UNIVERSITI PUTRA MALAYSIA

HABITAT PREDICTIVE MODELLING AND GEOSPATIAL DATABASE OF Batagur affinis (CONTOR, 1847) IN KEMAMAN RIVER, MALAYSIA

FASIHAH MOHD YUSOF

FPAS 2018 17

HABITAT PREDICTIVE MODELLING AND GEOSPATIAL DATABASE OF *Batagur affinis* (CONTOR, 1847) IN KEMAMAN RIVER, MALAYSIA

By

FASIHAH MOHD YUSOF

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

May 2018

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Master of Science

HABITAT PREDICTIVE MODELLING AND GEOSPATIAL DATABASE OF *Batagur affinis* (CONTOR, 1847) IN KEMAMAN RIVER, MALAYSIA

By

FASIHAH MOHD YUSOF

May 2018

Chairman : Nor Rohaizah Jamil, PhD
Faculty : Environmental Studies

A freshwater turtle species, southern river terrapin or *Batagur affinis* is listed as a Critically Endangered species in International Union for Conservation of Nature (IUCN) Red List for Threatened Species. Hence, in purpose to achieve the cost effective and well-guided future monitoring and habitat rehabilitation program, the understanding on their optimum physical habitat requirement is highly paramount. Parallel to that mission, one of the main objectives of this research is to understand their physical habitat requirements and habitat preferences of this keystone species to maintain its sustainability inside the lower part of Kemaman River. The habitat suitability index (HSI) for six main physical parameters were constructed and the optimum flow for *B. affinis* was proposed by employing the concept of Environmental Flow Assessment (EFA) using habitat modeling simulations approach. Based on the developed HSI, the highest preference range for velocity and depth were between 0.1-0.2 m/s and 2.0-3.0 m respectively, for the nesting bay sediment grain size, the highest preference index recorded were between 0.06 – 2.0 mm, which classified as sandy sediment. Next, for degree of nesting bank slope, the highest preference index recorded were between 7-9^{o} with average of 8.55^{o}. In addition, for canopy coverage preferences aspect, approximately about 3 to 4 percent of coverage recorded the highest preference for *B. affinis'* roaming area. However, the curve shows no pattern of preference for total suspended solid parameter (TSS). For second objective, based on habitat simulation, the maximum Area Weighted Suitability, AWS of the habitat availability for *B. affinis* is 32.439 m^2/m at a simulated flow of 26.84 m^3/s while the minimum AWS is 3.606 m^2/m at flow of 4.474 m^3⁄s. AWS values decrease at simulated flow of 32.439 m^2/m and continuously decrease while the flow is increasing. The AWS values are then been categorized into three different group which are Optimum Available Range (OAHR), Degrading Available Habitat Range (DAHR) and Severely Degrading Available Habitat Range (SDAHR). Based on habitat simulation, the OAHR for *B. affinis* is

between 26.84 - 30.46 m^3/sec. This is the recommended flow that should be retained in Kemaman River to ensure the habitat availability and sustainability of this species. While, the value of DAHR is <26.84 m^3/sec, and depleting of discharge within this flow ranges will cause a decreasing in Area Weighted Suitability (AWS). However, within this range, the rate of habitat deterioration is moderate. Other than that, the value of SDAHR is >30.46 m^3/sec, and within this range, significant deterioration in AWS are resulted from only subtle changes in stream flow. For third objectives, the developed geospatial database will help in future species conservation effort as the information can be kept in a visual map presentation in a more interactive and manageable manners which subsequently can help to save a lot of information-searching time and align strategies in a more precise result-oriented basis.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Master Sains

PERMODELAN HABITAT DAN DATA GEO-RUANG BAGI *Batagur affinis* (CONTOR, 1847) DI SUNGAI KEMAMAN, MALAYSIA

Oleh

FASIHAH MOHD YUSOF

Mei 2018

Pengerusi : Nor Rohaizah Jamil, PhD
Fakulti : Pengajian Alam Sekitar

Tuntung sungai atau Batagur affinis merupakan antara spesies tuntung yang terancam berdasarkan senarai spesis terancam yang dikeluarkan oleh Kesatuan Pemuliharaan Alam Antarabnagsa (IUCN). Oleh yang demikian, bagi memastikan usaha pemuliharaan yang efektif pada masa akan datang, kajian terperinci adalah diperlukan untuk memahami keperluan habitat fizikal bagi spesis ini. Antara objektif utama kajian ini dijalankan adalah bertujuan untuk membina Indeks Kesesuaian Habitat (HSI) bagi enam parameter fizikal utama dan memberi cadangan mengenai luahan sungai optimum bagi *Batagur affinis* dengan menggunakan konsep Analisa Luahan Persekitaran (EFA) menerusi kaedah Habitat Simulasi. Enam stesen persampelan dipilih bagi tujuan cerapan data hidraulik-hidrologi; manakala sejumlah 100 lokasi pemerhatian dikumpul untuk memantau kawasan rayau *B. affinis* di hilir Sungai Kemaman. Berdasarkan HSI, julat kesesuaian tertinggi untuk halaju dan kedalaman sungai masing-masing mencatatkan nilai antara 0.1-0.2 m / s dan 2.0-3.0 m, manakala untuk saiz sedimen beting pasir persarangan, indeks kesesuaian tertinggi yang direkodkan adalah bagi saiz partikel berukuran diantara 0.06 - 2.0 mm (pasir). Bagi indeks kesesuaian tahap kecerunan tebing persarangan, nilai indeks tertinggi yang direkodkan adalah berada dalam lingkungan kecerunan diantara 7-9^{o}. Seterusnya, untuk kesesuaian litupan kanopi, kira-kira 3 hingga 4 peratus liputan kanopi mencatatkan kesesuaian tertinggi bagi spesis ini. Walau bagaimanapun, bagi parameter kandungan pepejal terampai (TSS), indeks kesesuaian tidak menunjukkan sebarang corak yang nyata bagi spesis ini. Seterusnya, bagi objektif kedua, nilai maksima bagi Pemberat Kesesuaian Habitat (AWS) bagi spesis ini adalah 32.439 m^2/m pada luahan berkadaran 26.84 m^3/s, manakala nilai minima AWS adalah sebanyak 3.606 m^2/m pada luahan berkadaran 4.474 m^3⁄s. Secara keseluruhannya, nilai AWS akan mencapai kemuncak pada nilai 32.439 m^2/m dan akan menurun apabila nilai luahan meningkat. Nilai AWS ini kemudiannnya dibahagikan kepada tiga kategori iaitu Julat Habitat Optimum (OAHR), Julat Habitat Penurunan

