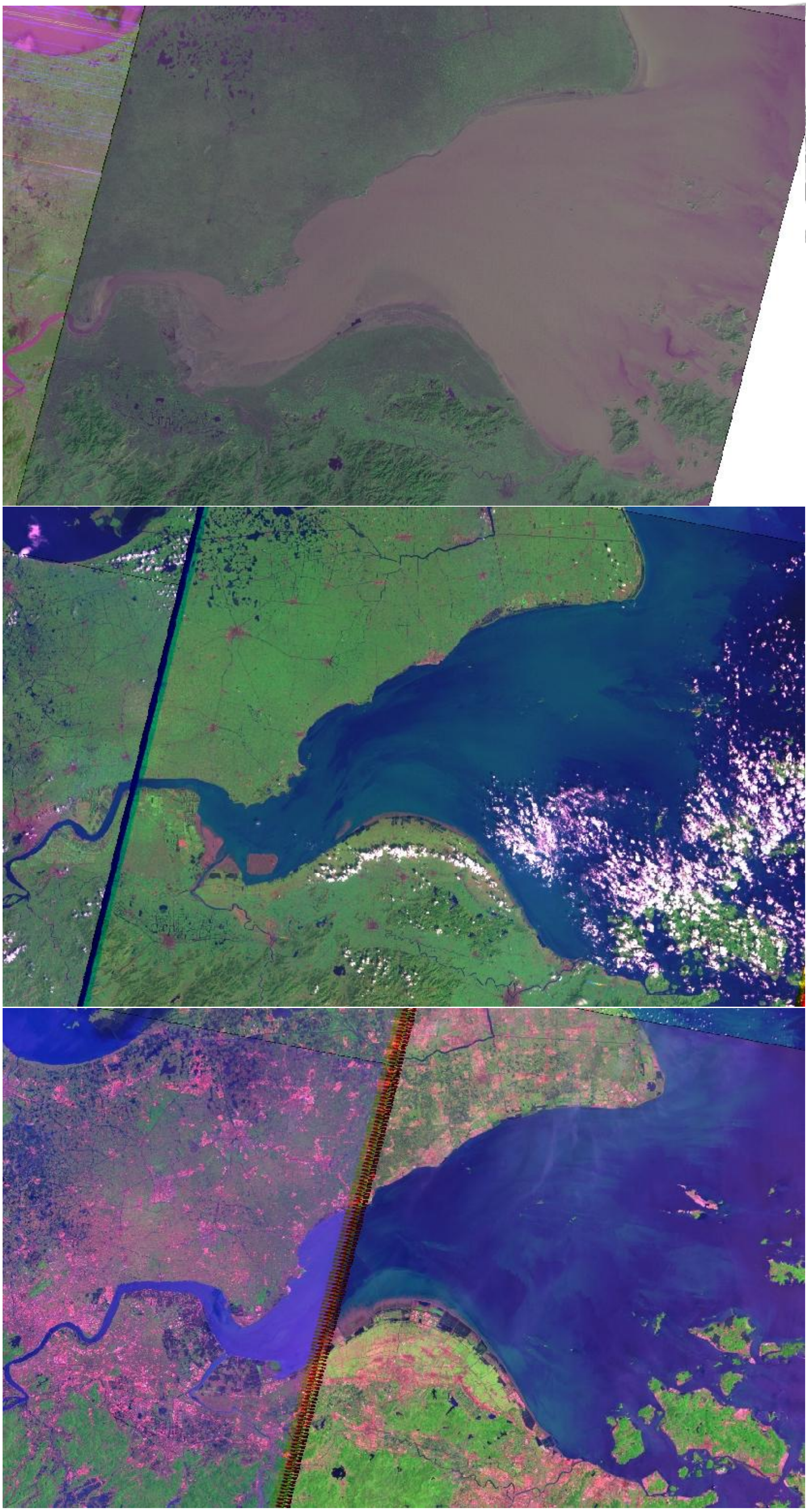


Fig.20 The Qiantang River (錢塘江) of China 1970s(A) 1990s(B) 2010s(C)

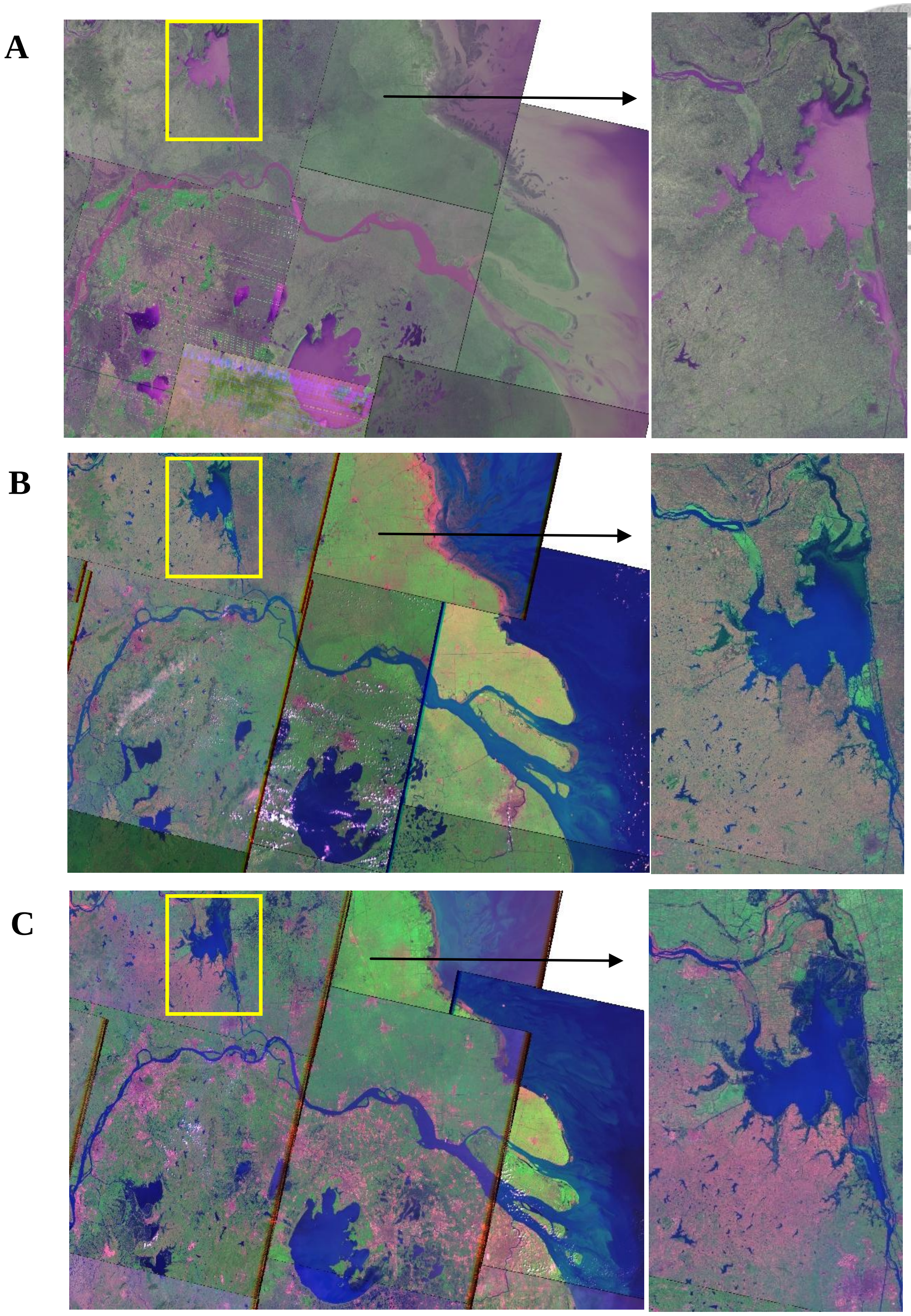
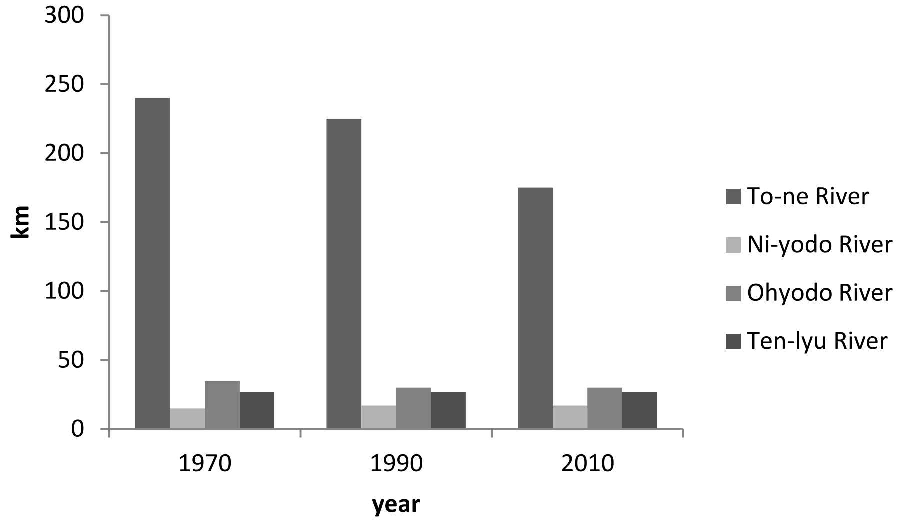


