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Required flows for aquatic ecosystems in Ma River, Vietnam

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Abstract**—** *Ecological flow requirements for the Ma River in dry season were assessed in three reaches of Ma – Buoi, Ma – Len and Ma – Chu. 5 indictor fish species was chosen based on biodiversity survey and roles of those species in aquatic ecosystem as well as local communities. Biological and hydrological data (dry season of 2016-2017) and 35 year recorded hydrological data were collected and analyzed as input data for a physical habitat model River HYdraulic and HABitat SImulation Model – RHYHABSIM. Model results shown that the optimal flows of the reaches were very much higher compare with the minimum annual low flow - MALF. In this study, $MALF_{7day}$ were applied to calculate the recommended minimum flows of the three reaches. The recommended required minimum flows for Ma – Buoi, Ma – Len and Ma – Chu reaches were 51 m^3/s, 49 m^3/s and 61 m^3/s, respectively. It must be stressed that this study only assessed whether or not there is enough habitat available for the river to sustain a healthy ecosystem.*

Keywords**— *Ma River, Minimum Annual Low Flow – MALF, Required flows, River HYdraulic and HABitat SImulation Model – RHYHABSIM, Weighted Useable Area –WUA.***

I. INTRODUCTION

Flow management, in its basic sense, is the allocation of the resources, water, for specific uses and purposes. The different uses for an individual flow could include domestic used water, irrigation, fisheries, recreation, carrier of treated waste-water, and the maintenance of the natural/native biodiversity etc. At any point in time, the water quantity in a flow is affected by natural factors such as precipitation and geology, as well anthropogenic influences including the physical alteration of the stream, river, dams\weirs, and surface and groundwater abstraction [1].

Water abstraction plays an important part in most surface water systems, especially, the water that is present in a flow even during extended dry periods. Over exploitation of flow's water resources can significantly reduce a stream's base flow to the point where once permanent streams become ephemeral. This change can have severe consequences for the native flora and fauna of the flow (i.e. [2], [3], [4]).

In order to manage the freshwater resources, both an inventory of the water resource available and an assessment of the ecology of the natural (unaltered) freshwater ecosystem need to be undertaken. Habitat models such as habitat hydraulic models are one of the tools available to evaluate how changing flow regimes will affect the physical habitat for the biological communities [5]. These models combine the hydrological and biological variables in a system, simulating how available habitat for a particular species will change with differing hydrological responses to resource utilization [6], [7]. RHYHABSIM (short for River HYdraulic and HABitat SImulation Model) was developed by Ian Jewett in the 1980s and is continuingly being improved, intended for use by water managers [5], [8]. RHYHABSIM is able to model habitat responses to changing hydrological conditions, and has been identified as a management tool for assessing current ecosystem condition.

Hydraulic-habitat models marry water depth and velocity predictions made by a hydraulic model with fish frequency-or density-based habitat suitability criteria (or curves) (HSC) for these hydraulic, and other physical, habitat variables (e.g., substrate) to predict weighted useable area (WUA; more correctly termed the area weighted suitability) [9], [10].

Habitat models, such as RHYHABSIM, attempt to quantify the flow required to maintain a healthy ecosystem, thus providing stream/river managers with important information from which to base their water management decisions (such as water abstraction) upon.

This paper looks at the application of RHYHABSIM as a tool to aid the management of freshwater ecosystems. Applying on a case study of Ma River, Vietnam, the model is used to predict the flows needed to provide the necessary habitat to sustain naturally recruiting populations of local fish species in dry season. The application of the model is evaluated with regard to its usefulness from a resource manager's perspective.

II. STUDY SITE AND METHODOLOGY

2.1 Study site

The Ma River is a river in Asia, originating in northwest of Vietnam. It runs for 400 km through Vietnam, Laos, and then back through Vietnam, meeting the sea at the Gulf of Tonkin.

The largest tributaries of the Ma River are the Chu River (or the Nam Sam River as it is called in Laos), the Buoi River, and the Cau Chay River. All of them join the Ma River in Thanh Hoa Province in North Central Vietnam. The Ma River creates the Ma River Delta (also called the Thanh Hoa Delta), the third largest in Vietnam.