(DAHR), dan Julat Habitat Berbahaya (SDAHR). Julat OAHR untuk *B. affinis* adalah diantara 26.84 - 30.46 m^3 / saat yang mana di dalam julat luahan ini, *B. affinis* akan mencapai tahap kesesuaian habitat yang paling tinggi dan terbaik. Oleh itu, luahan di dalam julat OAHR ini juga adalah nilai luahan kawasan kajian yang amat disarankan bagi tujuan konservasi dan pemuliharaan *B. affnis* di kawasan hilir Sungai Kemaman. Selain dari itu, julat DAHR adalah pada <26.84 m^3 / saat, dan sebarang penurunan kadar luahan dari julat ini akan menyebabkan penurunan nilai kesesuaian habitat yang ada. Walau bagaimanapun, kemerosotan pemberat habitat dalam julat ini adalah berkadaran sederhana. Manakala, Julat SDAHR adalah > 30.46 m^3/saat, di mana dalam julat ini, sebarang perubahan kecil dalam luahan sungai akan membawa kepada kesan yang besar dan serius terhadap kesesuaian pemberat habitat bagi spesis ini. Berdasarkan objektif ketiga pula, data geo-ruang telah berjaya dibangunkan dan hasil daripadaa usaha ini, maklumat yang dikumpul akan dapat membantu dalam usaha pemuliharaan dimana semua maklumat disimpan didalam bentuk peta visual yang menarik dan mudah untuk diurus.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude towards my supervisor, Dr. Nor Rohaizah Jamil for all countless help and supports. The completion of this thesis would be impossible without her wise ideas and advices. I am grateful of having someone who are capable to withstand my weakness and never ending silly questions.

As for my co-supervisors, Dr. Hasliney Hashim and Dr. Shahrul Anuar Mohd Sah, their contributions were not any lesser than my supervisor. I really appreciate their concern and helps throughout the progress and not to mention their valuable encouragements.

For Chen Pelf Ngok, the representative of Turtle Conservation Society, Pak Wazer and the Tuntung Geng, thank you so much! I think I cannot complete this research without your help.

My backbone of success, of course would be from my parents. Been always be my strongest pillar since I was a child, supporting my dreams and help those become a reality! No words can describe how meaningful they are. To my siblings, I love you all for being so supportive for me to chase after my dreams.
Last but not least, my lovely friends at faculty and OHANI, thanks for your endless supports through days and nights! Big hug from me guys!

This thesis was submitted to the Senate of the Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Nor Rohaizah Jamil, PhD
Senior Lecturer
Faculty of Environmental Studies
Universiti Putra Malaysia
(Chairman)

Rohasliney Hashim, PhD
Senior Lecturer
Faculty of Environmental Studies
Universiti Putra Malaysia
(Member)

Shahrul Anuar Mohd Sah, PhD
Professor
School of Biological Sciences
Universiti Sains Malaysia
(Member)

_____
ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software

Signature: _____ Date: _____

Name and Matric No: Fasihah Mohd Yusof, GS44350

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

HSI	Habitat Suitability Index
IFIM	Instream Flow Incremental Methodology
USFWS	U.S. Fish and Wildlife Service
AWS	Area Weighted Suitability
MaCGDI	Malaysian Centre for Geospatial Data Infrastructure
SEFA	System for Environment Flow Assessment
DWNP	Department of Wildlife and National Park
IUCN	International of Union for Conservation of Nature
CITES	Convention on International Trade of Endangered Species of Wild Fauna and Flora
GIS	Geographical Informmation System
SMART	Spatial Monitoring and Reporting Tool
HSC	Habitat Suitability Curve
IFG	Instream Flow Group
PHABSIM	Physical Habitat Simulation
RHYHABSIM	River Hydraulic and Habitat Simulation
DIVAST	Depth Integrated Velocity and Solute Transport
BM	Body mass
SCL	Straight carapace length
SCW	Straight carapace width
ADCP	Acoustic Doppler Current Profiler
TSS	Total Suspended Solids
HDPE	High-density polyethylene
HABSEL	Habitat Suitability Model

VDF	Velocity distribution factors
SSI	Standardized Suitability Index
CSI	Combined Suitability Index
OAHR	Optimal Available Habitat Range
DAHR	Degrading Available Habitat Range
SDAHR	Severely Degrading Available Habitat

CHAPTER 1

INTRODUCTION

1.1 Problem statement

Freshwater turtles are among the world's most endangered vertebrates, as they are most at risk of impending extinction compared to avian, amphibians, mammals or even sharks and rays (IUCN, 2000; Auliya, 2007). As one of the freshwater turtle species, the Southern River Terrapin *(Batagur affinis)* or locally known as tuntung sungai is listed as a Critically Endangered in IUCN Red List of Threatened Species and CITES (Appendix I) (IUCN, 2000). On top of that, this species also categorized as one of the top 25 most critically endangered freshwater turtles worldwide (Anderson et al., 2011). In Malaysia, *B. affinis* population (formerly known as *Batagur baska*) was once very common in the main river network in Kedah, Perak and Terengganu state in Peninsular Malaysia (Moll et al, 2015). However, their populations have declined drastically in the wild all over Malaysia (Moll et al, 2015, Chen, 2017).

As a keystone species, terrapins play a role as a top predator in riverine ecosystem and its function to control a bloom of highly invasive species has made river terrapins are valuable to be conserved (Ernst and Lovich, 2009). The keystones are species with disproportionate effects on the food web in relation to their relatively low biomass proportion in the ecosystem. Their presence is crucial in maintaining the organization and diversity of their ecological communities. Second, it is implicit that these species are exceptional, relative to the rest of the community, in their importance (Mills, 1993).

