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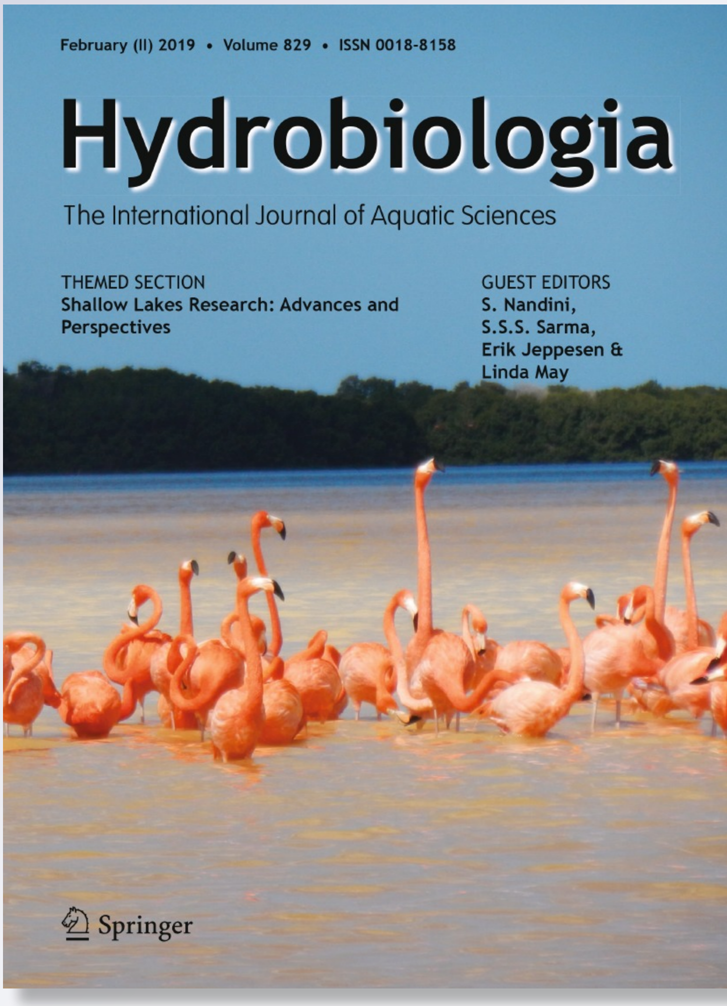

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SHALLOW LAKES RESEARCH

Remote sensing application for the study of rapid flushing to remediate eutrophication in shallow lagoons (Albufera of Valencia)

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Abstract Albufera of Valencia shallow lagoon experiences water clarification about once a year. This study aimed to observe the timing of water clarity events and to detect the associated flow during these periods. Spatial variation in chlorophyll *a* along the Albufera was observed using remote sensing images. Due to the lagoon's spatial complexity and the varying water qualities flowing in from more than 60 tributaries, remote sensing was the only approach that could obtain images simultaneously covering the entire lagoon. The data were used to explore the evolution, duration and intensity of the clear-water phase, and the lagoon's subsequent re-eutrophication. The duration and intensity of the clear-water phase varied across the lagoon, but complete water quality renovation occurred in 1 week. Our analysis demonstrates that rapid flushing could remediate the lagoon eutrophication.

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X. Sòria-Perpinyà (✉) · M. R. Miracle · J. Soria · E. Vicente
Cavanilles Institute of Biodiversity and Evolutionary Biology (ICBiBE), University of València, Campus Paterna, 46980 Paterna, València, Spain
e-mail: javier.soria-perpina@uv.es

J. Delegido
Image Processing Laboratory (IPL), University of Valencia, Scientific Campus, 46980 Paterna, València, Spain

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Introduction

Lake retention time (also called residence time or flushing time) is a well-established factor that influences lake ecology (Kalff, 2002). Retention time controls in-lake phosphorus concentrations, which affects the amount of phytoplankton (Elliott et al., 2009). Water and nutrient inputs are two key elements in the Albufera current hydrological cycle and are likely drivers of significant changes in the lagoon, such as clear-water phases (CWPs).