Fig.21 The Yangtze River (長江) of China 1970s(A) 1990s(B) 2010s(C)

A



B

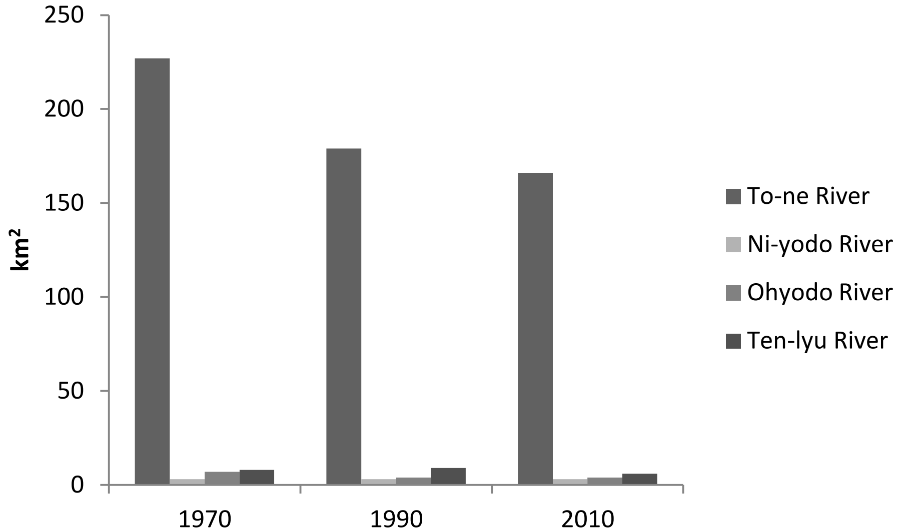
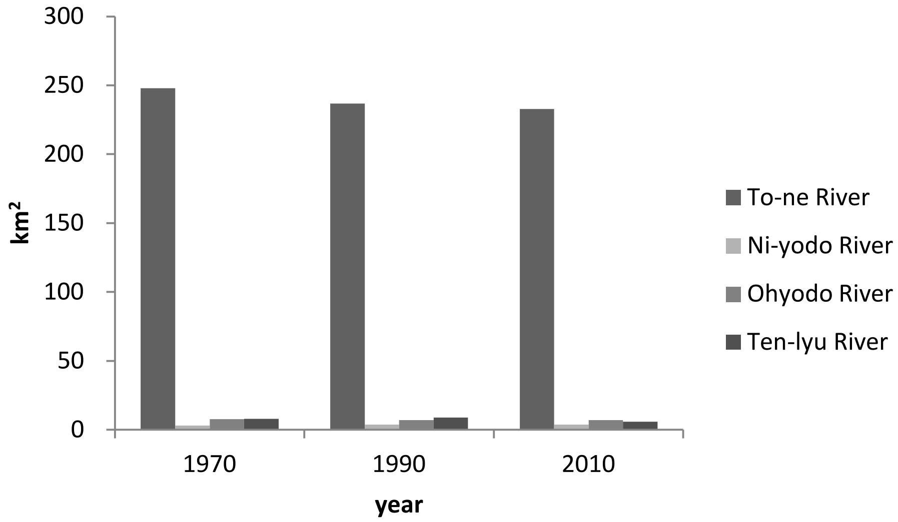


Fig.22 The bar chart of four Japanese rivers nature length (A), and area (B) in 1970, 1990 and 2010

C



D

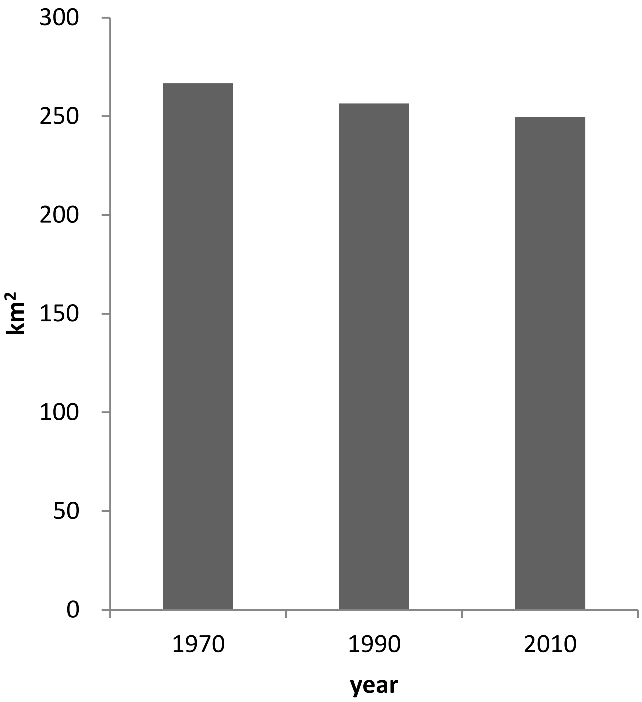
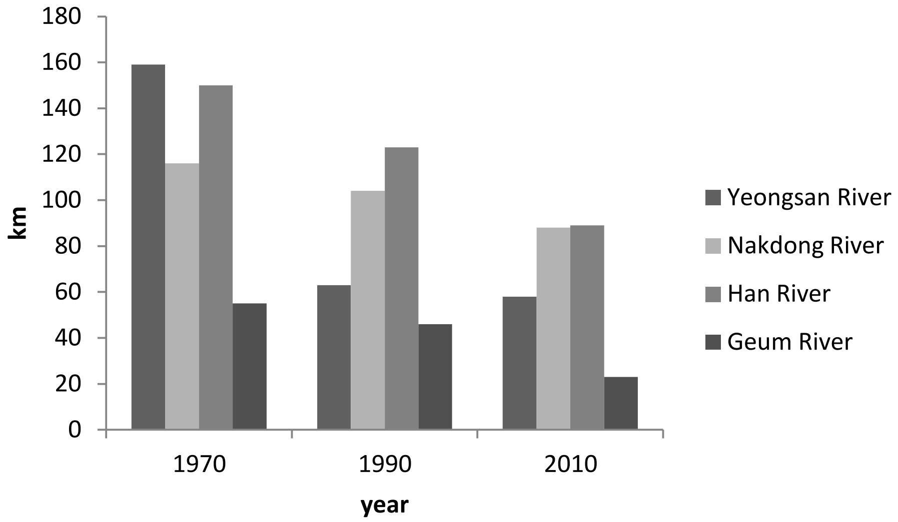


Fig.22 The bar chart of four Japanese rivers HQI (C) in 1970, 1990 and 2010; four Japanese rivers total HQI value in 1970, 1990 and 2010 (D)