As their diet relies on hard-shelled invertebrates (Erazmus 2012), river terrapins are capable in controlling periwinkles *(Littoraria* spp*)* population (Levesque, 1999) as this easily-reproduced species is a common prey of many important aquatic floras throughout the river system (Tucker et al. 1995; Munscher et al. 2012). In other part of the world like in Virginia, terrapins also consume on mobile fauna and epifauna in sea grass beds located near marshes (Tulipani, 2013). This top predator species exert top-down control thereby affecting community structure through foraging (Valiela et al., 2004) by increasing plant biomass to sustain biodiversity by feeding on grazers and sessile organisms and in river beds (Silliman and Bertness 2002; Tulipani, 2013). In a nut shell, terrapin's existence has a very huge potential to give influence towards the ecosystem structure within its habitat through foraging and prey choice (Silliman and Bertness, 2002).

However, considered as conservation-dependent, the species population would not persist without the intensive and accurate recovery efforts. The probability of natural self-sustained survivorship of the species is uncertain with their wild habitat remains

impacted. Despite of its worrisome declining population number due to highly altered ecosystem, to date, only Perak and Kemaman River have been recorded to sustain *B. affinis* species with almost no other survivors are recorded to occupy other river system in this country (Moll et al., 2015).

The over consumption of their eggs as a food source prior to World War II (Moll, 1980 and 2004), was once considered as culprit of its declining population, however, activities from sand mining and weir construction are now the current major threats for this species (Moll, 1997). Subsequently, conserving the remnant of the population in their highly altered river habitat is now the real challenge. Decades of cost-intensive rehabilitation programmes pioneered in Perak River produced a despairing result since local wild terrapin population in Perak River made no positive indication to forestall declining wild terrapin trend (Moll et al., 2015; DWNP, unpub.). Perak River ecosystem used to offer the largest population of this species in their natural habitat. The recent unpublished report by DWNP showed a dramatic decline of the river terrapin population at the lower Perak River to as much as less than 40 wild nests (recorded in 2009), in comparison to 932 nests reported in 1989-1990 (Moll, 1980; Wildlife Department of Malaysia, 2009). Other than Perak River, a few private organisations of NGOs such as Turtle Conservation Society (TCS) are actively leading in conservations in Kemaman River, and since the wild terrapin in this river system are more sufficiently available in number for research purposes, this river has been chosen as the study area to understand their physical habitat requirement.

Based on recent studies, the most established study on terrapins are highly available for Diomand-back terrapin species (or *Malaclemys* terrapin) such as in is North Corolina Estuary (Hildebrand, 1929; Montevecchi, 1975; Palmer, 1988; Athens, 1998; Butler, 2004), while data for river terrapin (or *Batagur affinis*) in Asians are insufficiently deprived especially on their physical habitat requirement. The rapid extraction of sand has impacted the morphology of the area, causing the some rapid changes in river movement and physical characteristic. Due to that idea, the understanding of current physical condition should be well documented and that can be achieved through out this research.

1.2 Research questions

1) What is the maximum preference of physical environmental condition for *B. affinis*?
2) How does a species' physical habitat change with changes in a stream's flow characteristics?
3) Where is the roaming area for this species? And how they are temporally and spatially distributed?
4) What is the physical habitat preference of *B. affinis'* roaming area? How this information could help in deciding a specific and priority sequencing for the habitat restoration planning?

1.3 Research objectives

1) To construct a Habitat Suitability Index (HSI) of *B.affinis* in Kemaman River by adopting Selectivity Index method using six dominant physical parameters.
2) To determine the Area Weighted Suitability (AWS) and recommended optimum flow for *Batagur affinis* in Kemaman River by using Habitat Modelling method.
3) To develop a Geospatial Database of *B. affinis* based on seasonal migratory routing in Kemaman River.

1.4 Scope of study

This study focused on Kemaman River as this ecosystem provides habitat for a highly endemic species of freshwater river terrapin, *Batagur affinis*. The study area is limited to the lower region of main Kemaman River between Seberang Tayur Village until a river-crossed weir at Pinang Village. 13.67 km river stretch at the main channel and another additional 3 km of Cherul River tributary gave a cumulative of 16.7 km of total river reach for the study area. Despite of many other contribution factors that may influence the species sustainability, such as predation, illegal catch, food source availability and natural disaster, however, this study will primarily focus on the physical habitat factors of *B. affinis* which reflects why the concept of environmental flow (EA) was employed in this study. Inputs for EA are primarily rely on physical factors of the river (Eg: Velocity, Depth, Discharge, Substrate) to produce the habitat predictive modeling for *B. afiinis* in Kemaman River. However, the biological factor such as food availability will be discussed in general base on literature review and field observation to support the physical habitat factors of this research. Six sampling stations were selectively appointed for the hydraulic-hydrologic survey; while a total of 100 observation points have been used by considering the most-frequently spotted sites for active nesting points as well as historical points along the study stretch. The development of Habitat Suitability Index (HSI) of *B. affinis* in Kemaman River was highly relying on these primary data collection during 15 months sampling periods (May 2015 - August 2016). More than 25 fieldwork trips for primary data collection were successfully conducted in different climate-hydrological seasons to validate the existing hydraulic variables properties, while 15 years of hydro-climatological data were obtained as secondary data from the related agencies for a long-term historical data analysis and calibrations. To complete the hydraulic sampling and site observations, a telemetry technique using radio tracking activities has been done. The radio transmitter devices were attached on 12 carapaces of adult female terrapins during nesting season, purposely for these movement-tracking activities. By using this technique, the roaming area of *B. affinis* was identified and has been integrated with the hydraulic variables to produce a Habitat Suitability Index (HSI). Modelling software developed by Aquatic System Analysis known as is System of Environmental Flow Analysis (SEFA), has been used as it able to integrate hydraulic and habitat variables, by incorporating the concept of Environmental Flow Assessment (EFA) by using Habitat Modeling principles. At the end of the study, the Habitat Suitability Index (HSI) and Area Weighted Suitability Area (AWS) which was developed

specifically for this species can be used as the benchmark for environmental flow setting for Kemaman River, taking species conservation as the goal.