The hydrology of the Albufera lagoon is regulated by the local water council according with the needs of the surrounding agricultural lands, primarily rice paddies. The lagoon outflow to the Mediterranean Sea is regulated by sluice gates that are located on the outlet canals. From November to the beginning of January, the sluice gates are closed, and the lagoon water level is about 20 cm above the annual average. The pumps that drain the fields during cultivation are turned off, and the fields below lake level are flooded to encourage the decomposition of organic remains. During January and February, there is a higher water renewal rate at the lake. Flooded rice fields are pumped empty, water flows out to the sea through the Albufera open sluice gates, and the lagoon water level also falls. The rice fields remain dry until the beginning of May, when they are flooded again for cultivation. During rice planting, the sluice gates are partially closed to maintain a mean water flow and a mean water level (Miracle & Sahuquillo, 2002).

During higher water renewal periods, short-term clear-water events sometimes occur, with the chlorophyll *a* concentration ([Chl-a]) dropping below 5 µg l^{-1}. These intermittent events offer a unique perspective on the dynamics of this shallow coastal lagoon (Miracle & Sahuquillo, 2002; Romo et al., 2005). They are dependent largely upon the hydrological regime and result in a strong increase in water transparency that can last for up to 5 weeks. This transparency is associated with a reduction in phytoplankton biomass and a change in the plankton community composition that is characterized by a decline in cyanobacteria and an increase in chlorophytes and diatoms as well as the large cladoceran, *Daphnia magna* Straus (Sahuquillo et al., 2007; Onandia et al., 2014). CWPs are driven by several interrelated factors, including: (i) intense flushing induced by the draining of the rice paddies into the surrounding watershed, leading to a reduction in the phytoplankton biomass as it is transported from the lagoon to the sea; (ii) mild water temperatures that enhance the net growth of *D. magna*, and (iii) decreased fish predation on zooplankton caused by high fish catches during these periods (Romo et al., 2005).

In recent decades, CWP events were especially noticeable at the end of February or the beginning of March in 2000 and 2010 as well as in November 2015 and January 2017. Remote sensing provides a convenient tool with which to observe spatial variations in [Chl-a] along the Albufera and the associated changes in flows and hydrodynamics within this complex system. It also provides a method of simultaneously measuring the water quality in a lagoon with more than 60 tributaries. In 2000, two Landsat satellites were operational (Landsat 5 and 7), making it possible to obtain images every 8 days.

The satellite images from the 2000 CWP allowed us to observe how water enters the Albufera lagoon. The water input was of sufficient quantity and quality to affect the associated plankton community and generate the CWP. The analysis of this process can provide insights into how to prolong the CWP to remediate the lagoon eutrophication.

Materials and methods

Study site

The Albufera and Devesa Natural Park (Fig. 1) near Valencia (Spain), covers a surface area of 210 km^2 and contains a coastal oligohaline lagoon (Albufera of Valencia) with a mean depth of 1.0 m, a surface area of 23.2 km^2, a volume of 23×10^6 m^3, a salinity of 1–2‰ and a water renewal rate of about 10 times per year. Details of the main limnological features of the lagoon have been documented by Vicente & Miracle (1992).

Fig. 1 Study area: Albufera and Devesa Natural Park (solid line), drainage area of rice paddies (broken line) to Albufera lagoon, and sampling points on the lagoon

Methods

The CWP that occurred in 2000 was studied by Miracle & Sahuquillo (2002) when two Landsat satellites were operational. Eight remote sensing images were analyzed to provide information on spatial variations in [Chl-a] over January, February, and March. Landsat imagery was downloaded from the European Space Agency & United States Geological Survey Landsat archives; the dataset comprised two Landsat 5 images and six Landsat 7 images. ENVI software version 5 (Harris Corporation) was used for image processing and the QUAC tool was used to apply an atmospheric correction.

An algorithm to calculate [Chl-a] in the Albufera lagoon was adapted from the method of Zhou et al. (2004), using the ratio of band 4 (Near Infrared) to band 3 (Red) of Landsat 5 and the supporting field data. To calibrate the estimated data, water samples were collected using a hydrological water sampler from four different points within the lake (Fig. 1) between April 2013 and May 2015. Twenty-three sampling campaigns were completed, and 92 georeferenced samples were collected. Validation was performed using the [Chl-a] values from the Generalitat Valenciana historical database that coincided with five of the eight selected images within a time window of 1 day. We were able to use 23 values for the comparison between the estimated data and the field data; their adjustment was verified with a linear regression and the root mean square error (RMSE) was calculated.

