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A spatial approach to climate-resilient infrastructure in coastal social-ecological systems: The case of *dumbeong* in Goseong County, South Korea

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ABSTRACT

Sustainable landscape planning and management of coastal habitats has become an integral part of the global agenda due to anthropogenic pressures and climate change-induced events. As an example of human-engineered infrastructure that enhances the sustainability and resilience of coastal social-ecological systems (SES), we have presented the *dumbeong* system, a farmer-engineered and managed irrigation system based on Korean traditional ecological knowledge. We analyzed the spatial relationship of *dumbeongs* with coastal landscape attributes and droughts in Goseong County in South Korea. We used generalized linear models (GLMs) to examine the effects of land cover and recent (2001–2010) standardized precipitation index (SPI) on the abundance of *dumbeongs*. Then, we projected near future (2020–2050) changes in the SPI-based drought risk for the *dumbeong* system using representative concentration pathway (RCP) climate scenarios. We found that forest and marine water areas have positive relations with *dumbeong* abundance, whereas SPI has a negative relation, indicating that the *dumbeongs* are more abundant in areas close to sea water and forests, and with higher incidences of drought. Derived climate change scenarios show that the study region will experience higher incidence of drought. Our findings provide empirical evidence for the *dumbeong* system as an effective community designed and driven adaptive response to local hydrological processes and climatic conditions, and as climate-resilient infrastructure that strengthens sustainability and resilience of coastal SES. Based on our findings, we provide recommendations for sustainable landscape management and optimal use of the *dumbeong* system in coastal regions.

1. Introduction

Koreans have traditionally developed locally appropriate solutions for harvesting water in rural agricultural landscapes to adapt to spring droughts and the mountainous terrain of South Korea. For example, Korean communities have engineered and intergenerationally managed appropriately located and scaled agricultural ponds called *dumbeongs* that store freshwater and rainwater for irrigation in crucial farming periods (Yoon et al., 2019). The location of a *dumbeong* is selected to optimize the collection and distribution of groundwater or spring water in relation with other landscape elements such as streams and rice paddy fields (Fig. 1a).

Landscape-based management and knowledge for efficient water harvesting is a common theme in Korean traditional ecological knowledge (TEK) (Kim et al., 2017a, 2017b). Korean farmers have relied on their TEK, developed over thousands of years of ecological, climatic, and cultural experience, to create a village landscape that has sustained agricultural productivity and livelihoods (Kim et al., 2017a). This village landscape forms a complex social-ecological system interacting across spatial and temporal scales (Kim et al., 2017b), and displays unique spatial characteristics. For example, studies of cultivated communal village groves, a representative landscape element in Korean traditional villages, show that the occurrence of the groves is related to village population size, forest cover, precipitation in the coldest quarter of the year, and mean diurnal range in temperature (Kim et al., 2018). Thus, it is plausible to assume that the occurrence of the *dumbeong*, also a representative landscape element in Korean villages, is related to geographic and climatic conditions of rural communities in Korea.

In our study, we analyze the *dumbeong* through the perspective of resilience of social-ecological systems (SES). The resilience concept highlights the interplay of system components across temporal and spatial scales (Cumming et al., 2013; Folke, 2006), and the capacity of a system to respond to disturbance, as well as absorb, internalize, and transcend stress

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(Berkes et al., 2000). We approach the *dumbeong* as a small-scale, human-engineered, and agency-managed landscape element characterized by close interactions among the three core components of resilient infrastructure (Yu et al., 2015): (1) soft human-made infrastructure, that is, knowledge and social institutions developed over generations; (2) hard human-made infrastructure, that is, the physical components of the *dumbeong* that have been optimized in scale, location, and function; and (3) the natural infrastructure, that is, the synergy of natural upstream and downstream landscape elements to optimize hydrological processes. Through the dynamics of these components, the *dumbeong* system, that is, a number of farmer-managed, relatively small-scale ponds that optimize the use of groundwater and rainwater, supports SES resilience by retaining water in critical climatic periods and sustaining local biota (Kim et al., 2016; Yoon et al., 2019).

Examination of the ecologically and socially embedded design, functions, and management practices of the *dumbeong* system can provide insights towards policy-driven landscape planning for enhancing SES resilience (Yu et al., 2015). Prior studies of collective action dynamics and interactions in an agency-managed irrigation system (AIS) from an SES perspective have focused primarily on the soft human-made infrastructure and natural infrastructure, while overlooking sustainability of the physical components (hard human-made infrastructure). For example, recent studies of *dumbeong* have highlighted its ecological function as a wetland that enhances local biodiversity by coupling with local socio-hydrological processes (Kim et al., 2016; Yoon et al., 2019). While ecological functions of *dumbeong* are important to examine for biodiversity conservation planning, physical factors such as neighboring land cover or climatic conditions that have presumably influenced the distribution of *dumbeong* are also significant to be addressed to understand the sustainability of *dumbeong* to function as climate-resilient infrastructure.