1.5 Significance of the study

As there is scarce information on this species' specific habitat preference, it would be very beneficial to understand the optimum physical habitat for the species to enhance their survival probability in the wild environment. As the flow is the major driver of all processes in a river system, thus, the quantification of flows is needed to preserve the ecosystem for the species. The quantified flow obtained from this research would benefit future river management and restoration plan of Kemaman River, hence, help the related stakeholder to strategize the needed action.

At the end of this research, the temporal and spatial distribution of *B. affinis* will be mapped and archived in a geospatial database within GIS environment, which has a potential linkage with other governmental geospatial database specifically to cater the conservation inventory and data records such as Malaysian Centre for Geospatial Data Infrastructure (MaCGDI).

This database will help in future species conservation effort as the information can be kept in a visual map presentation in a more interactive and manageable manners which subsequently can help to save a lot of information-searching time and align strategies in a more precise result-oriented basis.

1.6 Thesis organization

Chapter 1 consist on the background of this study, problem statements, and the objectives of this study. Scope and significance of the study are provided a comprehensive understanding. This chapter further introduces the physical habitat for *B. affinis* and the importance of healthy river towards its sustainability. Besides that, this chapter discusses on the definition, method of environmental flow assessment used in Malaysia and other country.

Chapter 2 provides a broad literature reviews in related studies. The current practise and background studies have been obtained from journals and academic books.

Chapter 3 covers the methodology of the research. The procedures on primary and secondary data collection, data analysis and modelling analysis for hydraulic-habitat simulation in System for Environmental Flow Analysis (SEFA) will be discussed in depth within this chapter.

Chapter 4 encompasses the results and discussions of this study. The hydraulic and habitat data are modelled and presented in form of Area Weighted Suitability (AWS). Subsequently, results are interpreted where the recommendations of flow required to sustain *B. affinis* population in Kemaman River are proposed in this section. The preferable physical parameters; velocity, depth and substrate for *B. affinis* will be discussed in context of Habitat Suitability Index (HSI). In conjunction of that, all analysed hydraulic and habitat data has been integrated into the geospatial database which also be presented in this chapter.

Chapter 5 proposed several recommendations for future research in filling the gap uncovered in this research, and how the findings in this research can help future research and conservation effort of this critically endangered species.

REFERENCES

Acreman, M.C. Ferguson JD (2010) *Environmental flows and the European Water Framework Directive. Freshwater Biology* 55:32–48.

Anderson, E. T., Minter, L. J., Clarke, E. O., Mroch, R. M., Beasley, J. F., & Harms, C. A. (2011). The effects of feeding on hematological and plasma biochemical profiles in green (Chelonia mydas) and Kemp's ridley (Lepidochelys kempii) sea turtles. *Veterinary Medicine International*, vol. 2011, Article ID 890829, 7 pages, 2011. https://doi.org/10.4061/2011/890829.

Appleton, K., Lovett, A., Sünnenberg, G., & Dockerty, T. (2002). Rural landscape visualisation from GIS databases: A comparison of approaches, options and problems. *Computers, Environment and Urban Systems*, *26*(2–3), 141–162. http://doi.org/10.1016/S0198-9715(01)00041-2

Arthington, AH, Pusey BC (2003) Flow restoration and protection in Australian rivers. River Res Appl 19:377–395. doi:10.1002/RRA.745

Arthington, A. H. (2012). *Environmental flows: saving rivers in the third millennium* (Vol. 4). Univ of California Press.

Athens, G. (1998). *Home Range, Habitat Selection, And Diet Of The Diamondback Terrapin (Malaclemys Terrapin) In A North Carolina Estuary*. Doctoral Dissertation, The University of Georgia.

Auliya, M. (2007). *An Identification Guide to the Tortoises and Freshwater Turtles of Brunei Darussalam, Indonesia, Malaysia, Papua New Guinea, Philippines, Singapore, and Timor Leste*. TRAFFIC Southeast Asia.

Ávila, S., Sunshine, D., Reynalte, T., David, A. & Zaniboni, F. E.. (2014). Pools and rapids as spawning and nursery areas for fish in a river stretch without floodplains. *Neotropical Ichthyology*, *12*(3), 611-622. Epub September 16, 2014.https://dx.doi.org/10.1590/1982-0224-20130116

Bauduin, S., McIntire, E., St-Laurent, M. H., & Cumming, S. (2016). Overcoming challenges of sparse telemetry data to estimate caribou movement. *Ecological Modelling*, *335*, 24–34. http://doi.org/10.1016/j.ecolmodel.2016.05.004

Baxter, A. S. (2017). Identifying Diamondback Terrapin Nesting Habitat in the Mission-Aransas Estuary, Texas.

Bodie, J. R., & Semlitsch, R. D. (2000). Spatial And Temporal Use of Floodplain Habitats By Lentic And Lotic Species Of Aquatic Turtles. *Oecologia*, *122*(1), 138-146.

Bovee, K. D. (1982). *Guide to stream habitat analysis using the instream flow incremental methodology*. National Technical Information Service, Springfield VA 22161 as PB 83-131052.

Bovee, K. D. (1986). *Development and evaluation of habitat suitability criteria for use in the instream flow incremental methodology* (No. FWS/OBS-86/7). USDI Fish and Wildlife Service.

Buchanan, T. J., & Somers, W. P. (1969). *Discharge measurements at gaging stations* (No. 03-A8). US Govt. Print. Off.,

Butler, J. A., Broadhurst, C., Green, M., & Mullin, Z. (2004). Nesting, nest predation and hatchling emergence of the Carolina diamondback terrapin, *Malaclemys* terrapin centrata, in northeastern Florida. *The American midland naturalist*, *152*(1), 145-155.

