KINGDOM OF CAMBODIA

Nation Religion King

MINISTRY OF AGRICULTURE, FORESTRY AND FISHERIES

FISHERIES ADMINISTRATION

Fisheries education in Cambodia: Bachelor of Science syllabus evaluation, support options and possible synergies

Cambodia Programme for Sustainable and Inclusive Growth in the Fisheries Sector:

Capture Component (CAPFISH-Capture)

March 2023

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Technical report

prepared for the Food and Agriculture Organization of the United Nations

and the Fisheries Administration (Ministry of Agriculture, Forestry and Fisheries)

of the Royal Government of Cambodia

by

Francesca PASOTTI

(Academic Capacity Building Expert)

Eric BARAN

(Fisheries Research Specialist)

CHUM Nith

(Research specialist)

HENG Kong

(IFReDI director)

Food and Agriculture Organization of the United Nations

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Cambodia Programme for Sustainable and Inclusive Growth in the Fisheries Sector: Capture Component (CAPFISH-Capture)

Fisheries education in Cambodia: Bachelor of Science syllabus evaluation, support options and possible synergies

Prepared by
FAO for FiA

Phnom Penh, March 2023

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LIST OF ACRONYMS

BSc: Bachelor of Science
CLO: Course Learning Outcomes (what students learn from a given course in a curriculum)
FAO: Food and Agriculture Organization of the United Nations
KNIA: Kampong Cham National Institute of Agriculture (Kampong Cham Province)
LLO: Lesson Learning Outcomes (what is taught in each course, what students learn from each lesson)
NIA: Preak Leap National Institute of Agriculture (Phnom Penh)
PLO: Program Learning Outcomes (what students learn from a curriculum)
RUA: Royal University of Agriculture (Phnom Penh)
RUA FoFA: Faculty of Fisheries and Agriculture at RUA
UKT: University of Kratie (Kratie Province).

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This study aimed at improving education in fisheries in Cambodia is dedicated to the memory of Mr. That Sovannarith (formerly Head of Fisheries Department, Kampong Cham National Institute of Agriculture), who passed away in November 2022.

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EXECUTIVE SUMMARY: Summary table of syllabus evaluation: needs and priorities for each priority course. Review based on curricula in specialized Year 2, Year 3 and Year 4. Year 1 ("Foundation year"), common to all students in all faculties, is not detailed here.

CODE	A1	A2	A3	A4
COURSE	**Fisheries conservation and management (KNIA) / Fisheries management (RUA) / Natural resources management and conservation (NIA) / Natural resources and environmental science (UKT)**	**Fish processing technology (KNIA) / Fish processing technology (RUA) / Processing and product management (NIA) / Post-harvest technology and processing (UKT)**	**Fisheries research and survey methods (KNIA) / Fisheries research and survey methods (RUA) / Research methodology (NIA)/ Research methodology and scientific writing (UKT)**	**Water Quality Analysis (RUA) / Soil and Water Chemistry Analysis (KNIA) / Water quality (NIA, UKT)**
NEEDS	RUA: important	RUA	RUA	RUA: important
	NIA: important	NIA	NIA	NIA: important
	KNIA: important	KNIA	KNIA	KNIA: important
	UKT: important	UKT	UKT	UKT: important
PRIORITY LEVEL	RUA: low			RUA: important
	NIA: low			NIA: important
	KNIA: low			KNIA: important
	UKT: low			UKT: important
MAIN NEEDS	RUA, NIA, KNIA, UKT: Marine content should be implemented	Review, identification of needs and provision of support under the UNIDO project Post-Harvest Fisheries Development project	The content of these courses could not be reviewed (no professors available during the mission)	RUA, NIA, KNIA, UKT: update and homogenize the content of courses across the four universities
	RUA, NIA, KNIA, UKT: promote visits of experts and visits to NGO sites			RUA, NIA, KNIA, UKT: assist with provision of water quality test kits and probes (RUA, NIA)
				RUA, NIA, KNIA, UKT: organise a workshop for teachers and lab staff to exchange ideas for field and practical activities
				RUA, NIA, KNIA, UKT: make use of each University's facilities and expertise to build practical activities (assignments for students) then turn them into video tutorials
				RUA, NIA, KNIA, UKT: support the establishment of an online platform for the exchange of teaching material and of the video tutorials
	ALL: Grant access to high quality online journals			
	ALL: Provide English courses to teachers			