Like the Red River (Song Hong) to the north, it has an irregular regime with maximum flow toward the end of the summer.

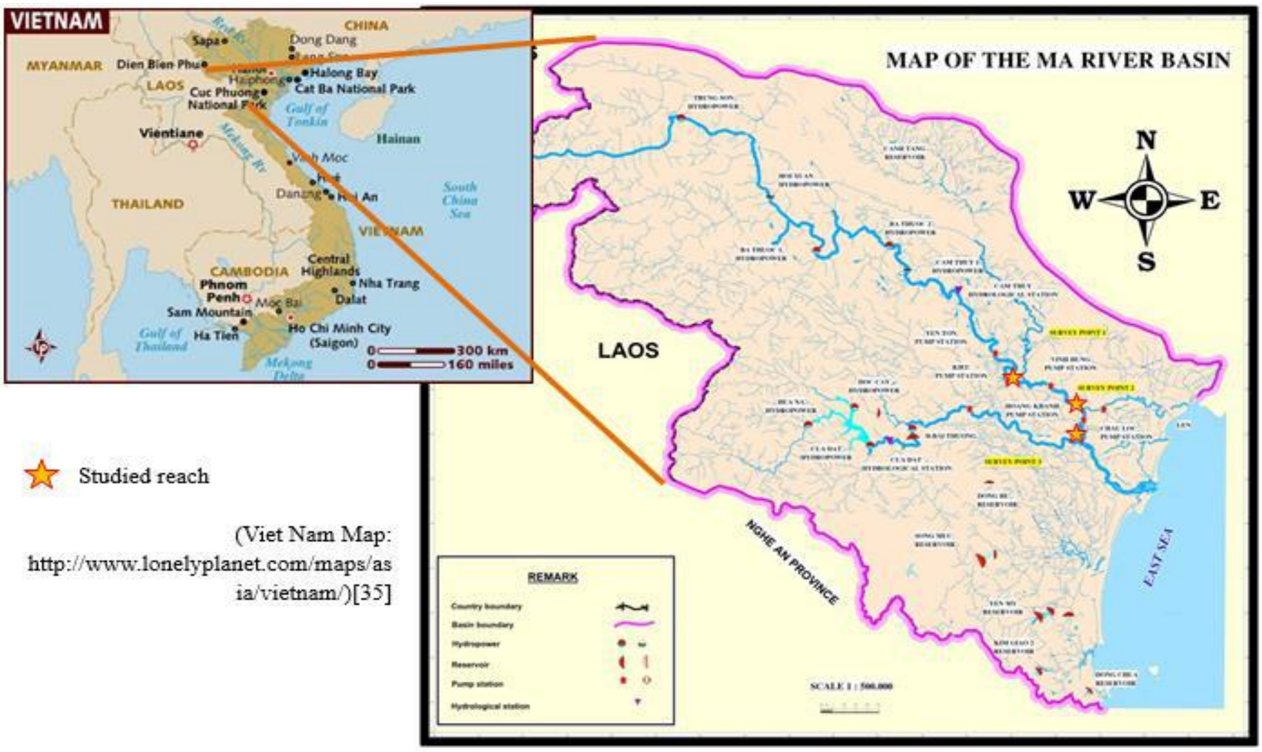

Fig. 1: Map of Ma River Basin

The Ma River delta differs, however, from that of the Red River because of its narrowness and the presence of sandy soil.

The average temperature in the Ma River basin is relatively high throughout the year. The average temperature recorded at the 14 meteorological stations within the Ma River basin varies spatially ranging from 20.9-23.0^{0}C, reflecting the topographical characteristics and altitudes of the locations. Annual rainfall is substantial with dominant winds from south and southeast during May to September months.

The river flow varies greatly in time and space. The river flow in cubic meters per second (m^3/s) varies quite greatly in Cam Thuy. The average discharge in April (111 m^3/s) is only one-third of the annual discharge (334 m^3/s) and one-seventh of the highest average discharge (in August). Data show that the highest discharges monitored at Cua Dai, Xuan Khanh and Cam Thuy are 442 m^3/s and 1,713 m^3/s, respectively, and 258 times higher than the lowest discharges at the same gauging station.