We hypothesize that *dumbeong*s are spatially related with landscape attributes and climatic conditions. To test this hypothesis, we analyze the spatial, functional, and planning characteristics of the *dumbeong*s in a selected study site in South Korea, by examining the relationship of the *dumbeong* system to landscape elements (land cover) and climatic factor (drought events). We further generate climate projections for the selected study to discuss the future climatic conditions, and relevance of and conservation challenges for the *dumbeong* system.

2. Materials and method

2.1. Study system

South Korea is a peninsula and its population is generally concentrated in coastal areas, with two-thirds of the country's terrain being

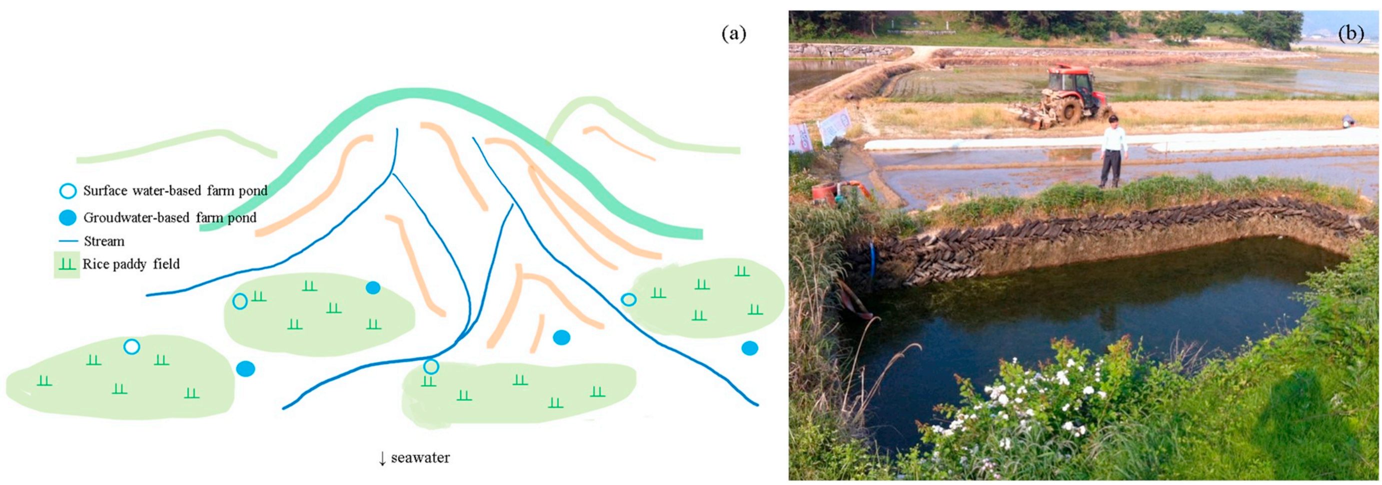

Fig. 1. Conceptual illustration of the *dumbeong* system in a coastal agricultural landscape (a) and a photo of a dumbeong in a rice paddy field in Goseong County, South Korea (b); taken by the first author in 2012.