Summary table (continued): needs and priorities

CODE	B1	B2	B3	B4
COURSE	**Fish physiology (KNIA, NIA, RUA)**	**Fish pathology and health management (KNIA) / Fish pathology (NIA RUA)**	**Fish anatomy (RUA) / Ichthyology (KNIA, NIA)**	**Limnology (KNIA) / Limnology (RUA) / Limnology and oceanography (NIA)**
NEEDS	RUA: important	RUA: lower	RUA: important	RUA: important
	NIA: important	NIA: lower	NIA: important	NIA: important
	KNIA: important	KNIA: major	KNIA: important	KNIA: important
	No course at UKT	UKT: major	No course at UKT despite the Institute of ichthyology	No course at UKT
PRIORITY LEVEL	RUA: major	RUA: lower	RUA: important	RUA: important
	NIA: major	NIA: important	NIA: important	NIA: important
	KNIA: major	KNIA: major	KNIA: important	KNIA: important
	KNIA: major	UKT: major	KNIA: important	UKT: major
MAIN NEEDS	RUA, NIA, KNIA, UKT: assist (external expert, translator) to update content by using recommended handbooks and online literature	RUA, NIA: assist (external expert, translator) to update content by using recommended handbooks and online literature	RUA, NIA, KNIA: assist (external expert, translator) to update content by using recommended handbooks and online literature	RUA, NIA, KNIA: assist (external expert, translator) to update content by using recommended handbooks and online literature
	RUA, NIA, KNIA, UKT: Fish Physiology and Ichthyology labs should have coordinated activities	KNIA: find external teachers to teach the content of the course	RUA, NIA, KNIA: provide large 3D models of bony fishes and cartilaginous fishes	UKT: the course is not in the curriculum but of high interest
		RUA, NIA, KNIA, UKT: agree on a common course content	RUA, NIA, KNIA: 3D models can be built by students	NIA: split the course into two: i) Limnology and ii) Oceanography
		RUA, NIA, KNIA, UKT: organise workshops for teachers to share know-how in practical lab activities		RUA: update the course with online sources and the Encyclopaedia of ocean sciences
		NIA, UKT: Establish collaborations with FiA to provide for external teachers		RUA, NIA, KNIA: high need for a contributor to enhance in Khmer the marine content
		RUA, NIA: Explore possible service agreements for sharing of molecular analysis equipment		UKT: request to have this course taught by guest lecturers
	ALL: Grant access to high quality online journals			
	ALL: Provide English courses to teachers			

Summary table (continued): needs and priorities for three additional courses

CODE	Complement 1	Complement 2	Complement 3
COURSE	**Fisheries Ecology (NIA)/ Ecology of Aquatic Ecosystems (KNIA) / Fisheries (RUA, UKT)**	**Systematic Aquatic Zoology (KNIA, RUA)**	**Biology (UKT)**
NEEDS	RUA: low	RUA: major	No course at RUA after Year 1
	NIA: important	No course at NIA	No course at NIA after Year 1
	KNIA: major	KNIA: major	No course at KNIA after Year 1
	UKT: major	No course at UKT	UKT: major
PRIORITY LEVEL	RUA: major	RUA: major	RUA: low (covered elsewhere)
	NIA: important	Part of "Ecology of aquatic ecosystems" at NIA	NIA: low (covered elsewhere)
	KNIA: major	KNIA: major	KNIA: low (covered elsewhere)
	UKT: major	UKT: low	UKT: major
MAIN NEEDS	RUA, NIA: assist (external expert, translator) to update content by using recommended handbooks and online literature	RUA, KNIA: assist (external expert, translator) to update content by using recommended handbooks and online literature	UKT: assist (external expert, translator) to update content by using recommended handbooks and online literature
	KNIA, UKT: find external teachers to teach this course	KNIA: help improving the teaching material and the logical structure	UKT: have more content on enzymes and protein function
	RUA, KNIA: have i) one course on freshwater and ii) one course on marine systems, and iii) add more marine content	RUA, KNIA: divide the course into two courses: i) Aquatic vertebrate zoology/anatomy and ii) Invertebrate zoology	UKT: improve teachers' capacity and practical activities by coordination between universities
	RUA, KNIA: invite external teachers to teach a condensed version of the two courses	RUA, KNIA: Organize a workshop to homogenize content across the two universities	
	ALL: Grant access to high quality online journals		
	ALL: Provide English courses to teachers		

