Water resource monitoring exploiting sentinel−2 and sentinel−2 like time series; application in yangtze river water bodies

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Abstract: As part of Dragon 4 project, the water extents of Wuchang and Shengjin lakes have been extracted from Sentinel-2 time series, using all exploitable images since the beginning of the acquisitions in 2015. The aim of the study is to assess the capability of the Sentinel-2 constellation and Landsat 8 over the Anhui region, especially the high temporal resolution. A total of 32 dates have been used and 10 Landsat 8 images (Libra) have been added to try to reduce the temporal gaps in the Sentinel-2 acquisitions caused by cloudy conditions. Extractions were done using a SERTIT-ICube automatized routine based on a supervised Maximum Likelihood Classification. These extractions allow to recreate the dynamic of the two lakes and show the drought and wet periods. During the 3 years interval, the surface peaks on July 2016 for both lakes. The lowest level appears at two different dates for each lake; on January 2018 for Wuchang, on February 2017 for Shengjin. Wuchang Lake surface area appears to be more variable than Shengjin Lake, with many local maximum and minimum between the end of 2017 and April 2018. In the case of Wuchang Lake, floating vegetation is a problem for automatic water surface area extraction. The lake is covered by vegetation during long periods of time and the water below can't be detected by automatic radiometric means. Nevertheless, Sentinel-2 stays a pertinent and powerful tool for hydrological monitoring of lakes confirming the expectation from the remote sensing wetland community before launch. The presence of NIR and SWIR bands induces a strong discrimination between water and other classes, and the systematic acquisitions create dense time series, making analysis more consistent. It makes possible to sensor events occurring over short periods of time. Thanks to this a link can be done between endangered bird species, such as the Siberian Crane and the Lesser White-Fronted Goose and periodically flooded areas. These midterm results illustrated the pertinence and powerful of multi-source optical satellite data for environmental analysis.

Key words:

Citation format: **Briant J,Huber C,Studer M,Cao L,Yi K P and Yésou H 2020. Water resource monitoring exploiting sentinel−2 and sentinel−2 like time series; application in yangtze river water bodies. Journal of Remote Sensing(Chinese). 24(S1): 147−153**

1 INTRODUCTION

The Yangtze floodplain is one of the largest in the world subject to summer monsoonal flood. It induces large variations of hydrological conditions over extended areas. As a result, very rich ecosystems have developed in the region and are of national, and even international importance for waterbirds wintering. In the past, the Yangtze floodplain biodiversity has already declined greatly due to human activities (Three-Gorge Dam, South-North Water Transfer Project), and, in the future, global warming is expected to lead to significant wetland losses.

Biodiversity stakes within Yangtze watershed are very important at national level but also international ones. These very rich ecosystems, being key wintering areas for many waterfowls of East Asia, are suffering from rapidly changing environments due to human activities . It's crucial to understand what the key factors and their effects are. As field data over large spatial and temporal scales are difficult to get, remote sensing and spatial analysis technology turns out to be a useful tool to access information. Within the DRAGON projects, work is on progress over Poyang Lake, in regards to vegetation recognition and dynamic, particularly within the core of the Poyang Lake natural Reserve, but also over smaller and less known sensitive areas such as Wuchang and Shengjin lakes (Anhui Province). Fig. 1 shows the location of the test sites of this study.

Wuchang Lake is situated on the northern bank of the Yangtze River in the Anhui Province. It's a shallow lake with an area of 100.5 km^2. The main rivers supplying the lake are the Yatan River, the Maojia River and the Taici River and the Xingfu River is the only link between the lake and the Yangtze River. Originally freely connected to the Yangtze, a sluice was built in 1959 on the Xingfu River for fishing and flood control. Since then, the growth of surface vegetation has been more important on the eastern part of the lake .