In the dry season, the runoff is only 4.76 billion m^3, making up 26% of the total annual runoff. The driest period is between February and April, which comprises

8% of the annual flow. March tends to have the lowest flow rates, contributing only 2.4% of the total [11]. Together with the demand for difference water uses, the requirement water for aquatic ecosystem in Ma River becomes an issue especially in dry season.

There are three reaches with 17 cross sections (4 to 8 cross sections per reach) were set up and investigated in the main flow of Ma River during dry season of 2016-2017. All the reaches are located in upstream of the distributaries of Ma River, the first one is Buoi River, second one is Len River and the last one is Chu River (Figure 1).

2.2 RHYHABSIM

RHYHABSIM uses a combination of a hydraulic simulation model to predict flow conditions, and biological models to quantify how the change in flow impacts available habitat for a number of fish species. Fish habitat predictions are quantified using an index called Weighted Usable Area (WUA), which incorporates the relative quantity and quality of available habitat at a given flow [12], [13]. WUA is expressed as an area of suitable habitat per length of river (m^2/m).

The most common use of RHYHABSIM modeling is to provide guidance when setting minimum flow limits for Ma River. This process uses the model results to help inform a minimum flow which balances in stream and out-of-stream uses. This is accomplished primarily by two steps:

- Identifying the point at which habitat loss decreases disproportionally to reduction in flow, known as the inflection point on the habitat × flow response (WUA) curve;
- Determining a flow-related baseline and assessing habitat relative to that baseline, usually the naturalized mean annual low flow (MALF);

The first step is often used where seasonal flow fluctuations (most notably low flows – dry season) are not the limiting factor in physical habitat for fish species. This is identified where the optimum flow for a given species is less than the mean annual low flow. Using the flow × WUA curve, the minimum flow is often chosen as the inflection point; where the relationship between flow and habitat is 1:1. At flows below this inflection point, a reduction in flow results in a proportionally greater reduction in habitat, thus increasing risk of habitat loss for the management species [14].

2.3 Stream Survey Methodology

The objective of the stream survey was to obtain the measurements needed to model the stream parameters that influence fish habitat: stream depth, velocity, discharge and substrate. The three reaches were surveyed according to standard RHYHABSIM protocol and methodology (provided in [15][16]). For this study, each survey site contained 4 to 8 cross-sections, with an even distribution of cross-sections between riffles, runs and pools. The survey took place in two parts – the initial (Feb, 2016), more intense survey, and follow-up visits. The initial visit was used by the model to establish the basic hydraulic parameters for the stream [16]. The follow-up visits (Feb, 2017), conducted at different stream discharge rates, were used to calibrate the model, which was then used to predict how the stream's physical attributes (velocity, width, depth and substrata) change with stream discharge.

At the initial survey for each of the 17 cross-sections, the following parameters were measured:

- Stream profile from the top of the stream bank
- the stream profile defined the confines of the stream.
- Flow velocity and discharge rate – velocity is particularly important, as it will vary across the cross-section, influencing the model results.
- The stream stage (water level) at one fixed point in the stream for each cross-section. The stream stage was measured at this point in the follow-up visits.
- The substrata across the profile of the streams. The substrate index is vegetation, mud/silt, sand, gravel, coarse gravel, cobbles, boulders and bedrock, classified as 1-8 respectively [4].

2.4 Indicator fish species

In this study, 5 following fish species were used to estimate required water flow for Ma River. 1) Common carp - *Cyprinus carpio* Linnaeus, 1758 (Cypriniformes: Cyprinidae); 2) Common armorhead catfish - *Cranoglanis henrici* (Vaillant, 1893) (Siluriformes: Cranoglanididae); 3) Greenback mullet - *Chelon subviridis* (Valenciennes, 1836) (Perciformes: Mugilidae); 4) Dusky sleeper - *Eleotris fusca* (Forster, 1801) (Perciformes: Eleotridae); and 5) Tank goby - *Glossogobius giuris* (Hamilton, 1822) (Perciformes: Gobiidae).