For our samples, [Chl-a] was measured in the laboratory using a spectrophotometric method. Samples were filtered through 0.4–0.6-µm GF/F glass-fiber filters. [Chl-a] was extracted using standard methods (Shoaf & Lium, 1976) and the calculation methods of Jeffrey & Humphrey (1975).

A key factor in the occurrence of CWP events is the volume of good-quality water flowing into the lagoon from the surrounding area. To determine the volume of water in the flooded fields that drain into the Albufera, we used the relationship established between the value of the Normalized Difference Water Index and the observed water depth in the selected field areas as reported by Soria et al. (2015). We derived the accumulated water volume in the flooded fields from the weighted average depth and the size of the flooded areas.

Results

After adapting the equation of Zhou et al. (2004) to the Albufera lagoon using field data, we obtained the following equation:

$$[\mathrm{Chl}\ a] = 216.73\,(\mathrm{B4}/\mathrm{B3}) + 15.754$$

where B4 = band 4 (near infrared) and B3 = band 3 (red) of the Landsat 5 and 7 images.

The algorithm calibration was made with a linear regression to relate the field data to the ratio of band 4 to band 3. This resulted in a correlation coefficient, r Pearson, of 0.83 from 92 samples, placing the degree of significance at less than 0.001.

To validate the applied algorithm, the linear regression method was used to compare the field data and the values estimated by the algorithm from the 2000 CWP Landsat images (Fig. 2). We obtained a R^2 of 0.93 from 23 samples. Regarding the calculated error, the RMSE reached a value of 29 $\mu g\ l^{-1}$.

The volume of water draining from the flooded paddy fields into the lagoon was estimated from an image taken on 29 January 2000 and found to be about $58 \times 10^6\ m^3$, which is twice the volume of the lagoon. About half of this amount entered the lagoon before the CWP occurred.

By applying the algorithm to L5 and L7 images we obtain maps of [Chl-a] that allow us to observe the spatial and temporal variations. The sequence of images selected (Fig. 3) shows the water clearing process of 2000 that began at the end of January. It started from the northern and southern shorelines of the lagoon (Fig. 3A), continued along the western shoreline (Fig. 3B), and finally reached the central and eastern parts of the lagoon (Fig. 3C, D) where canals connect it to the sea.

In the eight images processed over the entire CWP, it is possible to see the way in which the flooded rice paddy area drained. Within 7 days, approximately half of the total water capacity of the fields (more than $23 \times 10^6\ m^3$) had been discharged into the sea. As the capacity of the Albufera is $23 \times 10^6\ m^3$, the maximum [Chl-a] reduction was reached in only 7 days, between February 7 and February 15, 2000. In the last image (Fig. 3D), the [Chl-a] is increasing at the south and northwest even though the fields have not yet been completely emptied.

A similar process occurred during the re-eutrophication sequence (Fig. 4), but in double the amount of

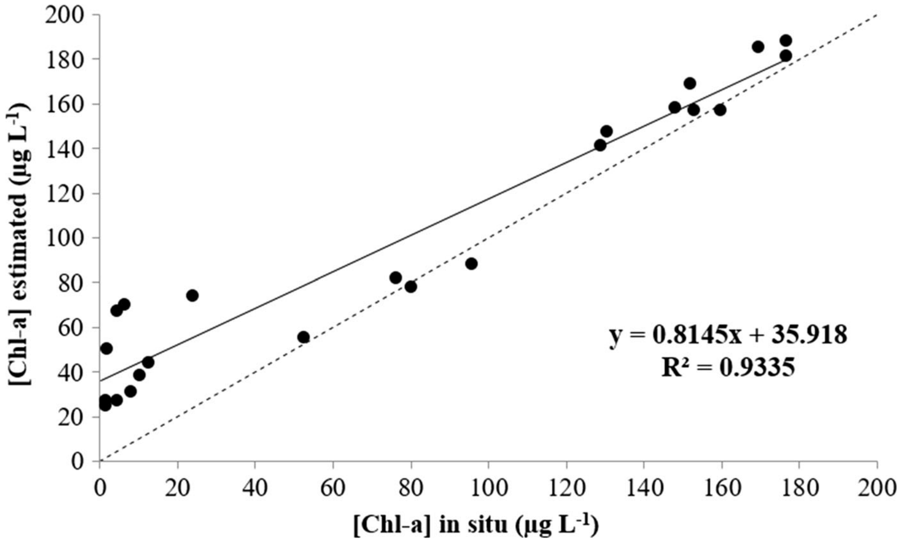

Fig. 2 Algorithm validation with field data. Solid line: lineal regression between in situ and estimated data. Broken line:straight line 1:1