A



B

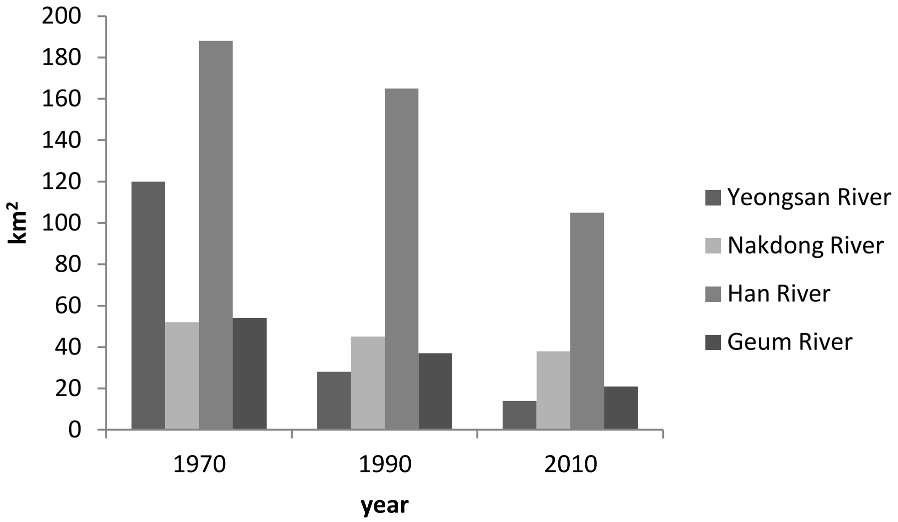
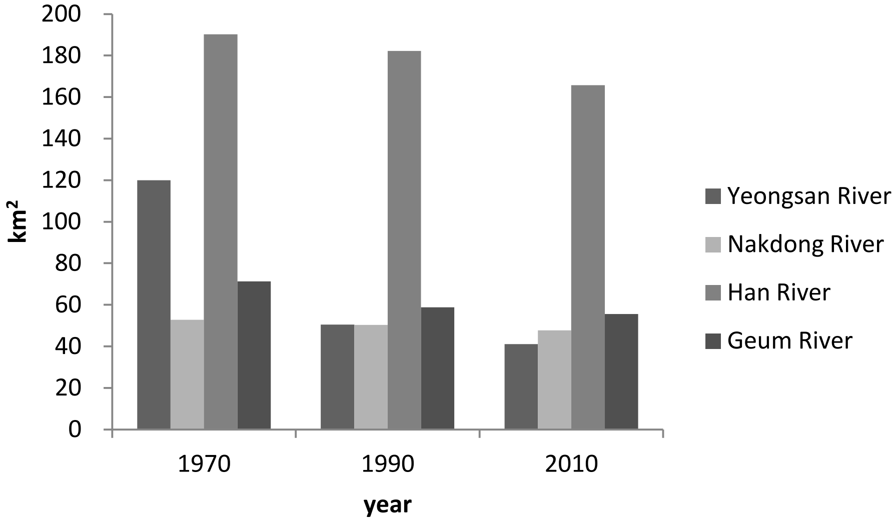


Fig.23 The bar chart of four Korean rivers nature length (A), and area (B) in 1970, 1990 and 2010

C



D

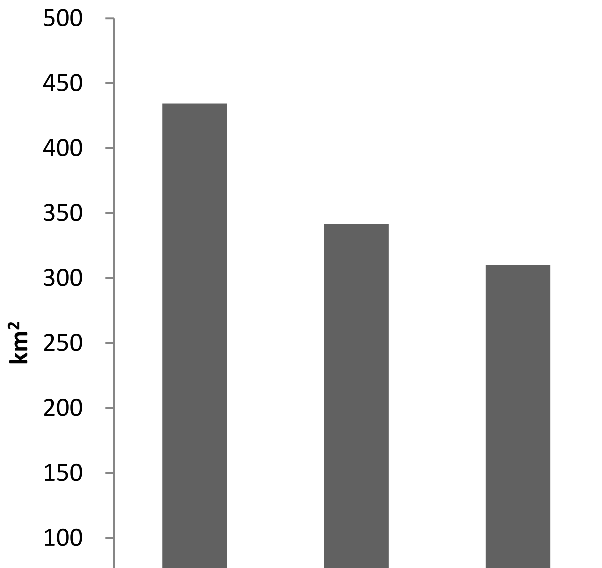


Fig.23 The bar chart of four Korean rivers HQI (C) in 1970, 1990 and 2010; four Japanese rivers total HQI value in 1970, 1990 and 2010 (D)

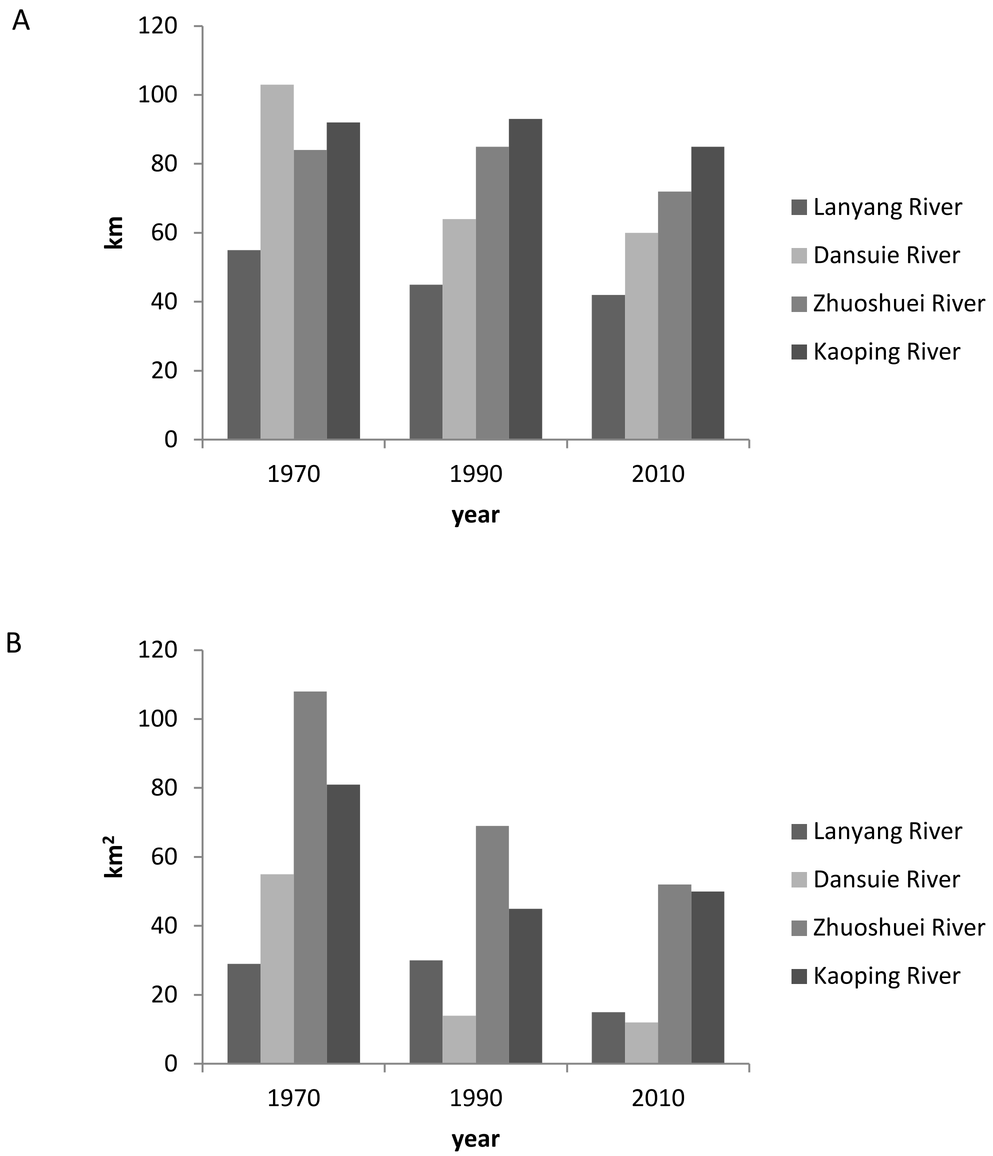
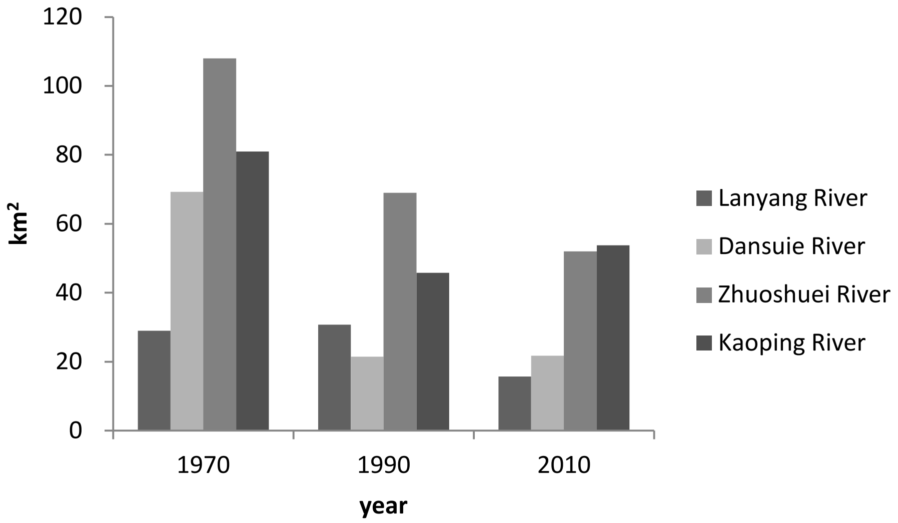