These 5 species were chosen because of following reasons: different possibility catching along of research areas in Ma River; inhabit in different water column: benthopelagic with common carp, common armorhead catfish and tank goby, demersal with greenback mullet and dusky sleeper; adapt with different optimum current speed: 0.3-0.4 m/s with common carp and tank goby, 0.4-0.6 m/s with common armorhead catfish and greenback mullet, 0.2-0.3 m/s with dusky sleeper; and many different following detail characteristics.

The first species, common carp - *Cyprinus carpio*, is a very common in freshwater and brackish environment throughout the world with the body size range in 25 - 36 cm as adult. This fish has highly commercial value in fisheries, aquaculture and also in aquarium. Common carp inhabit warm, deep, slow-flowing and still waters such as lowland rivers and large, well vegetated lakes and they can adapt with wide variety of conditions but generally favor large water bodies with slow flowing or standing water and soft bottom sediments [17]. Both adults and juveniles feed on a variety of benthic organisms and plant material. They spawn along shores or in backwaters and larvae survive only in very warm water among shallow submerged vegetation. Under tropical conditions, common carp breeds throughout the year but seasonal spawned in temperate waters [18].

The next chosen species is common armorhead catfish - *Cranoglanis henrici*. This species distribute in Thailand, Philippines, Indonesia, China (Hainan island, Guangdong, Guangxi, Yunnan) and Vietnam [19]. They live at bottom and near bottom, preferring moderately and slowly running waters with much sandy and muddy bottom. They usually live in colonies and are found mainly in the downstream of rivers in Northern provinces. *C. catfish* in general and *C. henrici* in particular are famous for their tasty and nutritious meat. *C. henrici* is found in all river systems from the North to the South of central Vietnam, but not found in the South [20], [21] with the spawning season from May to July [22].

Greenback mullet, *Chelon subviridis*, form schools in shallow coastal waters and enters lagoons, estuaries, and fresh water to feed. Juveniles may enter rice fields and mangroves. Greenback mullet feed on small algae, diatoms and benthic detrital material taken in with sand and mud; fry take zooplankton, diatoms, detrital material and inorganic sediment [23]. Spawning occurs at sea with pelagic and non-adhesive eggs [24].

The fourth species, Dusky sleeper - *Eleotris fusca*, is found in rivers, estuaries and coastal regions throughout the Indo-west Pacific, from the eastern coast of Africa to the Hawaiian Islands where this species spawns during May to December with most proportion from August to November [25], [26]. They occur in the lower reaches of freshwater streams, usually on mud bottoms and feed on crustaceans and small fishes [27]. Dusky sleeper spawns eggs on submerged plants with small leaves, female tends and fans the eggs until hatching and loosely guards the fry for a few days thereafter [28]. Juveniles are found mainly among mangrove roots in the more saline areas of lagoons and estuaries [28].

The last chosen species, Tank goby - *Glossogobius giuris*, is found mainly in freshwater and estuaries, but also enter the sea; this fish species also occur in canals, ditches and ponds [29]. The species has a marine larval stage, but can breed in fresh water. It has been recorded breeding during the 'dry' season in northern Australia and in summer in South Africa [30] and from March to September in Manchar Lake, Pakistan [31].

III. RESULTS

3.1 Biological Data – the Habitat Suitability Curves

The profiles for the thee stream reaches are shown in Table 1 and Figure 2. The upper reach consisted of fast habitats (depth > 0.80 m and velocity ≥ 0.82 m/s). The lower reach had deep-slow mesohabitat in its part (depth ~ 2.51 m and velocity ~ 0.15 m/s) with area of 475.84 m^2 and average width of 189.28 m. The lowest reach and the shallow-fast (depth ~ 2.81 m and velocity ~ 0.16 m/s) with area of 640.52 m^2 and average width of 228.12 m.