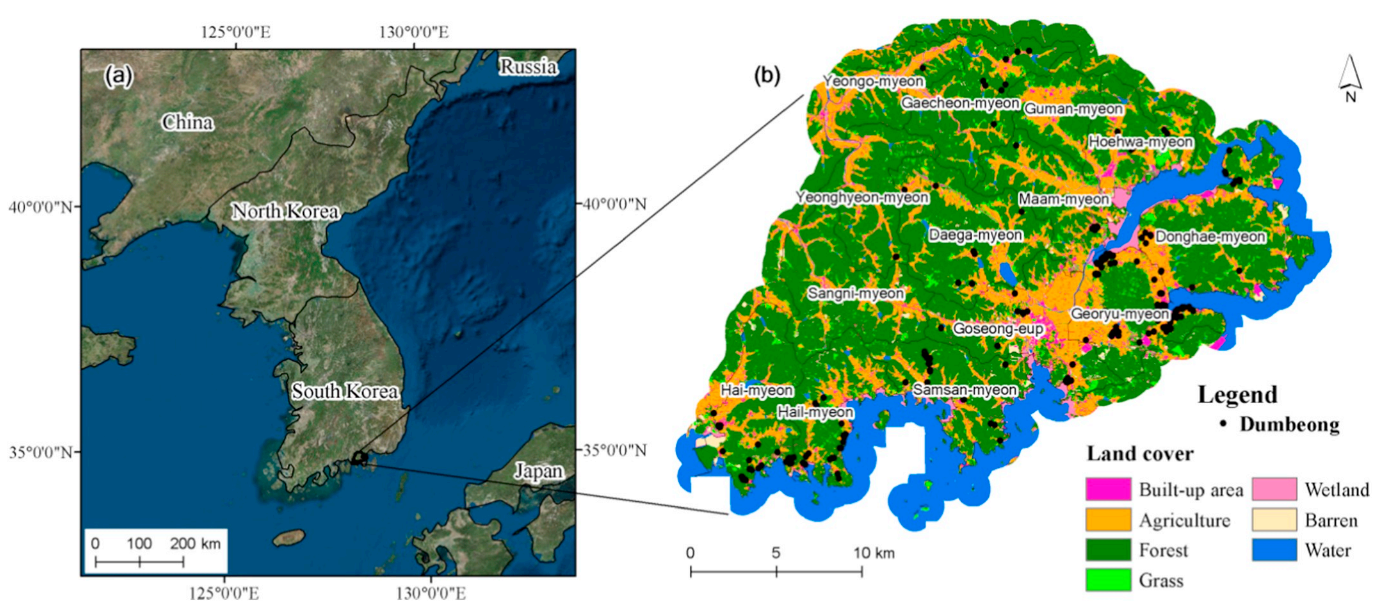

Fig. 2. Geographical location of Goseong County in South Korea and *dumbeong*s in Goseong County. Panel (a) shows a satellite image of the Korean Peninsula in Northeast Asian region (ESRI, 2019). Panel (b) shows the landcover of Goseong County and *dumbeong* distribution (n = 237).

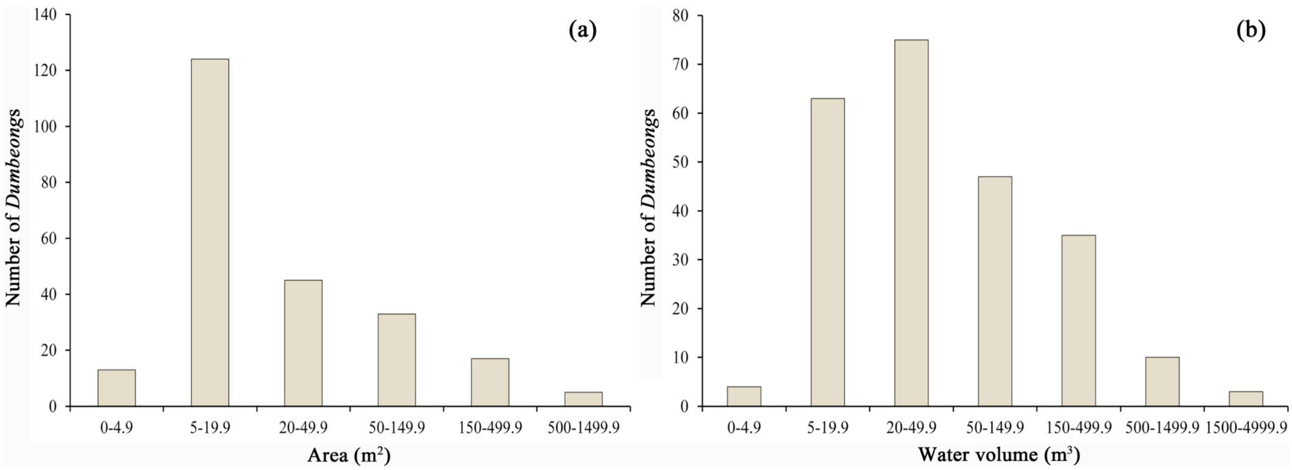

Fig. 3. Frequency graphs of area (m^2) and water volume (m^3) of *dumbeongs* in Goseong County, South Korea (n = 237).

mountainous. As a result, agriculture, predominantly rice farming, has been practiced in the gently sloped lands around the coast. The selected study area of Goseong County, a southern coastal county, has a history of droughts, and has over 200 *dumbeongs* that function as secondary water sources and support a distinct cultural and agricultural landscape (Fig. 1). Owing to its cultural significance, the *dumbeong* system in Goseong County will be designated as National Agricultural Heritage in 2019. While the Goseong County local government plans to develop its *dumbeong* system as an ecotourism site, as a means to conserve the system, local news stories report that some local farmers have raised their demand for a large dam to ensure reliable water supply in periods of drought.