time. After the CWP, the re-eutrophication started from the northwest and southern shorelines (Fig. 4A). Once the drainage process was complete, the re-eutrophication moved east where the canals that connect the lagoon to the sea are located (Fig. 4B). During re-eutrophication, higher [Chl-a] levels were achieved at the beginning of the process (Fig. 4C), eventually returning to annual average concentrations of more than 150 µg l^{-1} (Fig. 4D).

In summary, the mean [Chl-a] concentrations of the entire water surface from estimated values, for the eight processed images (Table 1), show a rapid process. The [Chl-a] concentration initial levels dropped until February 15; then it increased to higher than the initial concentrations, recorded on March 17, before returning to initial levels.

Discussion

Remote sensing provided an efficient and low-cost way to observe the phenomenon of water clarification across the entire surface of the Albufera lagoon. This demonstrates the advantages offered by remote sensing over in situ field monitoring methods (both conventional and new). In addition, remote sensing allows the knowledge of the lagoon for a total coverage with temporal concurrent data. The [Chl-a] estimated values from Landsat images are possibly due to the accuracy of the algorithm adapted to the Albufera lagoon, as demonstrated by the validation results. The RMSE of 29 µg l^{-1} is similar to that obtained by Doña et al. (2014) of 30 µg l^{-1} using the ratio of band 2 to band 4 from Landsat 5. If we use the mean value of the estimated validation data (98.34 µg l^{-1}), the error rate is 29%, similar to the 20% obtained by Lopez Garcia & Caselles (1990) using Landsat 5.

CWPs occur in the Albufera because agricultural activity stops throughout winter. The flooded rice paddies act like a large green filter, reducing the water nutrient load, and *D. magna* densities rise to high levels both in the paddies and the lagoon. When the flooded rice paddies are emptied, quality water enters from around the entire lagoon perimeter, causing total water renewal over a short period. In contrast, at other times of the year, water flows in at specific points and then out to the sea through the lagoon outlets, causing only partial water renewal in the lagoon. It shows in Fig. 4B and C, the blue zone located at the south-eastern part of the lagoon. This is due to the water entrance from the *sèquia* of Overa (a man-made irrigation canal).

During most of the year, the Albufera remains turbid, and is considered a hypertrophic lagoon, but during CWP periods, [Chl-a] levels reach mesotrophic and even oligotrophic ranges in many zones. The duration and intensity of the CWP varies across the lagoon, creating spatial heterogeneity as shown in Figs. 3 and 4. In 1987, Reynolds & Lund argued on a study of Grasmere Lake that the key factor that allowed the lake to resist a more complete transition to a typical eutrophic plankton environment appeared to