Fig.24 The bar chart of four Taiwan rivers nature length (A), and area (B) in 1970, 1990 and 2010

C



D

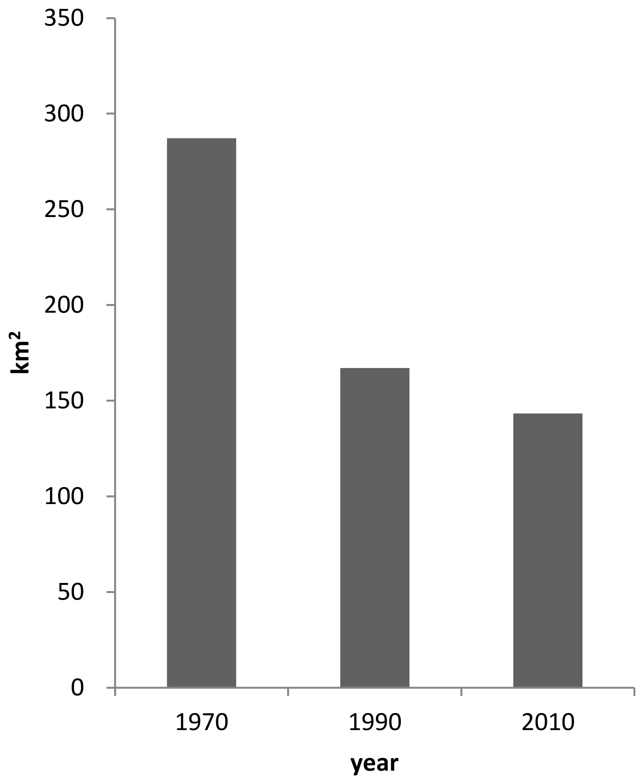
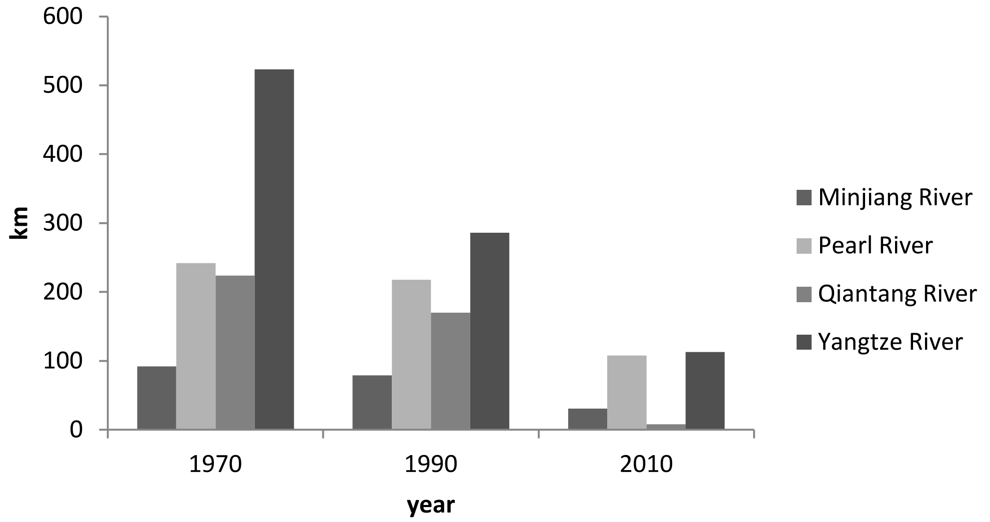


Fig.24 The bar chart of four Taiwan rivers HQI (C) in 1970, 1990 and 2010; four Japanese rivers total HQI value in 1970, 1990 and 2010 (D)

A



B

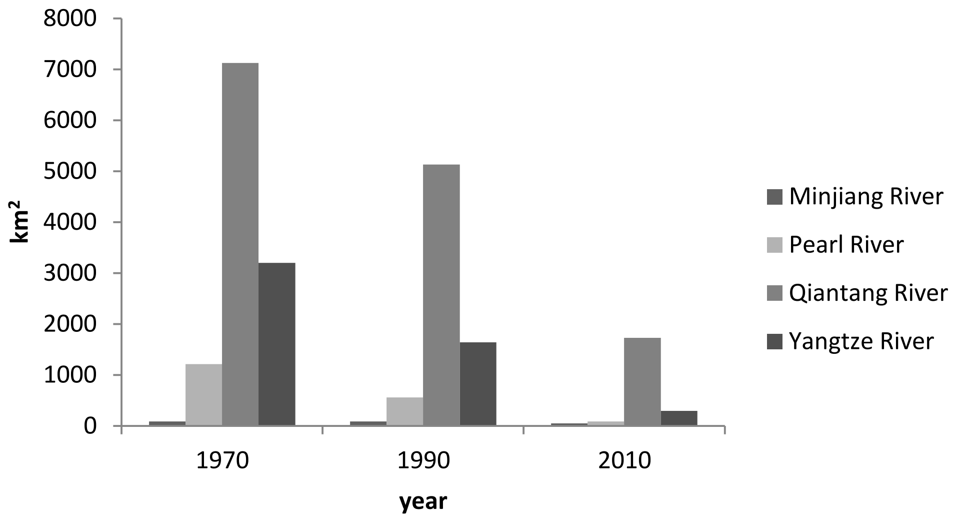
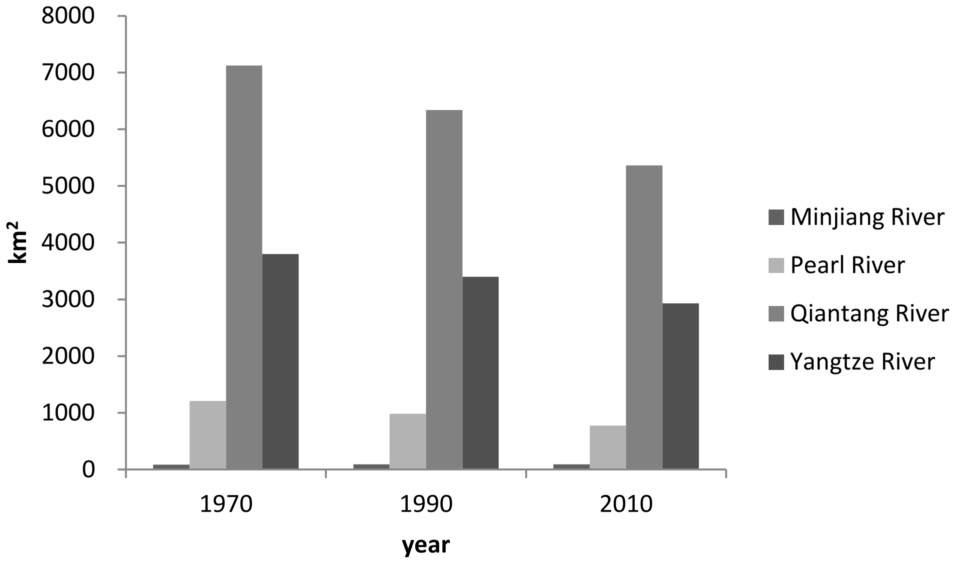


Fig.25 The bar chart of four China rivers nature length (A), and area (B) in 1970, 1990 and 2010