The Habitat Suitability Curves (HSC) (Figure 3) showed that a depth of 5.0 m and velocity of around 0.4-0.5 m/s are optimum (these are Food producing criteria, Waters 1976). The curves for substrate type indicated that all the five selected species was associated with a wide variety of substrate classes, such as mud/silt, gravel, coarse gravel and sand. The curves for *C. henrici, C. subviridis, E. fusca, G. giuris* indicated preference for large boulders and boulders, whereas *C. carpio* for sand and mud/silt only.

3.2 Model results

Ma – Buoi Reach

The habitat surveys of this reach were carried out at a flow of 80.62 m^3/s, at the survey flow of 76.80-84.97 m^3/s. The average width of this reach was 131.81 m, depth 0.89 m, and velocity 0.90 m/s. Substrate assessments at all sites were similar, with >95% sand and the remaining substrate a mixture of gravel and mud.

Maximum habitat for *C. henrici, G. giuris* and *C. carpio* was provided by a flow of 90 m^3/s, and the amount of suitable habitat began to fall when flows fall below 20 m^3/s. Maximum *C. subviridis* and *E. fusca* habitat was provided by a flow of 80 m^3/s, with a reduction beginning when flows fell below 20 m^3/s (Figure 4.1, Table 2).

Ma – Len Reach

The habitat surveys of this reach were carried out at average flow of 74.59 m^3/s, at the survey flow of 70.48-79.92 m^3/s. The average width of the river was 189.28 m, depth 2.51 m, and velocity 0.15 m/s. Substrate assessments at all sites were similar, with 73.6% sand and the remaining substrate a mixture of gravel and mud of 6.9 and 19.5, respectively.

According to Figure 4.2, Table 2, optimal flow for all the indicator species are very high compare with the previous reach. *C. henrici, G. giuris* and *C. carpio* was provided maximum habitat by a flow of more than 80 m^3/s, and the amount of suitable habitat began to fall when flows fall below 30 m^3/s. Maximum *C. subviridis* and *E. fusca* habitat was provided by a flow of 100 m^3/s, with a reduction beginning when flows fell below 30 and m^3/s.

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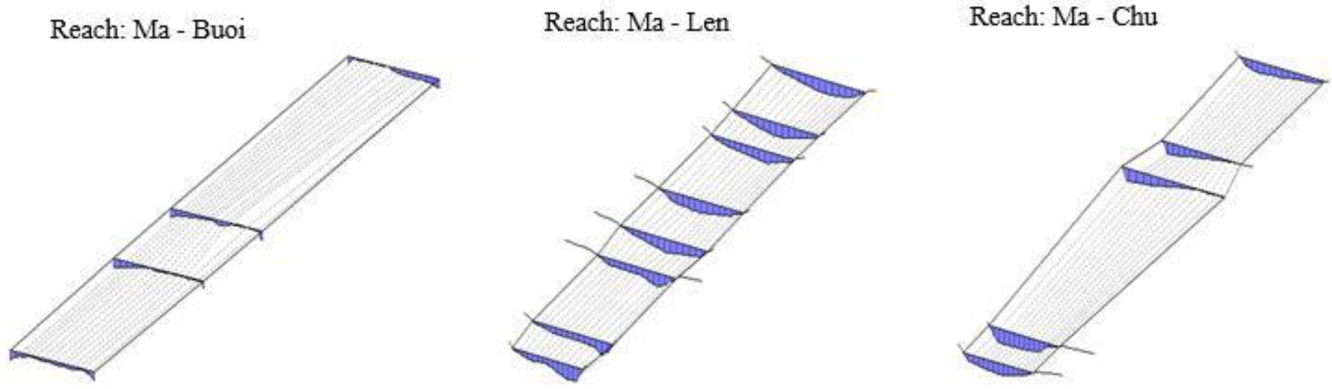

Fig. 2: Isometric view of the cross-sections in the three target reaches of Ma River. Blue color indicates water; solid line indicates the contour of the cross-section.