Cagnacci, F., Boitani, L., Powell, R.A., Boyce, M.S., 2010. Animal ecology meets GPS-based radiotelemetry: a perfect storm of opportunities and challenges. Philos. Trans. R. Soc. Lond. Ser. B 365, 2157–2162.

Cantor, T. (1847) Catalogue of reptiles inhabiting the Malayan peninsula and islands. Journal of the Asiatic Society of Bengal, 16, 607–656, 897–952, 1026–1078.

Capra, H., Plichard, L., Bergé, J., Pella, H., Ovidio, M., McNeil, E., & Lamouroux, N. (2017). Fish habitat selection in a large hydropeaking river: Strong individual and temporal variations revealed by telemetry. *Science of the Total Environment, 578*, 109–120. http://doi.org/10.1016/j.scitotenv.2016.10.155

Chen, P. N. (2017). Conservation of the Southern River Terrapin Batagur affinis (Reptilia: Testudines: Geoemydidae) in Malaysia: a case study involving local community participation. *Journal of Threatened Taxa*, *9*(4), 10035-10046.

Davenport, J. And Wong, T. M. 1986. Observations on the water economy of the estuarine turtles, *Batagur baska* (Gray) and *Callagur borneoensis* (Schlegel and Muller). Comparative Biochemistry and Physiology Part A: Molecular and Integrative Physiology 84:703–707.

Davenport, J., Wong, T. M., And East, J. 1992. Feeding and digestion in the omnivorous estuarine turtle Batagur baska (Gray). Herpetological Journal 2(4):133–139.

Glenos, S. M. (2013). *A comparative assessment of genetic variation of Diamondback terrapin (Malaclemys terrapin) in Galveston Bay, Texas in relation to other northern Gulf Coast populations*. University of Houston-Clear Lake.

Palmer, W. M., & Cordes, C. L. (1988). *Habitat Suitability Index Models: Diamondback Terrapin (Nesting)--Atlantic Coast* (No. FWS-82 (10.151)). National Wetlands Research Center Slidell La.

Conklin Jr, D. J., Canton, S. P., Chadwick, J. W., & Miller, W. J. (1995). Habitat suitability curves for selected fish species in the central Platte River, Nebraska. *Rivers*, *5*(4), 250-266.

Department of Wildlife and National Park, Malaysia. (2015) Annual Hatchling Report at Bota Kanan Terrapin Conservation Center, Perak. Unpublished Report.

Declan, M. J. (2011) Rivers and Streams: Life in Flowing Water. Nature Education Knowledge 3(10):19. Retrieved 22 June 2018 from

https://www.nature.com/scitable/knowledge/library/rivers-and-streams-life-in-flowing-water-23587918

Dittrich, A., Schmedtje, U., 1995. Indicating shear stress with FST-hemispheres – effects of stream-bottom topography and water depth. *Freshwater Biol*. 34, 107–121.

Dunson, W. A., & Moll, E. O. (1980). Osmoregulation in sea water of hatchling emydid turtles, Callagur borneoensis, from a Malaysian sea beach. *Journal of herpetology*, 31-36.

Dyer, S.J., O'Neill, J.P., Wasel, S.M., Boutin, S., 2002. Quantifying barrier effects of roads and seismic lines on movements of female woodland caribou in northeastern Alberta. Can. J. Zool. 80, 839–845, http://dx.doi.org/10.1139/Z02-060.

Erazmus, K. R. (2012). *Diet and prey choice of female diamond-backed terrapins (Malaclemys terrapin) in Jamaica Bay, New York*. Hofstra University.

Ernst, C. H., & Lovich, J. E. (2009). *Turtles of the united states and Canada*. JHU Press.

ESRI (2002). Open Design for Multipurpose Database. Retrieved from http://www.esri.com/news/arcnews/fall02articles/status-report.html

Fendi, K. G., Adam, S. M., Kokkas, N., & Smith, M. (2014). An Approach to Produce a GIS Database for Road Surface Monitoring. *APCBEE Procedia*, *9*, 235–240. http://doi.org/10.1016/j.apcbee.2014.01.042

Forester, J.D., Ives, A.R., Turner, M.G., Anderson, D.P., Fortin, D., Beyer, H.L., Smith, D.W., Boyce, M.S., (2007). State-space models link elk movement patterns to landscape characteristics in Yellowstone National Park. Ecol. Monogr. 77, 285–299.

Forsythe, P., Flitz, B., & Mullin, S. J. (2004). Radio telemetry and post-emergent habitat selection of neonate box turtles (Emydidae: *Terrapene carolina*) in central Illinois. *Herpetological Review, 35*(4), 333–335.

Fuselier, L., & Edds, D. (1994). Habitat partitioning among three sympatric species of map turtles, genus Graptemys. *Journal of Herpetology*, 154-158.

Gallagher, S., & California, U. (1999). Use of two-dimensional hydrodynamic modeling to evaluate channel rehabilitation in the Trinity River. *California, USAUS Fish and Wildlife Service, Arcata*

García de Jalón D, González del Tanágo M, Casado C (1992) Ecology of regulated rivers in Spain: an overview. *Limnetica* 8:161–166

Garg, J. K. (2015). Wetland assessment, monitoring and management in India using geospatial techniques. *Journal of Environmental Management*, *148*, 112–123. http://doi.org/10.1016/j.jenvman.2013.12.018

Ghanem, A. S., Steffler, P. E.., Hicks, F. A., & Katopodis, C. H. (1996). Two-dimensional hydraulic simulation of physical habitat conditions in flowing streams. *Regulated Rivers Research & Management*, *12*(23), 185-200.

Gibeau, M.L., Clevenger, A.P., Herrero, S., Wierzchowski, J., 2002. Grizzly bear response to human development and activities in the Bow River Watershed Alberta, *Canada. Biol. Conserv*. 103, 227–236

Giesecke, J., Jorde, K., 1998. *Simulation and assessment of hydraulic habitat in rivers. In: Proceedings of Modelling, Testing and Monitoring for Hydro Powerplants – III, Aix- en-Provence, France*. Int. J. Hydropower Dams, Sutton, UK, pp. 71–82.