C



D

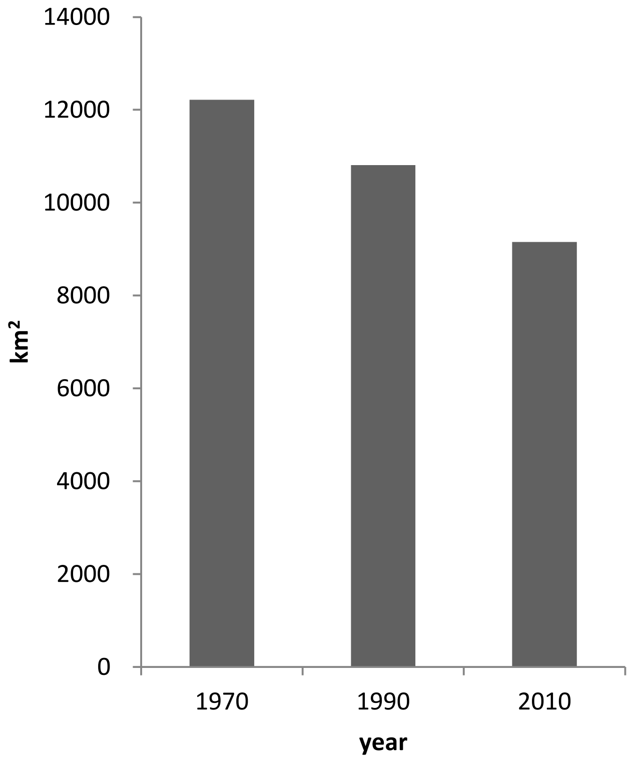


Fig.25 The bar chart of four China rivers HQI (C) in 1970, 1990 and 2010; four Japanese rivers total HQI value in 1970, 1990 and 2010 (D)

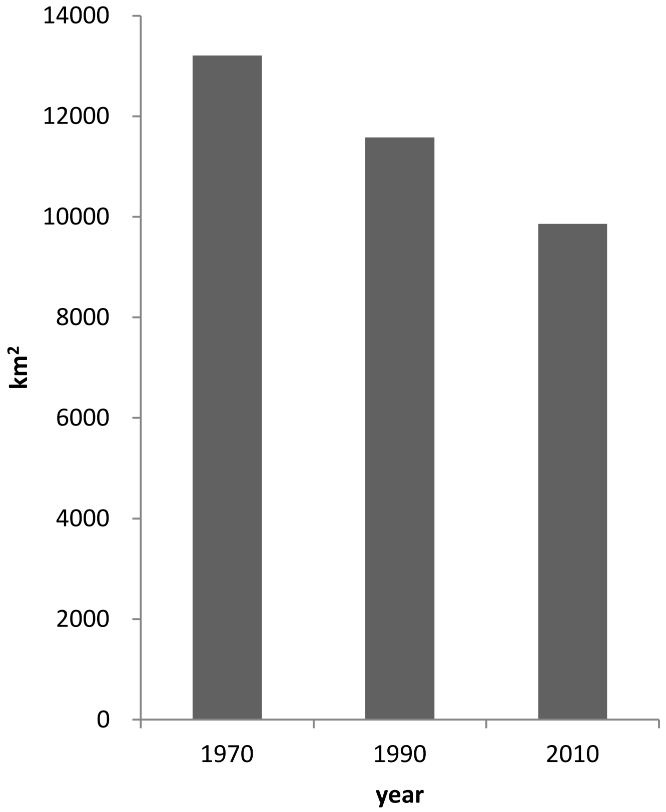


Fig.26 The bar chart of East Asia four countries HQI value in 1970, 1990 and 2010