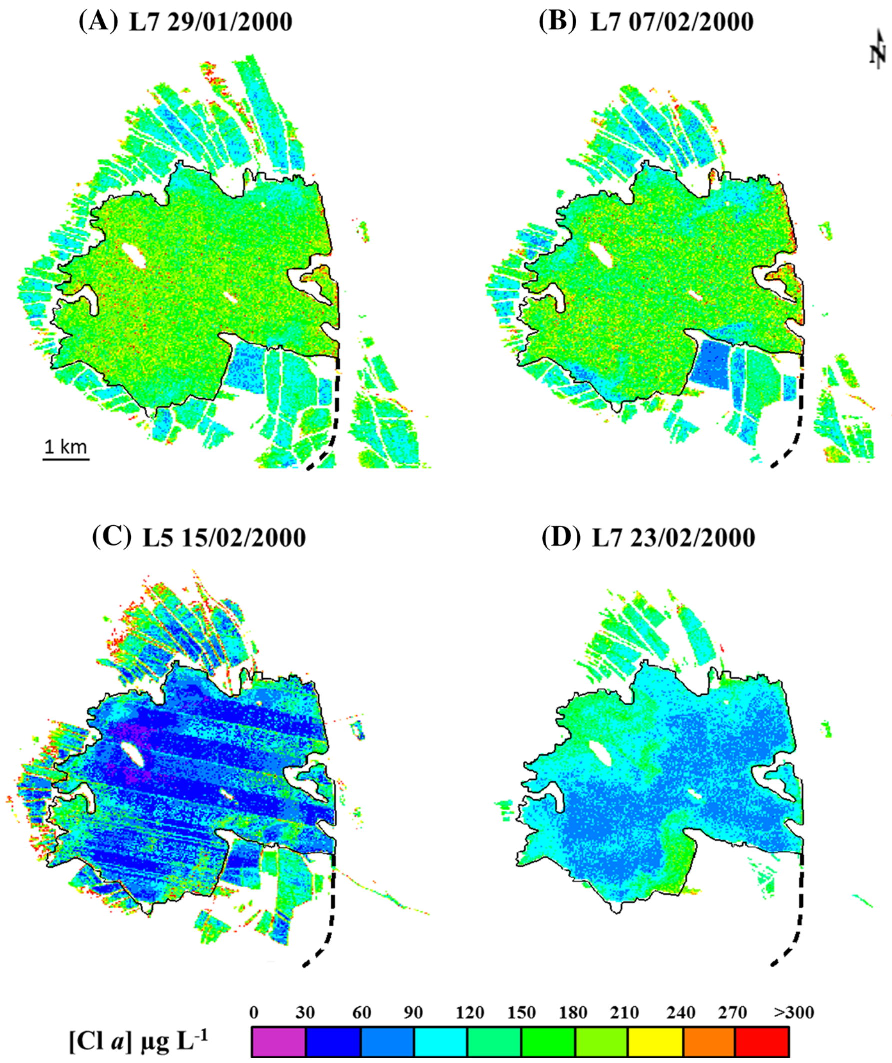

Fig. 3 Clear-water event using processed images of Landsat 5 (L5) and Landsat 7 (L7) to create thematic maps of [Chl-a]. *Note*: The banding in the Landsat 5 image, in this case a Memory Effect, causes banding-like patterns that change in magnitude across a scan

be the efficiency of episodic flushing during periods of high fluvial discharge sustained by heavy rainfall over the extensive mountainous catchment. Hydrological constant flushing rates dilute sewage-derived nutrients (especially phosphorus, in which the lake becomes deficient at times) as well as the displacement of standing crops of over abundant and undesirable phytoplankton species are thought to have an ameliorating effect on water quality (Reynolds et al., 2012). That strong water renewal might improve the lagoon's ecological status is also suggested by a survey carried out by Dumont & El-Shabrawy (2007) at a lagoon in the Nile delta. In that survey, rice and other crops released huge amounts of nutrients that washed down the drains into the watershed. The lagoon became eutrophied and only resisted hypertrophy because of the low residence time of its waters.

In the case of the Albufera lagoon, is it the high water renewal rate or the zooplankton filtration capacity that drastically reduces [Chl-a]? Our information suggests that CWP events cause a decline in the numbers of cyanobacteria and an increase in the levels of chlorophytes and diatoms as well as the large cladocera (such as *D. magna*) (Sahuquillo et al., 2007; Onandia et al., 2014). The study of the 2000 CWP event by Miracle & Sahuquillo (2002), provides data on the changes in the number of *D. magna* individuals. On February 7 (Fig. 3B), when one-third of the fields were emptied, there were about 100 ind. l^{-1} of *D. magna*. By February 15 (Fig. 3C), when [Chl-a]