Gimnig, J., Hightower, A., & Hawley, W. (2005). Application of geographic information systems to the study of the ecology of mosquitoes and mosquito-borne diseases. *In: Willem T, Pim M, Robert B, Editors. Environmental Change and Malaria Risk: Global and Local Implications*, 27–39.

Gippel, C. J., & Stewardson, M. J. (1998). Use of wetted perimeter in defining minimum environmental flows. *Regulated rivers: research & management*, *14*(1), 53-67.

Gordon, N. D. (2004). *Stream Hydrology: An Introduction For Ecologists*. John Wiley And Sons.

Chan, E. H., & Chen, P. N. (2011). Nesting Activity and Clutch Size of Batagur affinis edwardmolli from the Setiu River , Terengganu , Malaysia, *10*(1), 129–132.

Hao, C. F., He, L. M., Niu, C. W., & Jia, Y. W. (2016). A review of environmental flow assessment: methodologies and application in the Qianhe River. In *IOP Conference Series: Earth and Environmental Science* (Vol. 39, No. 1, p. 012067). IOP Publishing.

Hildebrand, S. F. (1929). *Review of experiments on artificial culture of diamond-back terrapin* (No. 1060). US Government Printing Office.

Hirji R, Davis R (2009) Environmental Flows in water resources policies, plans, and projects. Case studies. The International Bank for Reconstruction and Development/The World Bank

Hooker, S.K., Whitehead, H., Gowans, S., Baird, R.W., 2002. Fluctuations in distribution and patterns of individual range use of northern bottlenose whales. Mar. Ecol. Prog. Ser. 225, 287–297.

International Union for Conservation of Nature and Natural Resources. (2000). *The IUCN red list of threatened species*. IUCN Global Species Programme Red List Unit. Retrieved from http://www.iucnredlist.org/technical-documents/categories-and-criteria/2001-categories-criteria

Jelokhani-Niaraki, M., Sadeghi-Niaraki, A., & Choi, S. M. (2018). Semantic interoperability of GIS and MCDA tools for environmental assessment and decision making. *Environmental Modelling and Software*, *100*, 104–122. http://doi.org/10.1016/j.envsoft.2017.11.011

Jorde, K., Schneider, M., Zollner, F., 2000. Analysis of instream habitat quality—preference functions and fuzzy models. In: Wang, Hu (Eds.), Stochastic Hydraulics. Balkema, Rotterdam, pp. 671–680.

Jowett, I. G. (1989). *RHYHABSIM: river hydraulic and habitat simulation. A computer manual*.

Jowett, I. G. (1992). River hydraulics and instream habitat modelling for river biota. *Waters of New Zealand*, 249-263.

Jowett I. G. (1997) Instream flow methods. A comparison of approaches. Regul River 13:115–127. doi:10.1002/(SICI)1099-1646(199703)13:2<115::AID RRR440>3.0.CO;2-6

Jowett, I. G. (1998). Hydraulic geometry of New Zealand rivers and its use as a preliminary method of habitat assessment. *River Research and Applications*, *14*(5), 451-466.

Jowett, I. G., & Duncan, M. J. (2012). Effectiveness of 1D and 2D hydraulic models for instream habitat analysis in a braided river. *Ecological Engineering*, *48*, 92–100. http://doi.org/10.1016/j.ecoleng.2011.06.036

Jowett, I. G., Payne, T. R., & Milhous, R. T. (2014). SEFA-System for Environmental Flow Analysis. *Software Manual. Version*, *1*.

Kennard, M. J., Pusey, B. J., Olden, J. D., Mackay, S. J., Stein, J. L. and MARSH, N. (2010), Classification of natural flow regimes in Australia to support environmental flow management. Freshwater Biology, 55: 171–193. doi:10.1111/j.1365-2427.2009.02307.

King J, Louw D. (1998). Instream flow assessments for regulated rivers in South Africa using the Building Block Methodology. *Aquatic Ecosystem Health and Management* 1: 109–124.

King J.M, R.E, Brown CA. (1999). *World Commission on Dams Thematic Report: definition and implementation of instream flows*. World Commission on Dams: Cape Town.

King J.M, Tharme R.E (2000). *Environmental flow assessments for rivers: manual for the Building Block*

King, J. M., & Tharme, R. E. (2008). *Environmental Flow Assessments for Rivers : Manual for the Building Block Methodology*. *Water Research*.

King, J., Brown, C., & Sabet, H. (2003). A scenario- based holistic approach to environmental flow assessments for rivers. *River research and applications*, *19*(5- 6), 619-639.

Kyzirakos, K., Karpathiotakis, M., Garbis, G., Nikolaou, C., Bereta, K., Papoutsis, I., … Kontoes, C. (2014). Wildfire monitoring using satellite images, ontologies and linked geospatial data. *Journal of Web Semantics*, *24*, 18–26. http://doi.org/10.1016/j.websem.2013.12.002

Leopold, L. B., Wolman, M. G., and Miller, J. P. (1964). "Fluvial processes in geomorphology," W. H. Freeman and Company, San Francisco, California.

Leopold, L. B., Wolman, M. G., & Miller, J. P. (2012). *Fluvial processes in geomorphology*. Courier Corporation.

Levesque, E. M., & Fauth, J. E. (1999). *Effect of diamondback terrapin Malaclemys terrapin on the size and density of the salt water periwinkle, Littorina irrorata.* Southern New Jersey, *USA* (pp. 46-53).

Li, G., Cao, J., Zou, X., Chen, X., & Runnebaum, J. (2016). Modeling habitat suitability index for Chilean jack mackerel (*Trachurus murphyi*) in the South East Pacific. *Fisheries Research*, *178*, 47–60. http://doi.org/10.1016/j.fishres.2015.11.012

Lindeman, P. V. (1996). Distribution, relative abundance, and basking ecology of the razorback musk turtle, Kinosternon carinatum, in the Pearl and Pascagoula River drainages. *Nat. Hist*, *4*, 23-34.