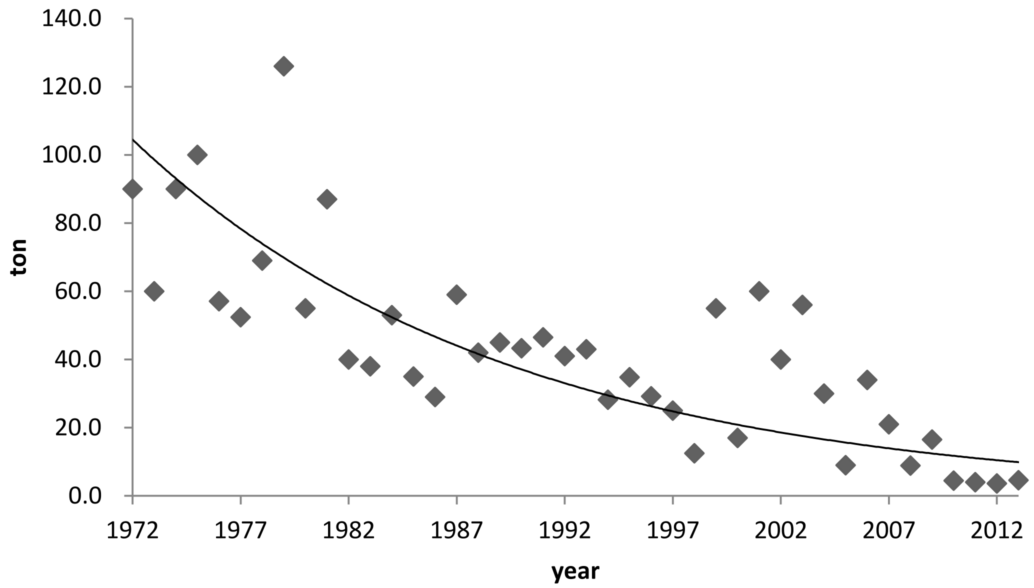


Fig.27 The eel resource run chart of Japan

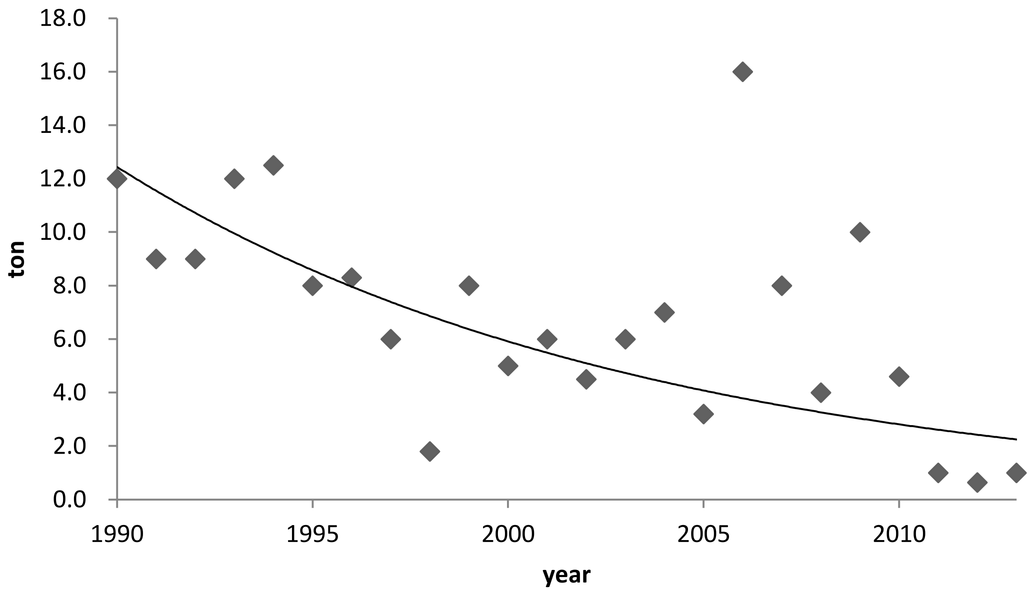


Fig.28 The eel resource run chart of Korea

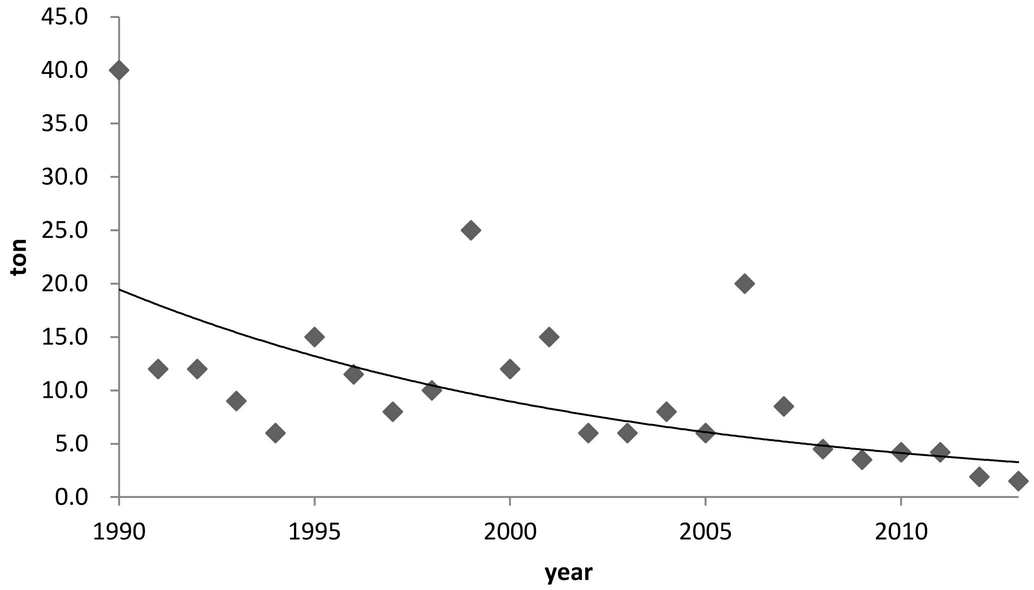


Fig.29 The eel resource run chart of Taiwan

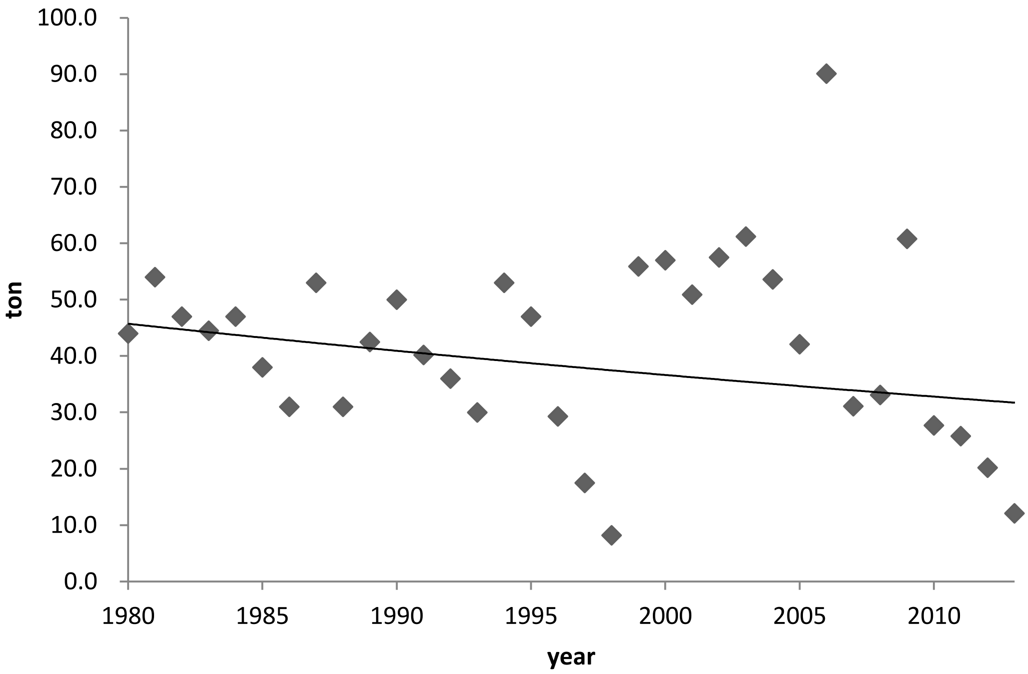


Fig.30The eel resource run chart of China

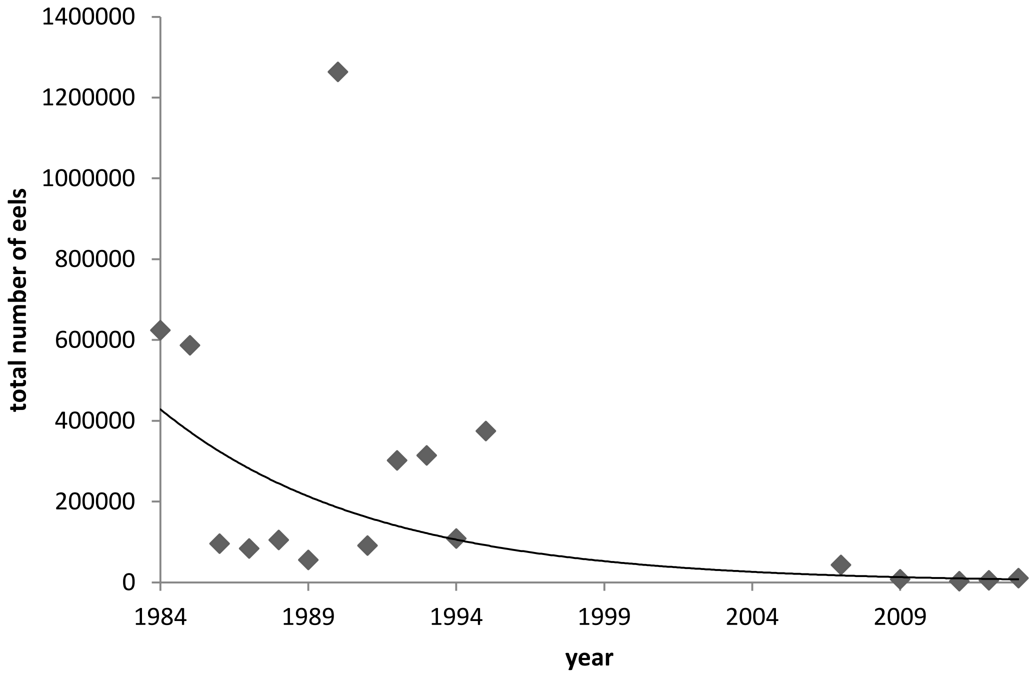


Fig.31 the eel resource run chart of Fulung

Table 1 The historical Landsat data path/row of Taiwan.

path/row	1970s	1990s	2010s
p126r42	V		
p126r43	V		
p126r44	V		
p126r45	V		
p117r43		V	V
p117r44		V	V
p117r45		V	
p118r43		V	V

Table 2 The historical Landsat data path/row of Japan.

path/row	1970s	1990s	2010s
p115r35	V		
p116r35	V		
p116r36	V		
p117r35	V		
p117r36	V		
p118r35	V		
p118r36	V		
p118r37	V		
p119r36	V		
p119r37	V		
p120r36	V		
p120r37	V		
p120r38	V		
p121r36	V		
p121r37	V		
p121r38	V		
p122r37	V		
p107r35		V	V
p107r36		V	
p108r35		V	V
p108r36		V	V

(Continued)

p109r35	V	
p109r36	V	
p109r37	V	
p110r35	V	
p110r36	V	
p110r37	V	
p111r36	V	
p111r37	V	V
p112r36	V	
p112r37	V	
p112r38	V	V
p113r36	V	
p113r37	V	
p113r38	V	

Table 3 The historical Landsat data path/row of Korea.

path/row	1970s	1990s	2010s
p123r35	V		
p123r36	V		
p124r34	V		
p124r35	V		
p124r36	V		
p125r34	V		
p125r35	V		
p114r35		V	V
p114r36		V	V
p115r34		V	V
p115r35		V	V
p115r36		V	V
p116r34		V	V
p116r35		V	V

Table 4 The historical Landsat data path/row of China.

path/row	1970s	1990s	2010s
p127r38	V		
p127r39	V		
p127r40	V		
p127r41	V		
p127r42	V		
p127r43	V		
p128r38	V		
p128r39	V		
p128p40	V		
p128r41	V		
p128r42	V		
p129r38	V		
p130r38	V		
p130r39	V		
p130r40	V		
p131r44	V		
p132r44	V		
p118r38		V	V
p118r39		V	V
p119r38		V	V