The B.Sc. pedagogic programs reviewed need substantial upgrading (content and teaching material/methodology). Although not reviewed here, some foundation year courses should be compulsory; in particular biology, geology, microbiology and genetics. Harmonization between programs and teaching methods is a key recommendation. Similarly, strengthening trainers in English is essential and needed in all universities reviewed. A consultant/expert might present different online platforms for e-learning. The marine-related content is very limited in all universities; its gradual integration is strongly recommended. Supporting remunerated guest lecturers from both Cambodia and from partner countries is also suggested. Linkages could be developed with the International "Master course of oceans and lakes" in Belgium or at the University of Wester Brittany, through sponsoring by European scholarships.

Technical staff in laboratories also require training, and such training can be accessed locally or through international programs.

Last, unused high-tech instruments such as Gas Chromatography Mass Spectrometer (GC-MS), Atomic Fluorescence and Atomic Absorption Spectrometers, and DNA amplification PCR machine are available in some institutes and could become part of a "inter-university service network" for reciprocal training and remunerated use between universities for research, or even by external clients (research institutes, food safety analyses, private companies).

1. INTRODUCTION

The Royal Government of Cambodia is committed to the sustainable management of fisheries resources and the viable development of the related fisheries sector of Cambodia. This commitment is in line with many of the UN Sustainable Development Goals for 2030, such as the contribution to poverty reduction, the increase in food and nutrition security at the national, regional and global levels and the improvement of ecosystem health and ecosystem services. To address these issues, the Fisheries Administration (FiA) of the Ministry of Agriculture, Forestry and Fisheries (MAFF) is implementing an EU-supported programme entitled the "Cambodia Programme for Sustainable and Inclusive Growth in the Fisheries Sector (CapFish)". The capture fisheries component under the programme, CapFish-Capture, comprises three pillars: 1) Fisheries conservation and management; 2) Fisheries post-harvest and trade; and 3) Fishing communities' social and economic development. FAO has been requested to provide technical assistance to the government's CapFish-Capture Workplan in the form of an EU funded Complementary Support Project, the "FAO Complementary Support to the Cambodia programme for sustainable and inclusive growth in the fisheries sector: Capture component" (in short "CapFish-Capture"). The aim of this project is to support the Fisheries conservation and management pillar within the CAPFISH Programme.

Within the FAO CapFish-Capture project, Output 7 is focused on more effective and relevant research for fisheries management. This includes assistance to national universities to make improvements to fisheries curricula (identify gap and options in curricula for inputs and development of training materials). The review and assistance process started in 2022 and is ongoing.

It is within this context that this report is presented, along with a series of recommendations to support the four Cambodian universities teaching fishery science. Its purpose is to evaluate their existing syllabus at the B.Sc. level and to identify pedagogic modernization needs and content improvement options.

The report covers an evaluation of a series of selected courses dealing with fishery science and research of the various curricula that are taught across four public Cambodian universities:

- The Royal University of Agriculture (RUA, Phnom Penh),
- Preak Leap National Institute of Agriculture (NIA, Phnom Penh),
- Kampong Cham National Institute of Agriculture (KNIA, Kampong Cham),
- University of Kratie (UKT, Kratie).

The process leading to the identification of these four partner universities is detailed in Annex 1. The University of Battambang (NUBB) also features fisheries-related courses under the Faculty of Agriculture and Food Processing, but with no B. Sc. students registered in the past few years.

Methodology

Information about the fisheries curriculum was collected in each university through a series of meetings, and we consulted the four universities between June and August 2022, then later through online meetings and e-mail exchange. The report was finalized in December 2022.