Lindeman, P. V. (2000). Resource use of five sympatric turtle species: effects of competition, phylogeny, and morphology. *Canadian Journal of Zoology*, *78*(6), 992-1008.

Liu, W. C., Liu, S. Y., Hsu, M. H., Kuo, A. Y. (2005). Water quality modeling to determine minimum instream flow for fish survival in tidal rivers. *Journal of Environmental Management* 76: 293–308

Louwen, A., Schropp, R. E. I., van Sark, W. G. J. H. M., & Faaij, A. P. C. (2017). Geospatial analysis of the energy yield and environmental footprint of different photovoltaic module technologies. *Solar Energy*, *155*, 1339–1353. http://doi.org/10.1016/j.solener.2017.07.056

Marcos-Sáiz, F. J., & Díez Fernández-Lomana, J. C. (2017). The Holocene archaeological research around Sierra de Atapuerca (Burgos, Spain) and its projection in a GIS geospatial database. *Quaternary International*, *433*, 45–67. http://doi.org/10.1016/j.quaint.2015.10.002

Marucco, F., McIntire, E.J.B., (2010). Predicting spatio-temporal recolonization of large carnivore populations and livestock depredation risk: wolves in the Italian Alps. J. Appl. Ecol. 47, 789–798, http://dx.doi.org/10.1111/j.1365-2664. 2010.01831.x.

Milhous, R. T., Wegner, D. L., & Waddle, T. (1984). *User's guide to the physical habitat simulation system (PHABISM)*(No. 81/43). US Fish and Wildlife Service.

Milhous, R. T., & Waddle, T. J. (2012). Physical Habitat Simulation (PHABSIM) Software for Windows (v.1.5.1). Fort Collins, CO: USGS Fort Collins Science Center. *Midcontinent Ecological Science Centre.*, (November), 288.

Moll, E. O. (1980). Dirty river turtles. *Nat. Hist*. 89:42-49.

Moll, E. O. (1984). River terrapin recovery plan for Malaysia. *Journal of Wildlife and Parks*, *3*, 37-47.

Moll, E. O. (1990). Status and management of the river terrapin *(Batagur baska) in tropical Asia*. WWF Malaysia.

Moll, E. O. (2004). *The ecology, exploitation and conservation of river turtles*. Oxford University Press on Demand.

Moll, E. O., Platt, S. G., Chan, E. H., Horne, B. D., Platt, K., Praschag, P., & Van Dijk, P. P. (2015). *Batagur affinis* (Cantor 1847)-Southern River Terrapin, Tuntong. *Conservation biology of freshwater turtles and tortoises Chelonian Research Monographs, 5*(8)166-178.

Mills, L., Soulé, M., & Doak, D. (1993). The Keystone-Species Concept in Ecology and Conservation. *BioScience, 43*(4), 219-224. doi:10.2307/1312122

Munscher, E. C., Kuhns, E. H., Cox, C. A., & Butler, J. A. (2012). Decreased nest mortality for the Carolina diamondback terrapin (Malaclemys terrapin centrata) following removal of raccoons (Procyon lotor) from a nesting beach in northeastern Florida. *Herpetological Conservation and Biology*, *7*(2), 176-184.

Muñoz-Mas, R., Martínez-Capel, F., Schneider, M., & Mouton, A. M. (2012). Assessment of brown trout habitat suitability in the Jucar River Basin (SPAIN): Comparison of data-driven approaches with fuzzy-logic models and univariate suitability curves. *Science of the Total Environment*, *440*, 123–131. http://doi.org/10.1016/j.scitotenv.2012.07.074

Montevecchi, W. A., & Burger, J. (1975). Aspects of the reproductive biology of the northern diamondback terrapin, *Malaclemys* terrapin. *American Midland Naturalist*, 166-178.

Mourshed, M. (2016). Climatic parameters for building energy applications: A temporal-geospatial assessment of temperature indicators. *Renewable Energy*, *94*, 55–71. http://doi.org/10.1016/j.renene.2016.03.021

Navarro, R. S., & Schmidt, G. (2012). Environmental flows as a tool to achieve the WFD objectives. Discussion Paper. S*tudy for European Comission*.

Palmer, W., & Cordes, C. (1988). Habitat Suitability Index Models: Diamondback Terrapin (Nesting)–Atlantic Coast. *DTIC Document*, *82*(March). Retrieved from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA322694

Palomino, J., Muellerklein, O. C., & Kelly, M. (2017). A review of the emergent ecosystem of collaborative geospatial tools for addressing environmental challenges. *Computers, Environment and Urban Systems*, *65*, 79-92.

Payne, T. R. (2003). The concept of weighted usable area as relative suitability index. *IFIM Users Workshop 15 June 2003 Fort Collins CO*, 1–14.

Payne, T. R., & Jowett, I. G. (2013). SEFA-Computer software system for environmental flow analysis based on the instream flow incremental methodology. Georgia Institute of Technology.

Pickard, B. R., Daniel, J., Mehaffey, M., Jackson, L. E., & Neale, A. (2015). EnviroAtlas: A new geospatial tool to foster ecosystem services science and resource management. *Ecosystem Services*, *14*, 45–55. http://doi.org/10.1016/j.ecoser.2015.04.005

Plummer, M. V., & Farrar, D. B. (1981). Sexual dietary differences in a population of Trionyx muticus. *Journal of Herpetology*, 175-179.

Plummer, M. V. (1977). Activity, habitat and population structure in the turtle, *Trionyx muticus*. *Copeia*, 431-440.

Poff, N.L., Zimmerman, J.K.H., 2010. Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. *Freshwater Biol*. 55, 194–205.

Postel S, Richter B (2003) Rivers for life: managing water for people and nature. Island Press, Washington, DC

Pritchard, P. C. H., & Trebbau, P. (1984). The Turtles Of Venezuela (No. 2). Society For The Study Of Amphibians And Reptiles Contribution To Herpetology.

Raleigh, R. F., Zuckerman, L. D., & Nelson, P. C. (1986). *Habitat suitability models and instream flow suitability curves: brown trout. US Fish & Wildlife Service Biological Services Program FWS*. OBS/-82/10.71.