The local government of Goseong County surveyed and reported the data of 237 *dumbeongs* (Goseong-gun, 2011), which includes global positioning system (GPS) coordinates, management conditions, water source, size, depth, and volume. We manually edited some of the GPS mis-locations of *dumbeongs* by inspecting high resolution satellite images from 2017 provided by Kakao Corp, South Korea (Fig. 2). Goseong County has 14 administrative divisions called *myeon*, referring to a local township. We conducted all our analyses with data at the *myeon* level, as it is an appropriate spatial scale for our analysis. We found that farmers demanding for a dam are from *myeons* with fewer *dumbeongs* (in the northern part of Goseong County in Fig. 2b).

The *dumbeongs* in Goseong County are located on average of 600 m distance from the primary water source such as reservoir or stream. The area of the *dumbeongs* ranges from 3 m^2 to 1300 m^2 with an average area of 59.34 m^2 (Fig. 3a); water volume ranges from 3.3 m^3 to 3900 m^3 (Fig. 3b); and the depth of the *dumbeongs* ranges from 30 cm to 460 cm. The descriptive statistics of the data are summarized in Table 1.

Table 1
Descriptive statistics of *dumbeongs* in Goseong County, South Korea. (Data source: Goseong-gun, 2011).

	Min	Max	Mean	Median	SD
Area (m^2)	3.00	1300.00	59.34	16.50	132.41
Water volume (m^3)	3.30	3900.00	141.49	37.10	348.90
Depth (cm)	30.00	460.00	228.07	227.50	75.22
Water source	Groundwater: 196, surface water: 39, both: 2				

2.2. Data analyses

We used generalized linear models (GLMs) with a log link function assuming a Poisson distribution, to examine the effect of land cover patterns and drought events on the abundance of *dumbeongs* at the *myeon* level. The forest land, agricultural land, and inland and marine water areas were calculated using a fine-scale (1:5000) 2012 land cover map and ArcGIS 10.1 (ESRI, 2012). We chose forest land, agricultural land, and inland and marine water areas as factors because they represent the source of water (forest land and inland water area), the likely location of *dumbeongs*, and areas where saline water causes agricultural challenges.

The standardized precipitation index (SPI), which indicates higher incidences of drought when the values are lesser (≤ -1), was used to estimate yearly drought conditions in 14 *myeons* using monthly precipitation data and the Meteorological Drought Monitor (MDM) tool (AgriMetSoft, 2017). The monthly precipitation data for 2001–2010 was collected from the Korean Climate Change Information Center database (www.climate.go.kr), which is derived from the Modified-Korean Parameter-elevation Regressions on Independent Slopes Model (MK-PRISM) for high-resolution gridded precipitation data (Kim et al., 2012). The observed data, interpolated based on elevation, distance, topographic facets, and coastal proximity, were averaged for each *myeon*. To analyze the effect of climate, we calculated the SPI for 2001–2010 with monthly precipitation data and used the median SPI for each *myeon*.

We generated Poisson models using package stats (Chambers and Hastie, 1992) in R (3.5.2) software (R Core Team, 2018) for identifying predictors for *dumbeong* abundance. Models were ranked using the MuMIn package in R (Barton, 2011) according to their Akaike's Information Criteria corrected for small sample size (AICc) (Anderson and Burnham, 2002). We presented the AICc value of the best model, and examined the significance of the land cover and climatic variables if they were included in the model. In addition, we presented the most parsimonious models with ΔAICc < 4. If the models had more than two independent variables, we assessed the relative importance of each independent variable using the MuMIn package in R. All independent factors were log-transformed (log [x + 1]) to improve normality. Before executing GLMs, we checked multicollinearity between all predictor variables by performing Pearson's correlations. The results showed that no variables were highly correlated (|r| < 0.7).

Future climate projections were obtained from the Korean Climate Change Information Center database (www.climate.go.kr) at 1 km resolution for the years 2020–2050. These were developed on the basis of a model that coupled with a regional climate model (HadGEM3-RA) and the MK-PRISM. The HadGEM3-RA model is based on version 3 of the Hadley Centre Global Environment Model (HadGEM3; Hewitt et al., 2011).