Received: XXXX-XX-XX; **Accepted:** XXXX-XX-XX

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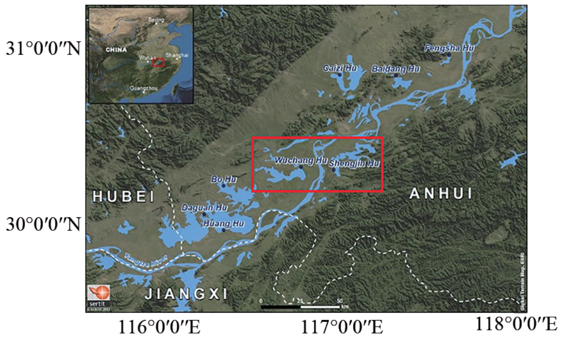


Fig.1 Anhui lakes location on the Yangtze banks

Shengjin Lake is facing Wuchang Lake on the south bank of the Yangtze River. Shengjin Lake is part of the Anhui Shengjin Lake National Nature Reserve, established in 1986. It has an average area of 76 km^2 and is supplied by the Zhangxie River, the Huangpen River, the Tangtian River and the Yangtze River. The lake is home for large population of waterbirds and is a key component of the regional biodiversity .

This paper presents the results of water extraction using Sentinel-2 like data (optical with NIR and SWIR) and some applications using these extracted water areas. A landcover around Shengjin Lake is realized in order to cross with water extractions. Data used are presented, then the method for water extraction over a period of 30 years with a long term view, and a shorten one focused on intra annual water variations analysis between 2015 and 2018. Obtained water surface area extractions are shown and coupled with the resulting landcover and biodiversity data.

2 Data

2.1 Water extent extraction

The first set of data consists of the entirety of the optically exploitable Sentinel-2 over Shengjin and Wuchang lakes, meaning all the images where the lakes are not covered by clouds. Since 2015, Sentinel-2 is capturing the world with an unprecedented combination of spatial and temporal resolutions, going from 10 to 60 m of spatial resolution and 5 days of revisit time at the equator, all in free access. Added to that, the interval of spectral bands monitored goes from coastal blue at 443 nm to Short-Wave InfraRed (SWIR) at 2190 nm, divided in 12 bands . Sentinel-2 allows a precise and systematic follow-up of hydrological systems regarding water surface area or vegetation coverage. These points combined make Sentinel-2 a great tool for the monitoring of the Yangtze floodplain and the DRAGON4 project. The area of interest defined by the two lakes requires two Sentinel-2 tiles (named 50RNU and 50RMU) to be fully captured. A total of 53 images are exploitable, covering 32 dates between October 2015 and April 2018. The year 2017 is the most furnished with data. The launch of the Sentinel-2B sensor in March 2017 increased the capture capacity of the Sentinel-2 constellation. The data density in 2018 is also great with 8 dates between the 1st December 2018 and the 7th April 2018, this is almost as many dates as during the whole 2016 year (11 dates).

Fig. 2 shows Shengjin Lake in false colors, with Near-InfraRed displayed on the red canal.

Landsat 8 images complete the Sentinel-2 data pool on long periods without Sentinel-2 available to densify the total data set. A total of 10 Landsat 8 images are used and the final data set has an average of one image every 22 days, all shown in Figure 3. The number of available images is higher since March 2017, thanks to the launch of the Sentinel-2B satellite.

Fig.2 Sentinel−2 acquired the 23/03/2018. False color composite, with B8, B4 and B3 in RGB (tiles 50RMU and 50RNU)

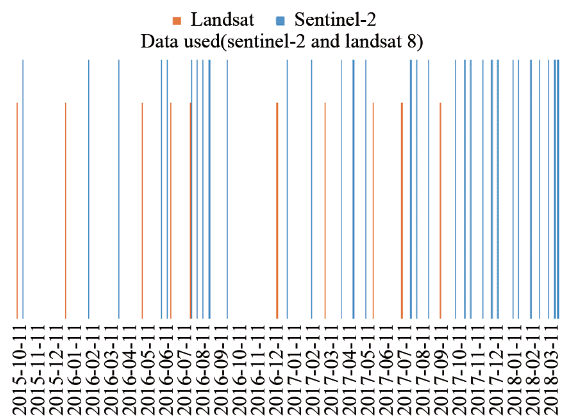


Fig.3 Time series of Sentinel−2 and Landsat 8 (the difference in ordinate is only to help differentiate sensors)

In addition to Sentinel-2 and Landsat 8, SPOT images have been downloaded from the Theia-world website through the SPOT World Heritage program. The latter gives access to archive data from satellites SPOT-1-2-3-4-5 and extents the study duration span. A total of 19 images were either completely or partially available over Shengjin and Wuchang lakes; 2 SPOT-1, 2 SPOT-3, 13 SPOT-4 and 2 SPOT-5, ranging from December 1987 to April 2009. The duration between two images during this period is too large to capture the lakes dynamic but can be used to calculate a total water occurrence product.