Reese, D. A. (1996). *Comparative demography and habitat use of western pond turtles in northern California: the effects of damming and related alterations* (Doctoral dissertation, University of California, Berkeley).

Richardson, E., Stirling, I., Hik, D.S., 2005. Polar bear (Ursus maritimus) maternity denning habitat in western Hudson Bay: a bottom-up approach to resource selection functions. Can. J. Zool. 83, 860–870, http://dx.doi.org/10.1139/Z05-075

Richter, B. D., Baumgartner, J. V., Powell, J., & Braun, D. P. (1996). A method for assessing hydrologic alteration within ecosystems. *Conservation biology*, *10*(4), 1163-1174.

Shively, S. H., & Jackson, J. F. (1985). Factors limiting the upstream distribution of the Sabine map turtle. *American Midland Naturalist*, 292-303.

Silliman B. R. and M. D. Bertness, 2002. A trophic cascade regulates salt marsh primary production. Proceedings of the National Academy of Science 99: 10500-10506.

Silva, P. A. D., Reynalte-Tataje, D. A., & Zaniboni-Filho, E. (2012). Identification of fish nursery areas in a free tributary of an impoundment region, upper Uruguay River, Brazil. *Neotropical Ichthyology*, *10*(2), 425-438.

Smoot, G.F., And Novak, C.E., 1968, Calibration And Mainte- Nance Of Vertical-Axis Type Current Meters: U.S. Geological Survey Techniques Of Water-Resources Investigations, Book 8, Chap. B2, 23 P. (Also Available At Http://Pubs.Usgs.Gov/ Twri/Twri8b2/.)

Spence, R., & Hickley, P. (2000). The use of PHABSIM in the management of water resources and fisheries in England and Wales. *Ecological Engineering*, *16*(1), 153-158.

Stalnaker, C. B., & Arnett, J. L. (1976). *Methodologies for the determination of stream resource flow requirements: an assessment* (No. 76/03). US Fish and Wildlife Service.

Stewardson, M. J., & Gippel, C. J. (2003). Incorporating flow variability into environmental flow regimes using the flow events method. *River Research and Applications*, *19*(5- 6), 459-472.

Strakosh, T. R., Neumann, R. M., & Jacobson, R. A. (2003). Development and assessment of habitat suitability criteria for adult brown trout in southern New England rivers. *Ecology of Freshwater Fish*, *12*(4), 265-274.

Tennant, D. L. (1976). Instream flow regimens for fish, wildlife, recreation and related environmental resources. *Fisheries*, *1*(4), 6-10.

Tharme, R. E. (1996). Review of international methodologies for the quantification of the instream flow requirements of rivers. *Water Law Review: final report for policy development, South African Department of Water Affairs and Forestry. Freshwater Research Unit:* University of Cape Town: Pretoria.

Tharme RE (2003) A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. River Res Appl 19:397–441. doi:10.1002/rra.736

Thomas, P. R., & Jowett, I. G. (2013). SEFA-Computer software system for environmental flow analysis based on the instream flow incremental methodology. Georgia Institute of Technology.

Tucker, A. D., FitzSimmons, N. N., & Gibbons, J. W. (1995). Resource partitioning by the estuarine turtle Malaclemys terrapin: trophic, spatial, and temporal foraging constraints. *Herpetologica*, 167-181.

Tucker, J. K., & Moll, D. (1997). Growth, reproduction, and survivorship in the red-eared turtle. Trachemys scripta elegans, in Illinois, with conservation implications. *Chelonian Conservation and Biology*, *2*, 352-357.

Tulipani, D. C. (2013). *Foraging ecology and habitat use of the northern diamondback terrapin (Malaclemys terrapin terrapin) in southern Chesapeake Bay*. The College of William and Mary.

Tunbridge, B. R., & Glenane, T. J. (1988). *A study of environmental flows necessary to maintain fish populations in the Gellibrand River and estuary*. Department of Conservation, Forests and Lands, Victoria, Arthur Rylah Institute for Environmental Research.

Turner, M.G., Wu, Y., Wallace, L.L., Romme, W.H., Brenkert, A., 1994. Simulating winter interactions among ungulates vegetation, and fire in Northern Yellowstone Park. Ecol. Appl. 4, 472–496.

USGS, 1999. Chronicle of Instream Flow Activities: Preliminary Draft of PHABSIM for Windows is Available for Initial Comments. http://www.mesc.usgs.gov/rsm/ifim-chron/ phabsim\ b.htm.

Valiela, I., D. Rutecki, S. Fox. 2004. Salt marshes: biological controls of food webs in a diminishing environment. Journal of Experimental Marine Biology and Ecology 300:131-159.

Welcomme, R. L. 1979. Fisheries Ecology of Floodplain Rivers. Longman Group Limited,London.

Wilson, L. J., McSorley, C. A., Gray, C. M., Dean, B. J., Dunn, T. E., Webb, A., & Reid, J. B. (2009). Radio-telemetry as a tool to define protected areas for seabirds in the marine environment. *Biological Conservation*, *142*(8), 1808–1817. http://doi.org/10.1016/j.biocon.2009.03.019

Yi, Y., Cheng, X., Yang, Z., Wieprecht, S., Zhang, S., & Wu, Y. (2017). Evaluating the ecological influence of hydraulic projects: A review of aquatic habitat suitability models. *Renewable and Sustainable Energy Reviews*, *68*(July 2016), 748–762. http://doi.org/10.1016/j.rser.2016.09.138

Yin, X.A., Yang, Z.F., Petts, G.E., 2012. Optimizing environmental flows below dams. River Res. Appl. 28, 703–716.

Zeiler, M. (2002). *Modeling Our World. The ESRI Guide to Geo*.

Zheng, C., Yang, W., Yang, Z.F., (2011). Strategies for managing environmental flows based on the spatial distribution of water quality: a case study of Baiyangdian Wetland, China. *Journal of Environ. Inform.* 18, 84–90.