We calculated the annual SPI index from 2020 to 2050 by using future precipitation data obtained from climate change scenarios based on Representative Concentration Pathways (RCPs) 4.5 and 8.5 (Moss et al., 2010). The RCPs have been used in the IPCC fifth assessment report (AR5) and are based on atmospheric CO_2-equivalent concentrations rather than direct emissions. The RCP 4.5 (low scenario) represents the radiative forcing level at 4.5 W/m^2 by the year 2100 and stabilizing after 2100 with 650 ppm CO_2-equivalent (Thomson et al., 2011), whereas RCP 8.5 is a business-as-usual emission scenario with the radiative forcing level expected to reach 8.5 W/m^2 by 2100 with 1370 ppm CO_2-equivalent (Riahi et al., 2011). In our study, RCPs 4.5 and 8.5 are adopted to identify discriminative patterns and trends in predicted precipitation changes to the meteorological drought. Under RCPs 4.5 and 8.5 scenarios, annual mean temperatures of South Korea in the year 2050 will increase by 1.9 °C and 3.0 °C, respectively, compared to the current mean of 11.3 °C.

3. Results

The non-zero coefficients of land cover (forest and marine water areas) and the SPI factors in the models were significant ($p < 0.05$). Forest and marine water areas had positive effects on the number of *dumbeongs* at the *myeon* level, while SPI had a negative effect. The relative importance of the three significant variables was 1, 1, and 0.93, respectively (Table 2).

Our result shows that there will be higher incidences of drought in the future under both scenarios. Severe droughts are expected between years of 2031–2033 and of 2037–2038 under RCP 4.5 (Fig. 4a). Overall, higher incidences of drought were expected under RCP 8.5 (Fig. 4b).

4. Discussion

Our research tested the hypothesis of the spatial context of *dumbeongs* by analyzing the abundance of *dumbeongs* in relation to land cover patterns and drought events, and further examined how the future climate change scenarios are likely to impact the sustainability and functioning of *dumbeongs* as climate-resilient infrastructure. We found that most *dumbeongs* are positively related with forest and marine water areas, and negatively related with the SPI index, with similar relative importance (1, 1, and 0.93, respectively). This indicates that most *dumbeongs* in Goseong County are located in coastal areas (marine water area) with neighboring forested areas (forest area) and higher incidences of drought.

The *dumbeong* system in Goseong County displays important aspects of a complex adaptive SES, particularly polycentric distribution, multilevel or multiscale stakeholders, and resistance to disturbances. In adaptive water management, the stakeholders involved and the social-ecological information used and shared are critical to the management process (Pahl-Wostl et al., 2007). Our results imply that Goseong County farmers, the main stakeholders, relied on their TEK and collective participation to build and manage their *dumbeongs* in adaptive response to local hydrological processes, landscape, and climatic conditions. Local studies conducted on the characteristics of wetlands in Gyeongsangnam-do, a southern province in South Korea, show that most of the isolated wetlands have a specific association to the local landscape and are often located next to rice paddy fields (Doh et al., 2012); this supports the findings of the *dumbeong*'s spatial characteristics. Watershed-based management or the use of landscape patches often appear in traditional management systems that have utilized TEK (Berkes et al., 2000) and contributed to the conservation of local biodiversity.

Table 2
Summary of model selection statistics for predicting the number of *dumbeongs* with forest area, marine water area, inland water area, agricultural area, and SPI, showing the most parsimonious models (ΔAICc < 4) with a Poisson error distribution.

Response	Model	AICc	ΔAICc	*w*AICc	Adj. r^2	Relative variable importance
Dumbeong	Forest area* + Marine water area*–SPI*	90.64	0.00	0.64	0.87	Forest area = 1, Marine water area = 1, SPI = 0.93, Inland water area = 0.25, Agricultural area = 0.18
	Forest area* + Marine water area*–SPI* + Inland water area	93.09	2.45	0.19	0.88	
	Forest area* + Marine water area*–SPI* + Agricultural area	93.23	2.58	0.18	0.88	

An asterisk (*) indicates significant variables (p < 0.05).
Adj. r^2 indicates the McFadden's adjusted r^2 (McFadden, 1974).