Table.1: Reach Hydraulic Geometry

Section	Flow (m^3/s)	Width (m)	Depth (m)	Velocity (m/s)	Area (m^2)
Ma-Buoi		**Reach length: 1,303.27 m**			
Section1	84.97	130.30	0.81	0.94	105.94
Section2	83.55	140.19	0.82	0.82	115.38
Section3	76.80	111.61	0.88	0.92	98.19
Section4	77.16	142.21	0.98	0.89	138.59
Reach	***80.62***	***131.81***	***0.89***	***0.90***	***117.64***
Ma-Len		**Reach length: 1,194.44 m**			
Section1	79.92	159.87	2.50	0.19	398.81
Section2	78.48	181.85	2.06	0.19	374.53
Section3	76.52	178.05	2.35	0.17	417.95
Section4	75.56	198.29	2.73	0.13	541.49
Section5	71.72	192.26	2.68	0.13	515.79
Section6	72.25	189.37	2.44	0.15	462.84
Section7	71.82	195.34	2.63	0.13	514.23
Section8	70.48	211.70	2.74	0.11	579.47
Reach	***74.59***	***189.28***	***2.51***	***0.15***	***475.84***
Ma-Chu		**Reach length: 1,587.82 m**			
Section1	105.84	190.47	3.34	0.16	635.61
Section2	101.61	190.25	3.96	0.13	754.10
Section3	107.97	281.72	2.32	0.15	654.26
Section4	116.51	214.63	2.13	0.22	456.71
Section5	116.59	231.44	2.71	0.18	627.63
Reach	***109.70***	***228.12***	***2.81***	***0.16***	***640.52***

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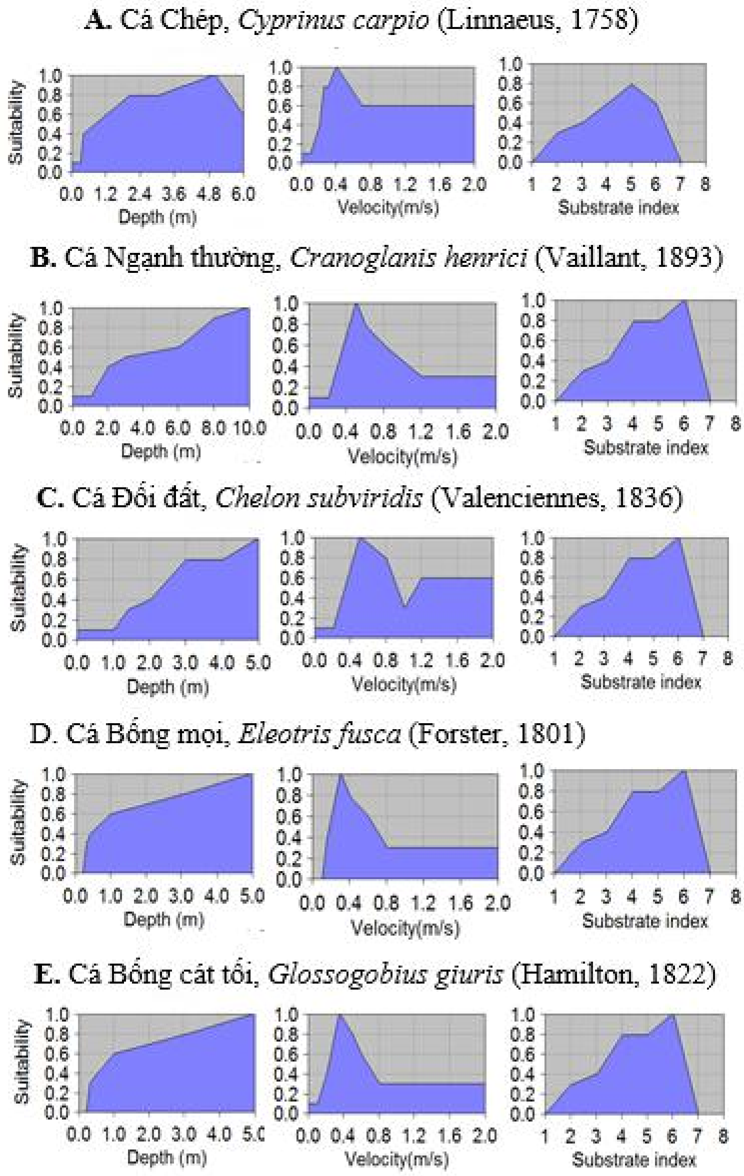

Fig. 3: The biological input to the model in the form of Habitat Simulation Curves.