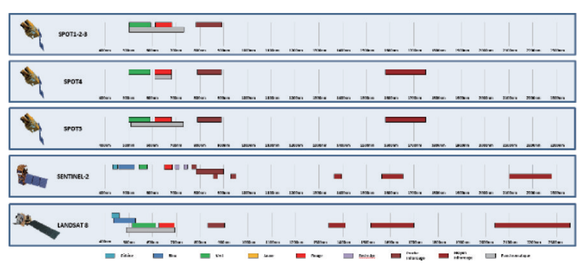


Fig.4 Sentinel−2, Landsat 8 and SPOT−1−3−4−5 spectral bands

Spectral bands for each sensor are summarized in Figure 4: Sentinel-2, Landsat 8 and SPOT-1-3-4-5 spectral bands. Sentinel-2 and Landsat 8 are two relatively similar sensors, Sentinel-2 being slightly more resolved spatially and temporally.

2.2 Landcover mapping around Shengjin

Two Pléiades images are used for this task. The multi-spectral (2,8 m resolution) Pléiades 1B from the 19th of November 2013 and Pléiades 1A from the 18th of November 2013.

Fig. 5 shows a subset of the Pléiades 1A used for the landcover classification. The multi-spectral image is used; less shadows and other potential disturbances are present compared to the pan-sharped image (0.7 m resolution), which make the classification easier in this case. The initial multi-spectral resolution is 2.8 m, which is then resampled to 2 m.

Fig.5 Pléiades acquired on the 19/11/2013. False color composition over Western Shengjin

3 Method

3.1 Water extent extraction

For Sentinel-2 and Landsat 8 data, processed bands are three optical (B02, B03, B04), one infrared (B08), and two SWIR bands (B11 and B12). This combination allows a good discrimination between water and other classes . Bands are first stacked in a single raster data set, then clipped to reduce the area to classify and decrease the computation time. Water surface area extractions are computed using a SERTIT-ICube automatized tool based on a supervised Maximum Likelihood Classification. The algorithm uses the Global Surface Water data sets as training . Sampling point are taken from pixels with an occurrence value higher than a specified threshold and each pixel is then classified as "water" or "not water".

The Maximum Likelihood Classification is a popular classification method. By supposing that classes are normally distributed, each one can be characterized by its covariance matrix and mean vector. The user creates a sample of each class, which will then be used to calculate the mean vector and covariance matrix. A pixel is then classified in the class with its maximum likelihood. The likelihood for each class is calculated as follow in Equation 1.

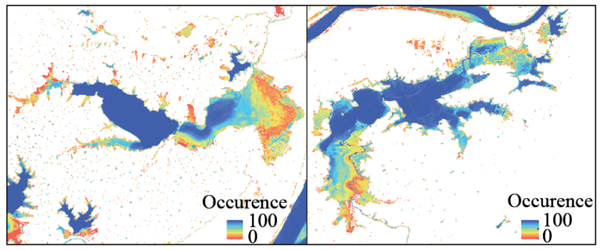


Fig.6 Pekel's Global Surface Water product over Anhui lakes, Wuchang on the left, Shengjin on the right

$$L_i(X) = \frac{1}{(2\pi)^{\frac{n}{2}}|V_i|^{\frac{1}{2}}} exp\left[-\frac{1}{2}(X - M_i)^T V_i^{-1}(X - M_i)\right] \quad (1)$$

Where X is the measurement vector, $|V_i|$ is the determinant of the covariance matrix, V_i^{-1} is the inverse of the covariance matrix and $(X\text{-}M_i)^T$ is the transpose of the vector $(X\text{-}M_i)$. M_i and V_i, respectively the mean vectors and the covariance matrix, are estimated from the training sample. A pixel is then classified as i if Li(X) > Lj(X) for all i and j.