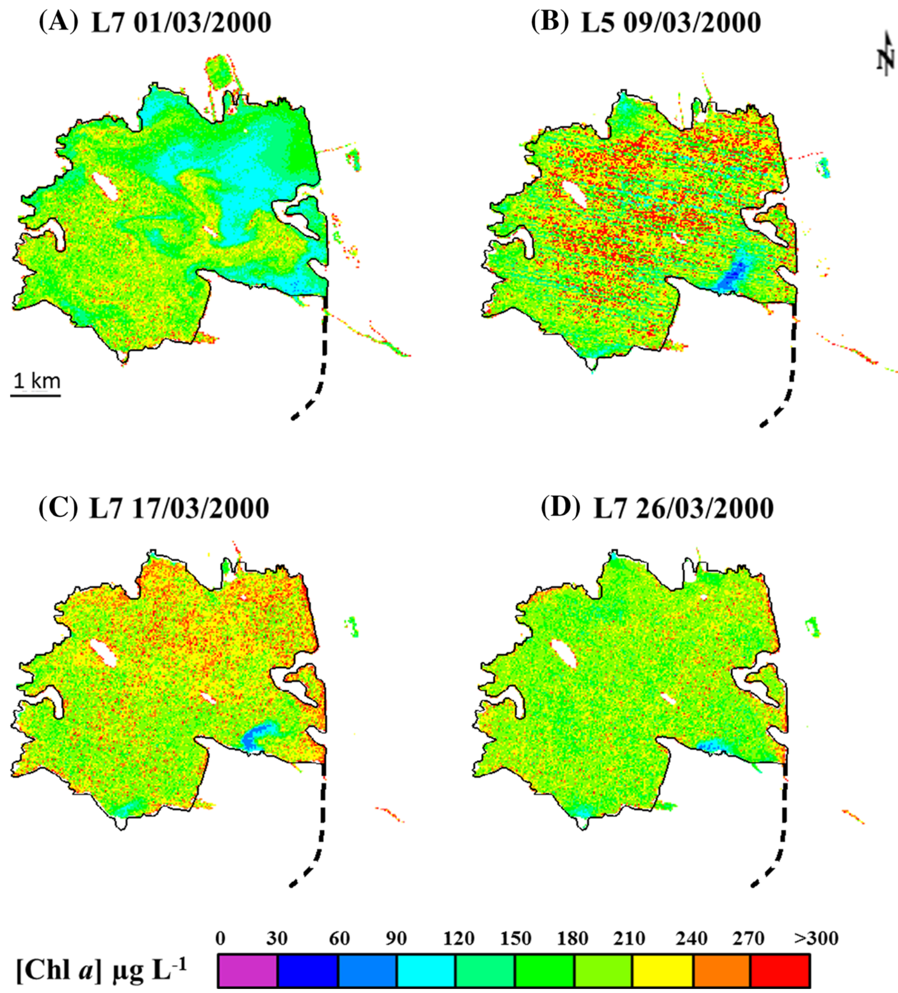

Fig. 4 Re-eutrophication using processed images of Landsat 5 (L5) and Landsat 7 (L7) to create thematic maps of [Chl-a]. *Note*: The banding in the Landsat 5 image, in this case a Memory Effect, causes banding-like patterns changing in magnitude across a scan

Table 1 Temporal changes of chlorophyll *a* concentration in the lagoon using the mean of values of the entire water surface from estimated values. Maximum and minimum values are also indicated

Day	[Chl-*a*] (µg l^{-1})		
	Mean	Min.	Max.
January 29	211	49	487
February 07	196	44	493
February 15	76	24	278
February 23	92	32	266
March 01	182	37	400
March 09	207	47	563
March 17	252	73	457
March 26	220	72	383

reached minimum values, only a few additional fields had been emptied, and the density of *D. magna* dropped to 20 ind. l^{-1}. Finally, on February 22 (Fig. 3D), after almost all the fields had been drained, the *D. magna* density increased to more than 300 ind. l^{-1}. This indicates that the number of *D. magna* individuals is directly related to the volume of water entering the lagoon.

In eutrophic lakes, phytoplankton include dominant organisms that are protected against grazing by their large size (Sommer et al., 1986). Experiments in the Albufera carried out in March 2011 and May 2012 by Onandia et al. (2015a) determined that the clearance rates of *D. magna* were low (0.3 ml ind.$^{-1}$ h^{-1}), likely due to the high abundance of filamentous cyanobacteria (30.6×10^3 filaments ml^{-1}). In this study, the phytoplankton biomass in March 2011 was 38 mm^3

l^{-1}. By May 2012, the biomass was 143 mm^3 l^{-1}. Romo et al. (2008) studied the phytoplankton trend in the Albufera for the 1998–2006 period. They found that the phytoplankton biomass was 100 mm^3 l^{-1} in January, less than 50 mm^3 l^{-1} in February–March and more than 100 mm^3 l^{-1} in the rest of the year. We suggest that the phytoplankton annual evolution in the lagoon does not vary substantially from year to year, since the system is dependent upon water management, which in turn depends on the needs of the rice cultivation.

However, these large phytoplankton species are affected by density-independent losses caused by flushing and settling (Scheffer, 1998), so flushing a lake with clean water can help eliminate colonial cyanobacteria (Scheffer, 1998). Flushing pulses in the range of 1–2% of the lake volume per day at a high enough frequency (20–30 d) are considered effective in preventing increases in cyanobacterial biomass (Padisák et al., 1999). Even small increases in the flushing rate can lead to the disappearance of slow-growing cyanobacteria if nutrient reduction has already occurred (Scheffer, 1998).