Ma – Chu Reach

The habitat surveys of Ma-Chu reach were carried out at an average flow of 109.70 m^3/s, at the survey flow of 101.61-116.59 m^3/s. The average width of the river was 228.12 m, depth 2.81 m, and velocity 0.6 m/s. Substrate assessments at all sites were similar, with 79.4% sand and the remaining substrate a mixture of gravel and mud of 3.9 and 16.7, respectively.

Maximum habitat for *C. henrici*, *G. giuris* and *C. carpio* was provided by a flow more than 100 m^3/s, and for *C. subviridis* and *E. fusca*, it was > 130m^3/s. The amount of suitable habitat began to fall when flows fall below 50 m^3/s for all *C. henrici, C. subviridis, E. fusca* , *G. giuris* and *C. carpio* (Figure 4.3, Table 2).

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Table.2: Flow requirement for fish species at each reach in Ma River

Reach/ Target fish species	**MALF (m^3/s)**	**MALF $_{7day}$ (m^3/s)**	**Optimum flow (m^3/s)**	**Declined Flow (m^3/s)**
Ma - Buoi	**50.59**	**56.00**		
Cyprinus carpio			80-110	<20
Cranoglanis henrici			70-100	<20
Chelon subviridis			70-100	<20
Eleotris fusca			80-110	<20
Glossogobius giuris			80-110	<20
Ma - Len	**55.48**	**60.89**		
Cyprinus carpio			>80	<30
Cranoglanis henrici			>80	<30
Chelon subviridis			>80	<30
Eleotris fusca			>80	<30
Glossogobius giuris			>80	<30
Ma - Chu	**63.37**	**70.34**		
Cyprinus carpio			>100	<50
Cranoglanis henrici			>100	<50
Chelon subviridis			>100	<50
Eleotris fusca			>100	<50
Glossogobius giuris			>100	<50

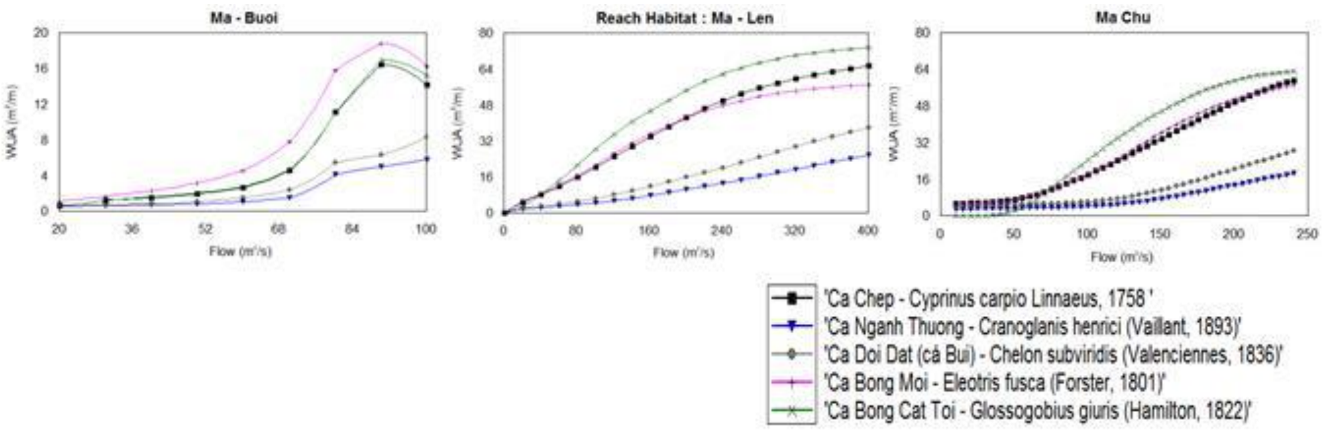

Fig. 4: Fishes' habitats in the three reaches of Ma River

Table.3: Recommended minimum flows

Reach	MALF 7day (m^3/s)	WUA (m^2/m)@ MALF 7 day	80% of WUA (m^2/m)@MALF 7 day	Corresponding Minimum Flow (m^3/s) (approximate)
Ma - Buoi	56.00	2.80	2.24	**51.00**
Ma - Len	60.89	45.70	36.56	**49.00**
Ma - Chu	70.34	38.80	31.04	**61.00**