Since Year 1 ("Foundation year") is common to all students in all faculties, it is not specific to the fisheries curriculum; as a consequence, the review focuses on curricula in specialized Year 2, Year 3 and Year 4. The objectives of the consultation were to:

- organise and facilitate meetings on fisheries-syllabus upgrade with staff from RUA, NIA, KNIA and UKT;
- arrange online discussions with university staff-to review their academic syllabus, and identify:
    - disciplines and courses common to several universities,
    - disciplines and courses that require support in each university,
    - how the content of courses can be improved, and
    - capacity development need;
- prepare a syllabus development analysis with recommendations, suggesting new themes and/or removal of obsolete and proposing new directions, methods or tools in the discipline and capacity development needs of university staff).

The present document presents this analysis, together with recommendations focused on four main points:

i) how to improve the syllabus in the disciplines identified by the Deans as needing upgrading (e.g. obsolete topics, new topics recommended, new approaches to the content),

ii) how to improve the pedagogy (e.g. material required, possible collaborations to improve the course content and resource sharing),

iii) how to improve staff capacity in the different universities, and

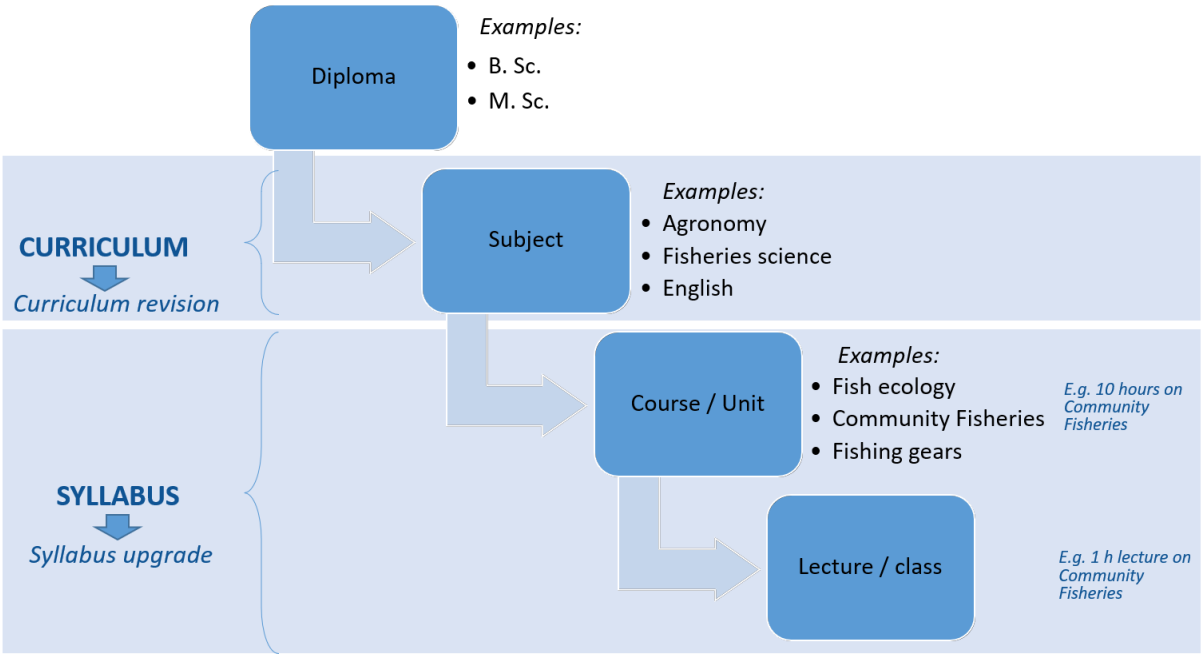
iv) where and how access up-to-date and relevant pedagogic material online (Annex 2)

The structure of the report deals with each course individually and focuses on general suggestions in a last section. Finally, a brief overview of the laboratory status and the technical staff training requirements is given in Annex 3.

TEXT BOX 1

Terminology and structure in B.Sc. academic programmes

The terms used throughout this report are clarified in the following graph:



The Bachelor of Science program spans over four years. Year 1 ("Foundation year") is common to all students in all faculties, it is not specific to the fisheries curriculum.