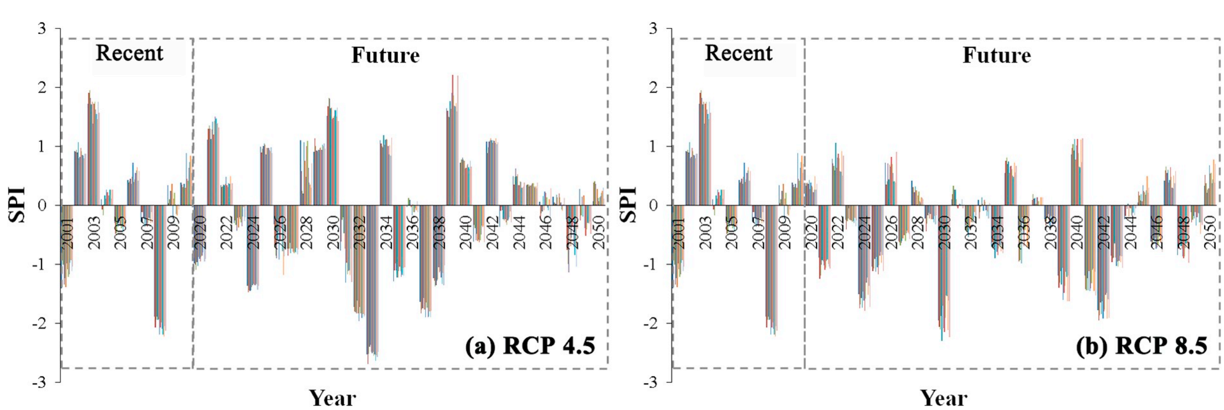

Fig. 4. Future SPI predictions for 14 *myeon* of Goseong County based on RCP 4.5 and RCP 8.5. SPI has seven categories: extremely dry (SPI ≤ -2.00), very dry (−1.99 ≤ SPI ≤ −1.50), moderately dry (−1.49 ≤ SPI ≤ −1.00), normal (−0.99 ≤ SPI ≤ 0.99), moderately wet (1.00 ≤ SPI ≤ 1.49), wet (1.50 ≤ SPI ≤ -1.99), and extremely wet (2.00 ≤ SPI) (McKee et al., 1993).

The study results also show that Goseong County will experience higher incidences of drought, thus there will be a need to maintain or improve irrigation efficiency. The social and ecological tradeoffs of large-scale mechanized irrigation systems are important issues regarding irrigation efficiency, as these systems are often ill-adapted to local socio-hydrological processes (Scott et al., 2014). Improved efficiency of agricultural water use shall be achieved through the use of time-tested, socially acceptable, ecologically embedded, and climate-resilient irrigation methods at the local level such as the *dumbeong* system, which are managed by adaptive and empowered local institutions, and supported by timely socioeconomic interventions (Oweis and Hachum, 2006). The *dumbeong* system can be a useful model of a water harvesting system for efficient supplemental irrigation (Rockström, 2003), as well as an example of infrastructure- and learning-based adaptive approach for ensuring human sustenance and strengthening local social-ecological resilience (Scott et al., 2014).

Our findings support the current discourse of Korean TEK that highlights the pragmatic use of landscape configuration and components in sustainable natural resource management (Lee, 2017). For the *dumbeong* system to continuously function as climate-resilient infrastructure, the scope of management and conservation should also be expanded to landscape-level so as to secure the hydrological processes. The *dumbeong* system is a result of Korean TEK, which provides various social-ecological services such as harvesting and providing water, regulating pollutants, conserving TEK, attracting cultural and ecological tourism, and strengthening local resilience (Yoon et al., 2019).

Sustainable landscape management approaches—that is, participatory sustainable land use and conservation approaches at the landscape scale—are useful in addressing the sustainable development challenges of ensuring economic vitality and environmental conservation (Sayer et al., 2013). We recommend that local and national level stakeholders in policy making and planning use a sustainable landscape management approach to ensure the optimal use of the *dumbeong* system, thereby optimizing its social, economic, and ecological purposes and functions in sustaining agriculture, livelihoods, and SES resilience. The downstream efficient use of water in the *dumbeong* system will have to be complemented with robust policy-driven measures and support for conserving upstream forested areas that are crucial for sustaining local hydrological processes (Immerzeel et al., 2010). It is known locally that there were more *dumbeong*s in Goseong County until a decade ago, and some have now disappeared due to road construction and development projects. In *myeons* with relatively fewer *dumbeong*s, it is particularly important to investigate the condition of the *dumbeong*s before planning further large-scale irrigation systems. In addition, the administrative and financial decision-making capacity of local stakeholders should be strengthened by strategic decentralization to support the local management of the *dumbeong* system and conservation of landscapes, as farmers' decision making and their collective action dynamics are integral to sustaining AIS (Ostrom and Gardner, 1993; Yu et al., 2015).

4.1. Further research

The challenges of sustaining water resources embrace and integrate multiple global processes including climate change, ecosystem resilience, and human demands for various purposes (Scott and Buechler, 2013). Our examination of the *dumbeong* system provides evidence of its functioning as resilient infrastructure that helps coastal communities to appropriately meet local water challenges and strengthen SES resilience. However, the *dumbeong* system operates through interactive dynamics among its hard, soft, and natural infrastructure components. Therefore, policy-driven actions for sustainable landscape management in coastal areas, including the future management of coastal AIS such as *dumbeong*, should be based on more reliable assessments of climate change impacts, local resilient infrastructure, and collective action dynamics among local stakeholders (Lloyd et al., 2013; Fazey et al., 2007).