IV. DISCUSSIONS

The method of using mean annual low flow (MALF) as an indicator to determine appropriate minimum flows based on RHYHABSIM model outputs have been applied for a number of studies [32]. It states that where maximum habitat is greater than the mean annual low flow (MALF), it is acceptable to set the recommended minimum flow at 80% of the habitat available at the MALF. This situation often exists in the reach Ma – Buoi in Ma River, where annual summer low flows cannot provide optimum conditions; therefore setting minimum flows at the habitat optimum is unrealistic. The approach described in the Sustainable Low Flow Project recognizes this and uses both habitat data and historical flow data to arrive at minimum flow recommendations that are realistic, conservative, and attainable. It is important to consider natural flow conditions without the influence of abstraction when setting minimum flows.

In several cases, 7-day MALF value was applied instead of 1-day MALF. An analysis of the relationships between the 7-day MALF and the 1-day MALF shows that the ratio ranges from 1.0 to more than 1.7. More than 80% of catchments have a ratio of less than 1.2, and the median ratio is 1.08 [33]. However, low flows is a set the limit to habitat quantity, providing that the duration of low flows is sufficient to engender a biological response [33]. Therefore, in this study, the value of 7-day MALF was used.

The suggested minimum flow rules given in the proposed National Environmental Standard (New Zealand) on ecological flows [34] are:

- For rivers and streams with mean flows less than or equal to 5 m^3/s, a minimum flow of 90% of the mean annual low flow (MALF).

- For rivers and streams with mean flows greater than 5 m^3/s, a minimum flow of 80% of MALF.

HSI graphs indicate that the optimum quality of fish habitat occurs at lower flows than optimum habitat quantity (WUA). It is recommended that WUA be the primary consideration when addressing minimum flows. WUA combines habitat quality with area (quantity), and is considered to be more conservative. From a fisheries management perspective, a greater supply of suitable habitat is more important for fish productivity than a small supply of high quality habitat [32], thus WUA was used to arrive at a minimum flow figure.

Taking into account of evaluating 5 species, and it was done through 4 to 7 section analysis is an essential factor when recommending a minimum flow and allocation limit. It requires that ecological "bottom lines" are maintained (Ngaruroro, 2008).

Based on the results of RHYHABSIM and the MALF value which were calculated based on analyzed data of 35 year (1980-2015), recommended minimum flows of the three reaches were proposed (Table 3). The recommended minimum flows for reaches Ma – Buoi, Ma – Len and Ma – Chu are 51 m^3/s, 49 m^3/s and 61 m^3/s, respectively.

It must be stressed that this study only assessed whether or not there is enough habitat available for the river to sustain a healthy ecosystem. Even if the streams are achieving the needed flows for suitable habitat, they still could be underperforming according to the environmental goals set (i.e. not achieving a 'good ecological condition'). Other factors could be influencing the biota, including pollution, predation, invasive species, sedimentation and alteration of stream morphology etc.

It should be recognized that optimal protection of in stream values cannot be achieved when social and economic considerations are accounted for. It is the goal of river management to achieve balance between all in stream values, while maintaining ecosystem health.

Monitoring and follow-up of the data is also important to assure the accuracy of the model results. Continual monitoring of the stream ecosystem is important to assure the accuracy of the model results. Monitoring of the actual flow recommendations, when they are in place, should include visual observations to decide if the flow limits set by the model and the following negotiation are actually meeting the hydromorphological demands of the streams such as covering riffles, providing enough depth in pools etc. The biological component should also be monitored to ensure that the flows are adequate. Monitoring will allow the data input and model output to be assessed and refined as conditions change both in the stream and as a result of management decisions. This will create a more solid basis for ongoing and future management decisions.

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