3.2 Landcover mapping around Shengjin Lake

The landcover over Shengjin sector is extracted for multi-spectral Pléiades images. The final landcover is composed of nine classes:

· water body
· urban area
· mineral
· bare soil
· wet bare soil
· wooded area
· green cropland
· other cropland
· grassland

The NDVI is derived and the image is segmented with eCognition® using the Spectral Difference Segmentation method. The latter uses radiometric variations to segment the image in objects. Parameters are:

· Maximum spectral difference: 20
· NIR and NDVI bands weight: 2

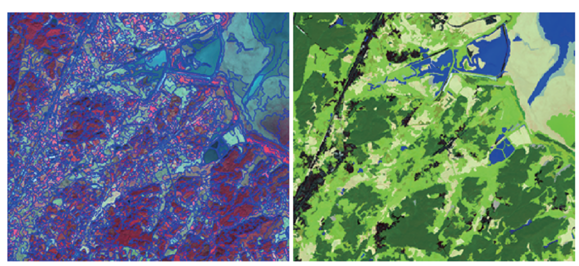


Fig.7 Sentinel-2 segmentation and the final classification of Shengjin landcover

The image is then classified using a k-Nearest Neighbors supervised classifier. Its principle is based on the selection of k training samples among the representative objects of each class. For each non-classified object, the Euclidean distances to the k nearest training objects are measured in the multi-dimensional space defined by the used parameters. The object is then assigned to the majority class among the k-nearest neighbors. The choice of classes and parameters is an important step. The considered radiometric parameters are:

· the mean value for each band

· the standard deviation of each band

And geometric parameters are:

· the object surface

· the length/width ratio

4 Results and discussion

4.1 Water extent extraction

Classification of water surfaces area is operated for each date and occurrence products are derived by looking at the frequency of water coverage for each pixel. A certain ambiguity remains over half of Wuchang Lake, the eastern side of the lake is highly variable and often covered by vegetation, and even though water is present below, it can't be extracted automatically. Needed corrections are done by photo-interpretation. Occurrences by year are presented in Fig. 8.

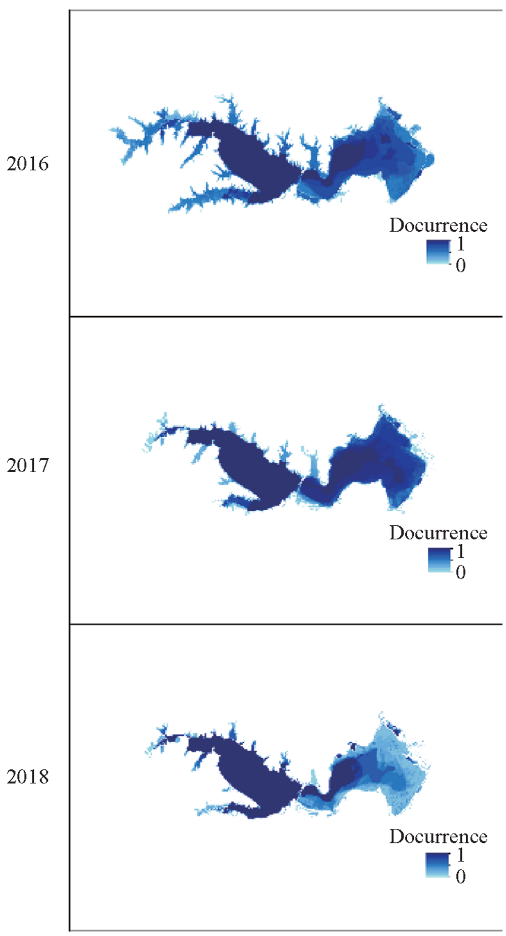


Figure 8A: Water surface occurrences frequency per year over Wuchang Lake

Both lakes present a "core" area where water is present at every date, and inundated areas where water appears only at certain periods. The western Wuchang Lake is constantly inundated whereas the eastern part is flooded only when climatic conditions require it to be, to discharge excess water during heavy rains. Shengjin Lake is permanently inundated at its center while the southern and northern parts are only sporadically covered by shallow water, which are required conditions for the presence of certain waterbird species.