(Continued)

p119r39	V	V
p119r40	V	V
p119r41	V	V
p119r42	V	V
p120r38	V	V
p120r39	V	V
p121r38	V	V
p121r39	V	V
p121r40	V	V
p122r44	V	V
p122r45	V	V
p123r44	V	V

Table 5 the four countries eel resource official data during 1970s to 2010s

Years	Japan (tons)	Taiwan (tons)	Korea (tons)	China (tons)
1972	90.0			
1973	60.0			
1974	90.0			
1975	100.0			
1976	57.1			
1977	52.4			
1978	69.0			
1979	126.0			
1980	55.0			44.0
1981	87.0			54.0
1982	40.0			47.0
1983	38.0			44.5
1984	53.0			47.0
1985	35.0			38.0
1986	29.0			31.0
1987	59.0			53.0
1988	42.0			31.0
1989	45.0			42.5
1990	43.3	40.0	12.0	50.0
1991	46.5	12.0	9.0	40.2

(Continued)

1992	41.0	12.0	9.0	36.0
1993	43.0	9.0	12.0	30.0
1994	28.2	6.0	12.5	53.0
1995	34.8	15.0	8.0	47.0
1996	29.2	11.5	8.3	29.3
1997	25.0	8.0	6.0	17.5
1998	12.5	10.0	1.8	8.2
1999	55.0	25.0	8.0	55.9
2000	17.0	12.0	5.0	57.0
2001	60.0	15.0	6.0	50.9
2002	40.0	6.0	4.5	57.5
2003	56.0	6.0	6.0	61.2
2004	30.0	8.0	7.0	53.6
2005	9.0	6.0	3.2	42.1
2006	34.0	20.0	16.0	90.1
2007	21.0	8.5	8.0	31.1
2008	8.9	4.5	4.0	33.1
2009	16.5	3.5	10.0	60.8
2010	4.5	4.2	4.6	27.7
2011	4.0	4.2	1.0	25.8
2012	3.6	1.9	0.6	20.2
2013	4.6	1.5	1.0	12.1

Table 6 the Fulung eel resource data during 1980s to 2010s

Year	Eel resource (single eel)
1983~1984	624408
1984~1985	587152
1985~1986	96176
1986~1987	84172
1987~1988	105344
1988~1989	55852
1989~1990	1263932
1990~1991	91432
1991~1992	302264
1992~1993	314604
1993~1994	108888
1994~1995	374932
1995~1996	
1996~1997	
1997~1998	
1998~1999	
1999~2000	
2000~2001	
2001~2002	
2002~2003	

(Continued)

2003~2004	
2004~2005	
2005~2006	
2006~2007	43536
2007~2008	
2008~2009	7917
2009~2010	
2010~2011	3229
2011~2012	5428
2012~2013	10841

Table 7 A. The nature habitat and artificial building length and area of Ten-lyu River (天龍川) of Japan

Year	Nature habitat		Artificial building		HQI	DL(km)	TL(km)	TA (km^2)
	L(km)	A (km^2)	L (km)	A (km^2)				
1970	27	8	0	0	8	0	27	8
1990	27	9	0	0	9	0	27	9
2010	27	6	0	0	6	0	27	6

L= Length. A= Area. HQI= habitat quality index. TL= Total Length. TA= Total area. DL= Dam length

Table 7 B. The percentage of HQI value of Ten-lyu River (天龍川) of Japan

	The percentage of HQI change (%)
1970s~1990s	13
1990s~2010s	-33
1970s~2010s	-25

Table 8A. The nature habitat and artificial building length and area of Ohyodo River (大淀川) of Japan

Year	Nature habitat		Artificial building		HQI	DL(km)	TL(km)	TA (km^2)
	L(km)	A (km^2)	L (km)	A (km^2)				
1970	35	7	2	1	8	0	37	8
1990	30	4	8	4	7	0	38	8
2010	30	4	8	4	7	0	38	8

L= Length. A= Area. HQI= habitat quality index. TL= Total Length. TA= Total area. DL= Dam length

Table 8 B. The percentage of HQI change value of Ohyodo River (大淀川) of Japan

	The percentage of HQI change (%)
1970s~1990s	-10
1990s~2010s	0
1970s~2010s	-10

Table 9 A. The nature habitat and artificial building length and area of Ni-yodo River (仁淀川) of Japan

Year	Nature habitat		Artificial building		HQI	DL(km)	TL(km)	TA (km^2)
	L(km)	A (km^2)	L (km)	A (km^2)				
1970	15	3	0	0	3	0	15	3
1990	17	3	8	1	4	0	25	4
2010	17	3	8	1	4	0	25	4

L= Length. A= Area. HQI= habitat quality index. TL= Total Length. TA= Total area. DL= Dam length

Table 9 B. The percentage of the HQI change value of Ni-yodo River (仁淀川) of Japan

	The percentage of HQI change (%)
1970s~1990s	25
1990s~2010s	0
1970s~2010s	25

Table10A. The nature habitat and artificial building length and area of To-ne River (利根川) of Japan

Year	Nature habitat		Artificial building		HQI	DL(km)	TL(km)	TA (km^2)
	L(km)	A (km^2)	L (km)	A (km^2)				
1970	240	227	44	28	248	29	313	255
1990	225	179	58	77	237	29	312	256
2010	175	166	107	89	233	29	311	255

L= Length. A= Area. HQI= habitat quality index. TL= Total Length. TA= Total area. DL= Dam length

Table 10 B. The percentage of the HQI change value of To-ne River (利根川) of Japan

	The percentage of HQI change (%)
1970s~1990s	-5
1990s~2010s	-2
1970s~2010s	-6

Table 11 A. The nature habitat and artificial building length and area of Han River (漢江) of Korea

Year	Nature habitat		Artificial building		HQI	DL(km)	TL(km)	TA (km^2)
	L(km)	A (km^2)	L (km)	A (km^2)				
1970	150	188	4	3	190	0	154	191
1990	123	165	31	23	182	0	154	188
2010	89	105	64	81	166	0	153	186

L= Length. A= Area. HQI= habitat quality index. TL= Total Length. TA= Total area. DL= Dam length

Table 11 B. The percentage of the HQI change value of Han River (漢江) of Korea

	The percentage of HQI change (%)
1970s~1990s	-4
1990s~2010s	-9
1970s~2010s	-13

Table 12A. The nature habitat and artificial building length and area of Geum River (錦江) of Korea

Year	Nature habitat		Artificial building		HQI	DL(km)	TL(km)	TA (km^2)
	L(km)	A (km^2)	L (km)	A (km^2)				
1970	55	54	13	23	71	0	68	77
1990	46	37	21	29	59	0	67	66
2010	23	21	48	46	56	0	71	67

L= Length. A= Area. HQI= habitat quality index. TL= Total Length. TA= Total area. DL= Dam length

Table 12 B. The percentage of the HQI change value of Geum River (錦江) of Korea

	The percentage of HQI change (%)
1970s~1990s	-18
1990s~2010s	-6
1970s~2010s	-22

Table 13 A. The nature habitat and artificial building length and area of Yeongsan River (榮山江) of Korea

Year	Nature habitat		Artificial building		HQI	DL(km)	TL(km)	TA (km^2)
	L(km)	A (km^2)	L (km)	A (km^2)				
1970	159	120	0	0	120	0	159	120
1990	63	28	64	30	51	12	127	58
2010	58	14	72	36	41	12	130	50

L= Length. A= Area. HQI= habitat quality index. TL= Total Length. TA= Total area. DL= Dam length

Table 13 B. The percentage of the HQI change value of Yeongsan River (榮山江) of Korea

	The percentage of HQI change (%)
1970s~1990s	-58
1990s~2010s	-19
1970s~2010s	-66

Table 14A. The nature habitat and artificial building length and area of Nakdong River (洛東江) of Korea

Year	Nature habitat		Artificial building		HQI	DL(km)	TL(km)	TA (km^2)
	L(km)	A (km^2)	L (km)	A (km^2)				
1970	116	52	2	1	53	0	118	53
1990	104	45	14	7	50	0	118	52
2010	88	38	29	13	48	0	117	51

L= Length. A= Area. HQI= habitat quality index. TL= Total Length. TA= Total area. DL= Dam length

Table 14 B. The percentage of the HQI change value of Nakdong River (洛東江) of Korea