Other authors have expressed the need to increase the Albufera lagoon's renewal with quality water. Onandia et al. (2015b) urged that the intake of quality water with low concentrations of phosphorus and nitrogen should be the main priority for local management efforts, since these external loadings have been identified as the predominant drivers of the lagoon system dynamics. Similarly, Romo et al. (2008) wrote about the need to increase the lagoon water renewal with quality water that was low in nutrients and flow rates close to those between January and March.

Key factors leading the occurrence of CWP events are the water inflow with low nutrient concentration in addition to a significant density of cladocerans (mainly *D. magna*) to dilute the presence of filamentous cyanobacteria, to favor the presence of diatoms, chlorophyceae, etc. and grazing zooplankton. This suggests that a slower emptying of the flooded fields would prolong the low concentration of filamentous cyanobacteria in the lagoon and extending a CWP, where cladocerans greazing would be crucial.

The current CWPs, when they occur, are too short (2 weeks) to be effective. Since it is not necessary to achieve a complete renovation of the lagoon, modifying the intensity and duration of the flushing pulses could extend the CWP until spring, enhancing macrophyte growth that stabilizes sediments and reduces recycling (Scheffer et al., 1993).

At present, the local water council is mainly under the direction of the farmers. Therefore, agricultural needs are prioritized above returning the lagoon to its natural clear-water state. The current water management policy of the administration seems to impose hydrological conditions of the lagoon and its surrounding ecosystems (Soria, 2006), making it difficult to improve the biological quality of the lagoon and to maintain the Park's wetlands (Romo et al., 2008).

In addition, the stated goal of the Júcar Basin Authority in its Watershed Program for the years 2015–2021 is to reduce the Albufera lagoon [Chl-a] to 30 µg l^{-1} by 2027. This value would classify the Albufera as a eutrophic lagoon under the EU Water Framework Directive (EWFD), which is insufficient to comply with the EWFD requirements.

The recovery of the Albufera lagoon requires quality inflows, elimination of nutrient inputs, and a water management strategy that prioritizes the lagoon environmental needs over other economic interests.

Conclusions

The algorithm to estimate the [Chl-a] from Landsat images is consistent and suitable for use within Landsat 4, 5, and 7 images, as they use bands at the same wavelength. This allows for long-term studies of the lagoon entire surface, specifically since 1984.

This study demonstrates the need for improved inflow water quality to return the Albufera to its previous oligotrophic state. The current CWPs, when they occur, are too short (2 weeks) to be effective. Modifying the intensity and duration of the flushing pulses could prolong the CWP through the spring, enhancing macrophyte growth and further extending the CWP.

Flushing pulses could be reassessed and redesigned as restoration measure that would contribute to the recovery of the Albufera, recreating a clear lagoon with beneficial biodiversity.

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References

Doña, C., J. M. Sánchez, V. Caselles, J. A. Domínguez & A. Camacho, 2014. Empirical relationships for monitoring water quality of lakes and reservoirs through multispectral images. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 7: 1632–1641.

Dumont, H. J. & G. M. El-Shabrawy, 2007. Lake Borullus of the Nile Delta: a short history and an uncertain future. AMBIO 36: 677–682.

Elliott, J. A., I. D. Jones & T. Page, 2009. The importance of nutrient source in determining the influence of retention time on phytoplankton: an explorative modelling study of a naturally well-flushed lake. Hydrobiologia 627: 129–142.

Jeffrey, S. T. & G. F. Humphrey, 1975. New spectrophotometric equations for determining chlorophylls *a*, *b*, *c1* and *c2* in higher plants, algae and natural phytoplankton. Biochemie und Physiologie der Pflanzen 167: 191–194.

Kalff, J., 2002. Limnology: Inland Water Ecosystems. Prentice Hall, Upper Saddle River.

Lopez Garcia, M. J. & V. Caselles, 1990. A multi-temporal study of chlorophyll-a concentration in the Albufera lagoon of Valencia, Spain, using Thematic Mapper data. International Journal of Remote Sensing 11: 301–311.