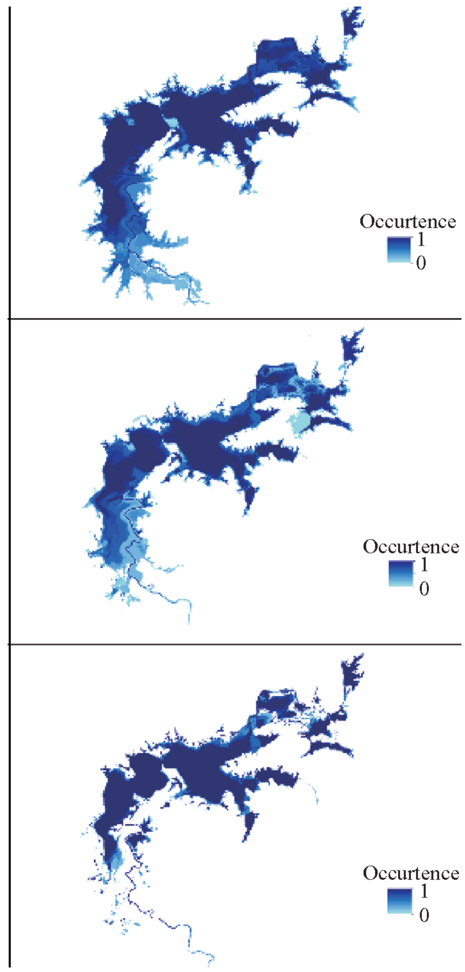
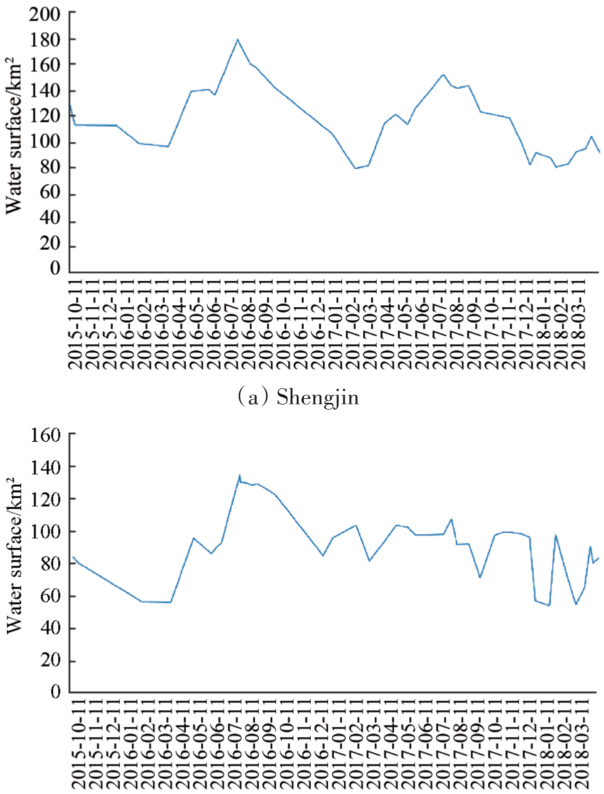


Figure 8B: Water surface occurrences frequency per year over Shengjin Lake

Water surfaces area are calculated for each extraction and the evolution of the lakes surface can be followed on Fig. 9.

Both lakes show a surface peak on August 2016. Seasonal variations are clearly visible looking at Shengjin Lake surface water area variation, with an increase in water surface during the rain season (from April to August) and a decrease during the dry season. This binomial behavior is typical of monsoon lake. On the contrary, the evolution seems more chaotic for Wuchang Lake, with many local peaks and lows in 2017. The eastern basin of Wuchang Lake is used to control the water level of the lake and is more anthropologically operated, which might explain its more "independent" behavior in regard to environmental conditions. Furthermore, the presence of vegetation at the surface make the water detection more challenging. The photo-interpretation step accomplished to correct the extraction is subject to operator's reading and might introduce classification errors.

The peak observed in 2016 can be linked to the 2016 monsoon episode, one of the most important of the last 10 years . The regular decrease in water surface area during the months after this peak also highlights the artificial regulation of the lakes. Indeed, between July 2016 and December 2016, the water surface areas decrease from 180 km^2 to 80 km^2 with an almost constant rate. In 2017, the surface peak is smaller than in 2016 but remains almost constant between the end of June and September and then a strong decrease until December 2017.