Agency-based modelling can be useful in understanding the collective action dynamics of the *dumbeong* system and trade-offs of the irrigation system. While Goseong County has experienced stronger droughts in recent years, intensification of agriculture and reducing farm workers are significant factors motivating the local farmers to demand for a large dam. The sharing of information on future climatic and socioeconomic consequences and the low-cost high-efficiency irrigation of the *dumbeong* system, along with its sustainable development co-benefits, may influence local attitudes and decision making on the use and conservation of the *dumbeong* system. Thus, further studies need to be conducted using behavioral models in analyzing human adaptive processes (Acosta-Michlik and Espaldon, 2008; Ostrom and Gardner, 1993), and the role of market support and information sharing in adapting to social-ecological changes (Acosta-Michlik and Espaldon, 2008) in this case. Finally, it is useful to examine the differences in long-term sustainability—including environmental, economic, and social costs and benefits—between a decentralized and distributed small-scale irrigation system such as the *dumbeong* system and large centralized irrigation using dams and reservoirs.

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References

Acosta-Michlik, L., Espaldon, V., 2008. Assessing vulnerability of selected farming communities in the Philippines based on a behavioural model of agent's adaptation to global environmental change. Glob. Environ. Chang. 18, 554–563.
AgriMetSoft, 2017. Meteorological Drought Monitor (Version 1) [Computer Software]. Available at. https://agrimetsoft.com/MDM.aspx.
Anderson, D.R., Burnham, K.P., 2002. Avoiding pitfalls when using information-theoretic methods. J. Wildl. Manag. 912–918.
Barton, K., 2011. MuMIn: Multi-model Inference. R Package Version 1.0.0. R Foundation for Statistical Computing, Vienna. Austria URL. http://cran.r-project.org/web/packages/MuMIn/index.html.
Chambers, J.M., Hastie, T.J., 1992. Statistical Models in S. Chapman and Hall, London.
Berkes, F., Colding, J., Folke, C., 2000. Rediscovery of traditional ecological knowledge as adaptive management. Ecol. appl. 10 (5), 1251–1262.
Cumming, G.S., Olsson, P., Chapin, F., Holling, C., 2013. Resilience, experimentation, and scale mismatches in social-ecological landscapes. Landsc. Ecol. 28, 1139–1150.
Doh, Y., Kim, J., Lim, L., Kim, S., Choi, J., Joo, K., 2012. Spatial distribution and social characteristics for wetlands in Gyeongsangnam-do Province (Korean with an English abstract). Kor. J. Ecol. Environ. 45 (2), 252–260 Jun 45.
ESRI, 2012. ArcGIS, Version 10.1. Redlands, California, USA. .
ESRI, 2019. ArcGIS - World Imagery Map Service. Retrieved from: https://www.arcgis.com/home/item.html?id=10df2279f9684e4a9f6a7f08febac2a9.
Fazey, I., Fazey, J.A., Fischer, J., Sherren, K., Warren, J., Noss, R.F., Dovers, S.R., 2007. Adaptive capacity and learning to learn as leverage for social–ecological resilience. Front. Ecol. Environ. 5, 375–380.
Folke, C., 2006. Resilience: the emergence of a perspective for social–ecological systems analyses. Glob. Environ. Chang. 16 (3), 253–267 Aug 1.
Goseong-gun, 2011. Report on the Current States of Gosoeng Dumbeong. Goseong-gun Dumbeongsiltaejosabogoseo, in Korean. .
Hewitt, H., Copsey, D., Culverwell, I., Harris, C., Hill, R., Keen, A., McLaren, A., Hunke, E., 2011. Design and implementation of the infrastructure of HadGEM3: the next-generation Met Office climate modelling system. Geosci. Model Dev. 4, 223–253.
Immerzeel, W.W., van Beek, L.P.H., Bierkens, M.F.P., 2010. Climate change will affect the Asian water towers. Science 328, 1382–1385.
Kim, M.-K., Han, M.-S., Jang, D.-H., Baek, S.-G., Lee, W.-S., Kim, Y.-H., Kim, S., 2012. Production technique of observation grid data of 1km resolution. J. Clim. Res. 7, 55–68.
Kim, J.H., Chung, H.Y., Kim, S.H., Kim, J.G., 2016. The influence of water characteristics on the aquatic insect and plant assemblage in small irrigation ponds in Civilian Control Zone, Korea. J. Wetl. Res. 18, 331–341.
Kim, G., Vaswani, R., Kang, W., Nam, M., Lee, D., 2017a. Enhancing ecoliteracy through traditional ecological knowledge in proverbs. Sustainability 9 (7), 1182 Jul.
Kim, G., Vaswani, R.T., Lee, D., 2017b. Social-ecological memory in an autobiographical novel: ecoliteracy, place attachment, and identity related to the Korean traditional village landscape. Ecol. Soc. 22 (2) May 29.
Kim, G., Kang, W., Park, C.R., Lee, D., 2018. Factors of spatial distribution of Korean