The B.Sc. is based in the acquisition of a minimum of 120 credits, split between Theorical studies (90% at NIA, 60% at RUA, 50% at KNIA) and Practical studies, plus 8 credits in all universities for Year 4 B.Sc. thesis (4 to 6 months of subject definition, field work, data analysis, writing and defence).
One credit corresponds to 16 hours of theory (in principle), and 32 hours of practice (in theory). The total can reach 2,500 hours of teaching over four years.

On Year 1, the student must choose "Basic subjects of specialization" and "Core subjects of specialization" in fisheries; all of which being taught during Years 2 to 4.

2. BACHELOR OF SCIENCE IN FISHERIES: SYLLABUS EVALUATION

2.1. Brief historical background

The four Universities that are part of this review as well as their Fishery curricula/courses were established at different times:

- NIA is the oldest university, founded in the 1950, with the Faculty of Fishery established in 1985 for an initial diploma (not comparable to a B. Sc. in terms of depth and time, but more of a professional diploma), whereas the first Bachelor degree started in 2003;
- RUA was founded in 1964 and the Faculty of Fishery was established in 1986;
- KNIA was founded in 1995 as Kampong Cham School of Agriculture (professional diploma degree) and changed to Kampong Cham National Institute of Agriculture (KNIA, Bachelor degree) in 2001 and the Fishery Department was established the same year;
- UKT was founded in 2015 with the first Bachelor degree in Agriculture and Community Development in 2018 (equivalent of the Fisheries curriculum of the other universities) and therefore the first cohort of B.Sc. students graduating in 2022.

This background information is important while considering the status of the educational program/content, the academic staff actively teaching, their age range and training level.
The four universities serve somewhat different students. The majority of students joining RUA and NIA are either already living in Phnom Penh or from nearby, and from a more wealthy social environment. Students in Kampong Cham and Kratie provinces are usually poorer and subject to higher transport and lodging costs. Involving KNIA and UKT was therefore an important step to improve equality in access to quality fisheries education throughout the country.

2.2. Fisheries and aquaculture science curricula: overall structure across all universities

The different Bachelor degrees offered in the four universities have in common one foundation year with a series of basic (non-fishery) courses and some courses already linked to fisheries (e.g. fish physiology). The Bachelor degree in Agriculture and Community Development at UKT has a specific structure, students being offered the possibility to join a 2-year professionalizing diploma or the complete 4-year Bachelor degree (the foundation year is present in both but the overall course offer is changed according to the learning outcome; see Table 1).

Table 1: Courses of the fisheries (and aquaculture) Bachelor of Science curriculum taught over 4 years, before the 2022-2023 curriculum revision.

KNIA: Kampong Cham National Institute of Agriculture; RUA: Faculty of Fisheries Science; NIA: Prek Leap National Institute of Agriculture; KTU: Kratie University

NIA	RUA	PLNIA	UKT
AQUACULTURE			
Coastal and Marine Aquaculture Fish Feed and Feeding Aquaculture Engineering Fish Pathology Genetics and Fish Breeding Aquaculture Life Feed for Aquaculture Integrated Farming System Fish Farm Management Fish Hatchery Techniques	Coastal and Marine Aquaculture Fish Nutrition Aquaculture Engineering Fish Pathology Genetics and Fish Breeding Inland Aquaculture Live Feed for Aquaculture Integrated Aquaculture Aquaculture Systems Analytical Techniques	Coastal Aquaculture Fish Feeding and Nutrition Aquaculture Engineering Fish Pathology and Health Mgt Genetics and Fish Breeding Inland Aquaculture, Good Practice	Coastal and Inland Aquaculture Fish and animal Feed Production
FISHERIES			
Fisheries Conservation and Mgt Fisheries Laws Fisheries Fisheries Economics Community Fishery Flooded Forest Fishing Gear Environmental Fisheries Fishing Business Rice Field Fisheries Mgt	Fisheries Management Fisheries Laws Fisheries Economics CFi Development and Mgt Fisheries Forestry Fishing gear and technology Fisheries Research and Surveys Gender in Fisheries Reservoir Fisheries	NRM and Conservation Fisheries Law and Legislation	Natural Resources and Envir. Science Fisheries
MARINE SCIENCE			
Oceanography and Navigation	Physical and Chem. Oceanography Coastal and Marine Biology Participatory Approaches to CZM		