(a) Shengjin

(b) Wuchang

Fig. 9 Water surface area time evolution over Wuchang and Shengjin Lakes

These results can be put in relation with Pekel's water occurrence product. While Pekel's occurrences give a very good overview of the functioning of a water driven system, analysis of shorter periods such as this one based on Sentinel-2 like imagery highlight the direct answer of the same system to meteorological conditions or anthropological practices. Such information is required for a precise characterization and understanding of these sensitive ecosystems and their waterflow behaviors.

4.2 Submerged landcover

The landcover around Shengjin Lake is presented in Fig. 10. It shows large areas of croplands and wooded area, taking up more than half of the covered surface.

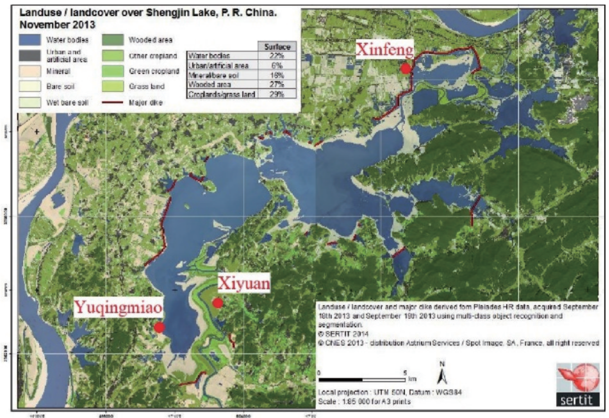


Fig. 10 Landcover around Shengjin Lake

Change in water extent means temporary flooding of land surfaces. These submersions can be voluntary such as in the case of rice culture, or hazardous (floods).

Table 1 presents the confusion matrix of the classification. Validation has been done by photo-interpretation, by comparing on the classification and the reference image, 500 randomly placed points. The main omission and commission errors are caused by close classes such as "Mineral", "bare soil" and "wet bare soil", "green cropland" and "other cropland" etc. This is well indicated by Users and Producer accuracies, UA and PA that are relatively low for these classes, with value respectively for UA and PA of 0.57 and 0.80 for mineral; 0.72 and 0.53 for wet bare soils; 0.50 and 0.60 green cropland. The final accuracies are the following Total exactitude and Kappa Index values of respectively 0.858 and 0.706, which can be considered as good.

Table 1 Confusion matrix of Shengjin landcover classification

Validation	Water body	Urban area	Mineral	Bare soils	Wet bare soils	Wooded area	Green cropland	Other cropland	Grassland	Omission error%
Water body	114	0	0	0	1	0	0	0	0	1
Urban area	0	24	0	0	0	2	0	5	0	23
Mineral	0	2	4	0	0	1	0	0	0	43
Bare soils	0	1	1	72	5	2	0	9	0	20
Wet bare soils	0	0	0	0	8	2	0	1	0	27
Wooded area	0	1	0	1	0	112	0	12	0	11
Green cropland	0	0	0	0	0	1	3	2	0	33
Other cropland	2	6	0	2	1	10	2	84	0	21
Grassland	0	0	0	0	0	1	0	1	5	29
Commission error %	2	29	20	4	47	15	40	26	0	KAPPA 0.706

Crossing the water occurrence with landcover allows to know what type of soil has been flooded during the last 3 years. Figure 11 shows the inundated surface types during the considered period. Croplands are the type of surface the most commonly flooded, probably due to the presence of paddy fields, which require to be inundated. Bare soils were also largely inundated.

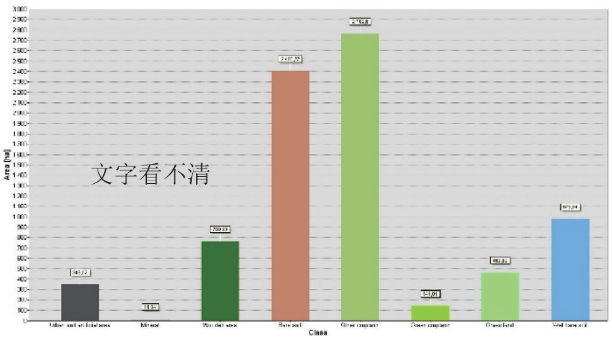


Fig. 11 Type of landcover inundated at least 1 time since October 2015 around Shengjin Lake

4.3 Water surface and biodiversity

A link can be done between endangered bird species, such as the Siberian Crane and the Lesser White-Fronted Goose and periodically flooded areas.