village groves and relevance to landscape conservation. Landsc. Urban Plan. 176, 30–37 Aug 1.
Lee, D., 2017. Geomantic practices of water acquisition and management during the Chosŏn Dynasty. In: Yoon, H.-K. (Ed.), P'ungsu: A Study of Geomancy in Korea 2017. SUNY Press, New York, pp. 115–138.
Lloyd, M.G., Peel, D., Duck, R.W., 2013. Towards a social–ecological resilience framework for coastal planning. Land Use Policy 30, 925–933.
McFadden, D., 1974. Conditional logit analysis of qualitative choice behavior. In: Zarembka, P. (Ed.), Frontiers in econometrics. Academic Press, New York.
McKee, T.B., Doesken, N.J., Kleist, J., 1993. The relationship of drought frequency and duration to time scales. In: Proceedings of the 8th Conference on Applied Climatology. American Meteorological Society, Boston, MA.
Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., Van Vuuren, D.P., Carter, T.R., Emori, S., Kainuma, M., Kram, T., 2010. The next generation of scenarios for climate change research and assessment. Nature 463, 747.
Ostrom, E., Gardner, R., 1993. Coping with asymmetries in the commons: self-governing irrigation systems can work. J. Econ. Perspect. 7, 93–112.
Oweis, T., Hachum, A., 2006. Water harvesting and supplemental irrigation for improved water productivity of dry farming systems in West Asia and North Africa. Agric. Water Manag. 80, 57–73.
Pahl-Wostl, C., Sendzimir, J., Jeffrey, P., Aerts, J., Berkamp, G., Cross, K., 2007. Managing change toward adaptive water management through social learning. Ecol. Soc. 12 (2), 30. [online] URL. http://www.ecologyandsociety.org/vol12/iss2/art30.
R Core Team, 2018. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria URL. http://www.R-project.org/.
Riahi, K., Rao, S., Krey, V., Cho, C., Chirkov, V., Fischer, G., Kindermann, G., Nakicenovic, N., Rafaj, P., 2011. RCP 8.5—a scenario of comparatively high greenhouse gas emissions. Clim. Chang. 109, 33.
Rockström, J., 2003. Resilience building and water demand management for drought mitigation. Phys. Chem. Earth Parts A/B/C 28, 869–877.
Sayer, J., Sunderland, T., Ghazoul, J., Pfund, J.-L., Sheil, D., Meijaard, E., Venter, M., Boedhihartono, A.K., Day, M., Garcia, C., van Oosten, C., Buck, L.E., 2013. Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. Proc. Natl. Acad. Sci. U. S. A. 110, 8349–8356.
Scott, C.A., Buechler, S.J., 2013. Iterative driver-response dynamics of human-environment interactions in the Arizona-Sonora borderlands. Ecosphere 4, art2.
Scott, C.A., Vicuña, S., Blanco Gutiérrez, I., Meza, F., Varela Ortega, C., 2014. Irrigation efficiency and water-policy implications for river-basin resilience. Hydrol. Earth Syst. Sci. 18, 1339–1348.
Thomson, A.M., Calvin, K.V., Smith, S.J., Kyle, G.P., Volke, A., Patel, P., Delgado-Arias, S., Bond-Lamberty, B., Wise, M.A., Clarke, L.E., 2011. RCP4.5: a pathway for stabilization of radiative forcing by 2100. Clim. Chang. 109, 77.
Yoon, S., Kim, G., Choi, H., Byun, C., Lee, D., 2019. Trait-based evaluation of plant assemblages in traditional farm ponds in Korea: ecological and management implications. J. Limnol. 78, 92–106.
Yu, D.J., Qubbaj, M.R., Muneepeerakul, R., Anderies, J.M., Aggarwal, R.M., 2015. Effect of infrastructure design on commons dilemmas in social-ecological system dynamics. Proc. Natl. Acad. Sci. 112, 13207–13212.