Table 1 (continued)

NIA	RUA	PLNIA	UKT
POST HARVEST			
Fish Processing Technology Product Quality Control	Fish Processing Technology	Processing and Product Mgt	Post-Harvest Tech. and Processing Quality Control of Agric. Products
FOUNDATION COURSES			
Research nethodology Water quality Fish physiology Fisheries statistics GIS Limnology	Research methodology Water quality Fish physiology Statistics and experimental design GIS Limnology Fish population dynamics English	Research methodology Fish physiology Statistic and SPSS GIS Limnology and oceanography Fish population dynamics English	Research method, scientific Writing Water quality Biology
UNIQUE COURSES			
Agricultural economics Farm management, biochemistry Fish anatomy Hydrochemistry Hydrological systems Project management plan Rural Development Administrative affairs Agricultural markets Agricultural Policy Field exposure visit Leadership Meteorology Topography Thesis writing method	Systematic aquatic botany Systematic Aquatic Zoology Fisheries and aquac. extension	Community dvtp and ecotourism Computer and internet practice Environmental Impact Assessment Economy of farm management Practical skills Project management	Introduction to community dvelop. Climate Change adaptation Integrated farming system

2.3. Selection of courses for upgrading

The courses to be upgraded were identified by the Deans of the respective faculties with the help of the teachers in charge. These courses (see Table 2) were divided into *eight priority courses* (4 courses common to all four universities -courses A1 to A4 below- and four courses common to three universities -courses B1 to B4) and fifteen lesser priority courses common to 2 universities only or specific to one university). During a series of meetings (10^{th}-17^{th} July 2022) the courses and their content were discussed and the main limitations and constraints were identified. A series of issues were found to be common and were used as a basis for the upgrading roadmap (summary in Table 2).

Eight priority courses

A1: Fisheries conservation and management (KNIA) / Fisheries management (RUA FoFA) / Natural resources management and conservation (NIA) / Natural resources and environmental science (UKT)

A2: Fish processing technology (KNIA) / Fish processing technology (RUA FoF) / Processing and product management (NIA) / Post-harvest technology and processing (UKT)

A3: Fisheries research and survey methods (KNIA) / Fisheries research and survey methods (RUA FoF) / Research methodology (NIA)/ Research methodology and scientific writing (UKT)

A4: Water quality analysis (KNIA) / Water quality (RUA FoF) / Soil and water chemistry analysis (NIA) / Water quality (UKT)

B1: Fish physiology (KNIA) / Fish physiology (RUA FoF) / Fish physiology (NIA)

B2: Fish pathology (KNIA) / Fish pathology (RUA FoF) / Fish pathology and health management (NIA)

B3: Fish anatomy (KNIA) / Systematic aquatic zoology (RUA FoF) / Ichthyology (morphology, taxonomy, etc.) (NIA)

B4: Limnology (KNIA) / Limnology (RUA FoF) / Limnology and oceanography (NIA)

Table 2 List of selected courses that require upgrading in the different Universities.

		Kampong Cham National Institute of Agriculture (KNIA)	RUA Faculty of Fisheries	Prek Leap National Institute of Agriculture (NIA)	University of Kratie (UKT)
8 courses flagged for support and joint development	**A1**	Fisheries conservation and management	Fisheries management	Natural resources management and conservation	Natural resources and environmental science
	A2	Fish processing technology	Fish processing technology	Processing and product management	Post-harvest technology and processing
	A3	Fisheries research and survey methods	Fisheries research and survey methods	Research methodology	Research methodology and scientific writing
	A4	Water quality analysis	Water quality	Soil and water chemistry analysis	Water quality
	B1	Fish physiology	Fish physiology	Fish physiology	
	B2	Fish pathology	Fish pathology	Fish pathology and health management	
	B3	Fish anatomy	Systematic aquatic zoology	Ichthyology (morphology, taxonomy, etc.)	
	B4	Limnology	Limnology	Limnology and oceanography	
15 courses identified for support but not coordinated enough for joint development			Fisheries ecology	Ecology of aquatic ecosystem	
					Biology
			Fisheries Economics		
		Fisheries			Fisheries
				Environmental Impact Assessment in fisheries	
				Community fishery management	Introduction to community development
		Rice field fisheries management			
		Fisheries experimental statistics	Statistics and experimental design		
			Fish population dynamics fisheries management	Fish population dynamic and stock assessment	
					Integrated farming system Climate change adaptation