Miracle, M. R. & M. Sahuquillo, 2002. Changes of life-history traits and size in *Daphnia magna* during a clear-water phase in a hypertrophic lagoon (Albufera of Valencia, Spain). Verhandlungen des Internationalen Verein Limnologie 28: 1203–1208.

Onandia, G., M. R. Miracle & E. Vicente, 2014. Primary production under hypertrophic conditions and its relationship with bacterial production. Aquatic Ecology 48: 447–463.

Onandia, G., J. D. Dias & M. R. Miracle, 2015a. Zooplankton grazing on natural algae and bacteria under hypertrophic conditions. Limnetica 34: 541–560.

Onandia, G., A. Gudimov, M. R. Miracle & G. Arhonditsis, 2015b. Towards the development of a biogeochemical model for addressing the eutrophication problems in the shallow hypertrophic lagoon of Albufera de Valencia, Spain. Ecological Informatics 26: 70–89.

Padisák, J., J. Köhler & S. Hoeg, 1999. The effect of changing flushing rates on development of late summer Aphanizomenon and Microcystis populations in a shallow lake, Müggelsee, Berlin, Germany. In Tundisi, G. & M. Sraskraba (eds), Theoretical Reservoir Ecology and its Applications. International Institute of Ecology, Brazilian Academy of Sciences & Backhuys, Leiden: 411–423.

Reynolds, C. S. & J. W. G. Lund, 1987. The phytoplankton of an enriched, soft-water lake subject to intermittent hydraulic flushing (Grasmere, English Lake District). Freshwater Biology 19: 379–404.

Reynolds, C. S., S. C. Maberly, J. E. Parker & M. M. De Ville, 2012. Forty years of monitoring water quality in Grasmere (English Lake District): separating the effects of enrichment by treated sewage and hydraulic flushing on phytoplankton ecology. Freshwater Biology 57: 384–399.

Romo, S., M. J. Villena, M. Sahuquillo, J. M. Soria, M. Gimenez, T. Alfonso, E. Vicente & M. R. Miracle, 2005. Response of a shallow Mediterranean lake to nutrient diversion: does it follow similar patterns as in northern shallow lakes? Freshwater Biology 50: 1706–1717.

Romo, S., A. García-Murcia, M. J. Villena, V. Sánchez & A. Ballester, 2008. Tendencias del fitoplancton en el lago de la Albufera de Valencia e implicaciones para su ecología, gestión y recuperación. Limnetica 27: 11–28.

Sahuquillo, M., M. Melão & M. R. Miracle, 2007. Low filtering rates of *Daphnia magna* in a hypertrophic lake: laboratory and in situ experiments using synthetic microspheres. Hydrobiologia 594: 141–152.

Scheffer, M., 1998. Ecology of Shallow Lakes: Population and Community Biology Series 22. Kluwer Academic Publishers, Dordrecht.

Scheffer, M., H. Hosper, M. L. Meijer, B. Moss & E. Jeppesen, 1993. Alternative equilibria in shallow lakes. Trends in Ecology and Evolution 8: 260–262.

Shoaf, W. T. & B. W. Lium, 1976. Improved extraction of chlorophyll *a* and *b* from algae using dimethyl sulphoxide. Limnology and Oceanography 21: 926–928.

Sommer, U., Z. M. Gliwicz, W. Lampert & A. Duncan, 1986. The PEG-model of seasonal succession of planktonic events in fresh waters. Archiv für Hydrobiologie 106: 433–471.

Soria, J. M., 2006. Past, present and future of la Albufera of Valencia Natural Park. Limnetica 25: 135–142.

Soria, J. M., S. Romo, T. Aledón, J. F. Izquierdo & S. Calvo, 2015. Estudio de la inundación otoñal en el Parque Natural de la Albufera de Valencia mediante imágenes de Landsat. In Proceedings of the XVI Congreso de la Asociación Española de Teledetección. Estación Biológica de Doñana (Sevilla, Spain): 370–373.

Vicente, E. & M. R. Miracle, 1992. The coastal lagoon Albufera de Valencia: an ecosystem under stress. Limnetica 8: 87–100.

Zhou, W., S. Wang & Y. Zhou, 2004. Determination of chlorophyll a content of the Lake Taihu, China using Landsat-5 TM data. Proceedings of IEEE-International Geoscience and Remote Sensing Symposium. September 20–24, 2004. Anchorage, AK, USA: 4893–4896.