	The percentage of HQI change (%)
1970s~1990s	-5
1990s~2010s	-5
1970s~2010s	-9

Table 15 A. The nature habitat and artificial building length and area of Dansuie River (淡水河) of Taiwan

Year	Nature habitat		Artificial building		HQI	DL(km)	TL(km)	TA (km^2)
	L(km)	A (km^2)	L (km)	A (km^2)				
1970	103	55	6	19	69	0	109	74
1990	64	14	22	10	22	22	86	24
2010	60	12	30	13	22	16	90	25

L= Length. A= Area. HQI= habitat quality index. TL= Total Length. TA= Total area. DL= Dam length

Table 15 B. The percentage of the HQI change value of Dansuie River (淡水河) of Taiwan

	The percentage of HQI change (%)
1970s~1990s	-69
1990s~2010s	1
1970s~2010s	-69

Table 16 A. The nature habitat and artificial building length and area of Lanyang River (蘭陽溪) of Taiwan

Year	Nature habitat		Artificial building		HQI	DL(km)	TL(km)	TA (km^2)
	L(km)	A (km^2)	L (km)	A (km^2)				
1970	55	29	0	0	29	0	55	29
1990	45	30	8	1	31	0	53	31
2010	42	15	11	1	16	0	53	16

L= Length. A= Area. HQI= habitat quality index. TL= Total Length. TA= Total area. DL= Dam length

Table 16 B. The percentage of the HQI change value of Lanyang River (蘭陽溪) of Taiwan

	The percentage of HQI change (%)
1970s~1990s	6
1990s~2010s	-49
1970s~2010s	-46

Table 17 A. The nature habitat and artificial building length and area of Zhuoshuei River (濁水溪) of Taiwan

Year	Nature habitat		Artificial building		HQI	DL(km)	TL(km)	TA (km^2)
	L(km)	A (km^2)	L (km)	A (km^2)				
1970	84	108	0	0	108	0	86	108
1990	85	69	0	0	69	0	85	69
2010	72	52	0	0	52	13	72	52

L= Length. A= Area. HQI= habitat quality index. TL= Total Length. TA= Total area. DL= Dam length

Table 17B. The percentage of the HQI change value of Zhuoshuei River (濁水溪) of Taiwan

	The percentage of HQI change (%)
1970s~1990s	-36
1990s~2010s	-25
1970s~2010s	-52

Table 18 A. The nature habitat and artificial building length and area of Kaoping River (高屏溪) of Taiwan

Year	Nature habitat		Artificial building		HQI	DL(km)	TL(km)	TA (km^2)
	L(km)	A (km^2)	L (km)	A (km^2)				
1970	92	81	0	0	81	0	92	81
1990	93	45	2	1	46	0	95	46
2010	85	50	7	5	54	0	92	55

L= Length. A= Area. HQI= habitat quality index. TL= Total Length. TA= Total area. DL= Dam length

Table 18 B. The percentage of the HQI change value of Kaoping River (高屏溪) of Taiwan

	The percentage of HQI change (%)
1970s~1990s	-44
1990s~2010s	17
1970s~2010s	-34

Table 19 A. The nature habitat and artificial building length and area of Minjiang River (閩江) of China

Year	Nature habitat		Artificial building		HQI	DL(km)	TL(km)	TA (km^2)
	L(km)	A (km^2)	L (km)	A (km^2)				
1970	92	86	4	1	87	0	96	87
1990	79	83	16	11	91	0	94	94
2010	31	47	61	63	94	0	92	110

L= Length. A= Area. HQI= habitat quality index. TL= Total Length. TA= Total area. DL= Dam length

Table 19 B. The percentage of the HQI change value of Minjiang River (閩江) of China

	The percentage of HQI change (%)
1970s~1990s	5
1990s~2010s	3
1970s~2010s	9

Table 20 A. The nature habitat and artificial building length and area of Pearl River (珠江) of China

Year	Nature habitat		Artificial building		HQI	DL(km)	TL(km)	TA (km^2)
	L(km)	A (km^2)	L (km)	A (km^2)				
1970	242	1208	6	1	1209	0	250	1209
1990	218	557	45	572	986	0	263	1129
2010	108	86	166	915	772	0	274	1001

L= Length. A= Area. HQI= habitat quality index. TL= Total Length. TA= Total area. DL= Dam length

Table 20 B. The percentage of the HQI change value of Pearl River (珠江)of China

	The percentage of HQI change (%)
1970s~1990s	-18
1990s~2010s	-22
1970s~2010s	-36

Table 21 A. The nature habitat and artificial building length and area of Qiantang River (錢塘江) of China

Year	Nature habitat		Artificial building		HQI	DL(km)	TL(km)	TA (km^2)
	L(km)	A (km^2)	L (km)	A (km^2)				
1970	224	7124	0	0	7124	0	224	7124
1990	170	5129	59	1609	6336	0	229	6738
2010	8	1727	229	4848	5363	0	237	6575

L= Length. A= Area. HQI= habitat quality index. TL= Total Length. TA= Total area. DL= Dam length

Table 21 B. The percentage of the HQI change value of Qiantang River (錢塘江)of China

	The percentage of HQI change (%)
1970s~1990s	-11
1990s~2010s	-15
1970s~2010s	-25

Table 22 A. The nature habitat and artificial building length and area of Yangtze River (長江) of China

Year	Nature habitat		Artificial building		HQI	DL(km)	TL(km)	TA (km^2)
	L(km)	A (km^2)	L (km)	A (km^2)				
1970	523	3199	344	799	3798	0	866	3998
1990	286	1637	576	2349	3399	0	862	3986
2010	113	291	749	3516	2928	0	862	3807

L= Length. A= Area. HQI= habitat quality index. TL= Total Length. TA= Total area. DL= Dam length

Table 22 B. The percentage of the HQI change value of Yangtze River (長江)of China

	The percentage of HQI change (%)
1970s~1990s	-11
1990s~2010s	-14
1970s~2010s	-23

Table 23. The eel resource in 1970s, 1990s and 2010s (A) and the percentage of the eel resource change value (B) of Japan

A

	The eel resource value (tons)
1970s	80.6
1990s	35.9
2010s	6.6

B

	The percentage of eel resource change value (%)
1970s~1990s	-56
1990s~2010s	-81
1970s~2010s	-92

Table 24. The eel resource in 1970s, 1990s and 2010s (A) and the percentage of the eel resource change value (B) of Taiwan

A

	The eel resource value (tons)
1990s	14.9
2010s	3.1

B

	The percentage of eel resource change value (%)
1990s~2010s	-79

Table 25. The eel resource in 1970s, 1990s and 2010s (A) and the percentage of the eel resource change value (B) of Korea

A

	The eel resource value (tons)
1990s	8.7
2010s	3.4

B

	The percentage of eel resource change value (%)
1990s~2010s	-60

Table 26. The eel resource in 1970s, 1990s and 2010s (A) and the percentage of the eel resource change value (B) of China

A

	The eel resource value (tons)
1980s	43.2
1990s	36.7
2010s	38.6

B

	The percentage of eel resource change value (%)
1980s~1990s	-15
1990s~2010s	5
1980s~2010s	-11

Table 27. The eel resource of year average in 1984~1995 and 2006~2013 (A) and the percentage of the eel resource change value (B) of Fulung

A

	The eel resource value (per eel)
1984~1995	334096
2006~2013	14190

B

	The percentage of eel resource change value (%)
(1984~1995)~(2006~2013)	-96

Table 28. The percentage of the HQI change value of Japan

	The percentage of HQI change (%)
1970s~1990s	-4
1990s~2010s	-3
1970s~2010s	-6

Table 29. The percentage of the HQI change value of Korea

	The percentage of HQI change (%)
1970s~1990s	-21
1990s~2010s	-9
1970s~2010s	-29

Table 30. The percentage of the HQI change value of Taiwan

	The percentage of HQI change (%)
1970s~1990s	-42
1990s~2010s	-14
1970s~2010s	-50

Table 31. The percentage of the HQI change value of China

	The percentage of HQI change (%)
1970s~1990s	-12
1990s~2010s	-15
1970s~2010s	-25

Table 32. The percentage of the HQI change value of East Asia

	The percentage of HQI change (%)
1970s~1990s	-12
1990s~2010s	-15
1970s~2010s	-25