2.4. Recommendations about specific courses

The following recommendations were developed based on the course content presented by teachers during the review. The wrap up meetings held with the Deans and Directors of RUA and NIA have served to confirm or reshape initial insights and road map.

2.4.1. Course **A1**: Fisheries conservation and management (KNIA) / Fisheries management (RUA) / Natural resources management and conservation (NIA) / Natural resources and environmental science (UKT)

This course aims at building the logical framework of an interdisciplinary science: resource management. The course does this with slightly different depth levels in the four Universities. This is explained by the various needs and employment opportunities in the province of each University.

KEY ISSUES:

- No real key issues were highlighted during the meetings. Nonetheless, there was a general request for participation of external experts in teaching and the possibility to bring students to visit management institutes such as the Fisheries Administration.
- When dealing with biodiversity and conservation, a background in genetics and molecular biology is necessary since the students may otherwise lack basic knowledge in a fast-evolving field which is becoming more and more part of monitoring and biodiversity assessment practices.
- The marine-related content within the course seems too limited and an upgrade -at least within RUA and NIA curricula- might be required.

RECOMMENDATIONS:

Recommendations to universities

- A recurrent workshop (or online meetings over 4 afternoons) could be organized with the participation of teachers from the four Universities, and Cambodian experts in inland and marine fishery science. The workshop would showcase research happening within Cambodia and give an up-to-date overview of the ongoing practices and the present challenges for fisheries management. Some of the workshop key themes and topics could be Cambodian fisheries trends in terms of catch (temporal and spatial scale) along the Mekong River and in the marine zone, the Tonle Sap ecological system, climate change threats, transboundary issues, Illegal Unreported and Unregulated fishing or the legal framework for marine fishery management in Cambodia.
- Local experts (from e.g. Marine Conservation Cambodia, Fauna and Flora International, or Fishery Administration officials) could be invited to give keynote speeches on these topics. This workshop would serve as a starting point for teacher's revised course content. Power Point presentations at workshops are typically shared between participants and could be used for lecture content update – with agreement and due acknowledgement of the external expert consulted- but also by citing the sources of newly added material.
- Indirect outputs of the workshop would be i) new peer-to-peer collaborations, ii) stimulation

of interest in professional training for some specific topics; iii) better knowledge of what is being done in Cambodia in the sector and iv) establishment of long term and regular guest lectures between institutes, NGOs and the four Universities.

- Transboundary collaborations could be of great benefit here: inviting Vietnamese and Thai colleagues involved in the management and monitoring of fresh water and marine resources may be extremely beneficial. This might foster joint research and create the basis for student exchange with neighboring countries. Two institutions of particular interest are:
  - the Hanoi University of Science and Technology Department of Water-Environment-Oceanography);
  - the Institute of Tropical Biology of Ho Chi Minh City (Department of Environmental Management and Technology);
    Both partners are involved in the use of meiofauna and sediment communities as environmental markers in monitoring of both riverine and marine systems;
  - the Faculty of Environmental Management of the Prince of Songkla University, Thailand.
- A suggestion for joining forces and "train the trainers": experts from NGOs or other Universities/Institutes in Europe/Asia could be invited to give lectures on specific topics in which they are involved and organize practical activities where a case study of resource management can be given to students during a 5-days Resource Management School. This could be done as a joint activity involving the four Universities and hence be held at one of the four facilities. Students might choose between different case studies, and be mixed within groups from different universities.
- The marine related content currently too limited could be improved in collaboration with external experts and lecturers and marine scientists who could stay for 2 weeks to work on both content and practical activities.
- The already ongoing collaborations between RUA, the Fisheries Administrations and the Marine Conservation Cambodia NGO is a source of marine related knowledge on marine conservation and management.