As seen in Fig. 12, some bird populations were only observed in the northern and southern parts of Shengjin Lake, were water coverage varies in time. Grazing waterfowl, such as the endangered Lesser White fronted geese and more common White fronted geese are located in areas having a relatively important variations in terms of inundation. These are at opposite locations, the Xinfeng area in the NorthEastern part, and the Xiyuan and Yuqingmiao in the SouthWestern area (locations visible in Figure 10). These areas are also the most exposed to changes induced by human activities.

Some other species require calm and steady water such as the vulnerable dabbling Baikal teal, for which Shengjin Lake is a resting area. Observations show that it can be found in areas where the water occurrence from Pekel and this study is high.

Changes in hydrological conditions induced by human activities might cause the disappearance of these bird populations from observations with already very few individuals .

5 Conclusion

Optical images are a great tool for water extraction. In the case of Sentinel-2 and Landsat 8, the presence of SWIR bands makes the extraction very precise using a basic trained algorithm. However they're sensible to climatic conditions and cloudy weathers make observations impossible. The temporal resolution of the Sentinel-2 constellation allows to compensate this problem by multiplying the number of passage over a same area, increasing the chances of good conditions; for each passage of Landsat 8 there are 3 of Sentinel-2, one every 5 days in average. The Maximum Likelihood Classification algorithm gives satisfying and quick results, water surface area is extracted for each available date. By combining all extractions, a water occurrence map is created for each year, which gives an overview of the lake surface behavior; the eastern Wuchang Lake appears indeed periodically flooded while the western part is always covered by water. Concerning Shengjin Lake, the center part of the lake remains inundated while the northern and southern parts dry up at some point during the year. It can be highlighted that these regions are home for endangered bird species and are threatened by changes of hydrological conditions. It would be interesting to study in further details the measures that might be needed to protect these species. Adding landcover data to water occurrences allows to see what sort of soil are flooded over time around lakes. Data over Shengjin show that culture are the most prone to be inundated, related to paddy fields in the area.

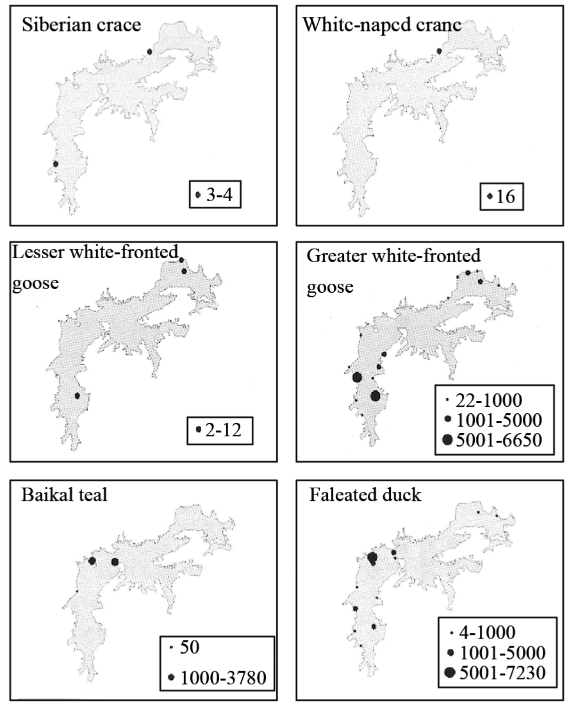


Fig.12 Distribution of some bird species over Shengjin Lake (Cheng et al., 2009)

6 ACKNOWLEDGMENT

This study was undertaken within the ESA-MOST Dragon 4 Cooperation Program – within the project "New Earth Observations Tools for Water Resource and Quality Monitoring in Yangtze Wetlands and Lakes" – project ID. 32442 and funded through a Dragon Young Scientist ESA Grant. Special thanks to Theia© land data services center for the access to SPOT imagery, obtained through the SPOT World Heritage program. Many thanks to the CNES SI-AP team for data and support delivered in the framework of the Pleiades User Thematic Commissioning Phase.

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