2.4.2. Course **A2**: Fish processing technology (KNIA) / Fish processing technology (RUA) / Processing and product management (NIA) / Post-harvest technology and processing (UKT)

A sub-component of the CapFish-Capture project, the Post-Harvest Fisheries Development project implemented by the United Nations Industrial Development Organisation (UNIDO), includes a "Support to post-secondary and higher education institutions for knowledge enhancement". This UNIDO Post-harvest project supports curriculum development, and the course about post-harvest and fish processing is not detailed here, recommendations being left to specialists in the discipline.

2.4.3. Course **A3**: Fisheries research and survey methods (KNIA) / Fisheries research and survey methods (RUA) / Research methodology (NIA)/ Research methodology and scientific writing (UKT)

The content of this course was not discussed during the review, as most professors in charge were not present during the consultation and field visits.
Hundreds of manuals, textbooks and online courses exist in data management, in statistics and in data analysis. Data analysis in particular can be specific to a discipline. Among this multitude of resources, a few key documents are recommended here. They are simple, cover biology and fisheries, data management, presentation of results in a paper, writing style and bibliographic style:

<u>Data gathering</u>

- Bunce L., Pomeroy B. 2003. Socioeconomic monitoring guidelines for coastal managers in Southeast Asia. World Commission on Protected Areas and Australian Institute of Marine Science. Townsville, Australia. 85 pp. [online]

<u>Data cleaning and management</u>

- Elgabry O. 2019. The ultimate guide to data cleaning. [online]
- Couleha M. B., Wells J. F. 2006. Guidelines for responsible data management in scientific research. Clinical tools Inc., North Carolina, USA. 46 pp. [online]

<u>Data analysis</u>

- Baran E., Warry F. 2008 Simple data analysis for biologists. WorldFish Center and Fisheries Administration. Phnom Penh, Cambodia. 67 pages. [online]
- Peck R., Olsen C., Devore J. 2008 Introduction to statistics and data analysis. Thomson Brooks/Cole. 885 pp. [online]
- Urdan T. C. 2017 Statistics in plain English. Taylor and Francis.

<u>Writing a report</u>

- Pickering C. 2012. How to write ecology research papers. Environmental Futures Centre, Griffith University, Australia. 47 pp. [online]
- Whitesides G. M. 2004 Writing a paper. Adv. Mater. 16; 15; 1375-1377 [online]
- APA writing guide. [bibliography referencing; online]

<u>Presenting results</u>

- Anderson C. 2013. Managing yourself: how to give a killer presentation. Harvard Business Review. 7 pp. [online]

2.4.4. Course **A4**: Water Quality Analysis (RUA) / Soil and Water Chemistry Analysis (KNIA) / Water quality (NIA, UKT)

This course provides theoretical and practical skills for the monitoring of water bodies and the management of ponds and other aquaculture closed/semi closed systems. Concepts such as i) dissolved oxygen concentration, its causes, its fluctuations and effects on the biota; ii) main cycles (Nitrogen, Phosphorous)and linked biogeochemistry processes; iii) physical properties such as water turbidity and implication for primary production. The course is of great importance.

KEY ISSUES:

- Lack of a handbook in Khmer
- Lack of good test kits for field work for practical activities
- Lack of field equipment such as pH meter, Temperature and Salinity meters.
- Interest in having better practical activities for the lab part

RECOMMENDATIONS:

Recommendations to universities

- The course is common to all Universities although with different levels of detail. NIA focuses on soil analysis (mostly mud, in relation to riverine and lacustrine sediment samples), whereas in the other courses no reference is made to soil analyses. The course at KNIA is much less detailed and would benefit from a large upgrade reflecting RUA and NIA content.
- Possibility to improve content and practical activities based on handbook "Water Quality Monitoring and Management Basis Technology and Case Studies, 1st Edition, 2018, Daoliang Li & Shuangyin Liu, Elsevier.
- RUA has expertise in rearing in ponds fresh-water species of commercial interest. UKT is developing hydroponic and a green-house planting facilities and also intends to develop a remote automated water quality system. KNIA is directly involved in the conservation of the Irrawaddy dolphins along the Mekong River. These unique capacities within each faculty should be exploited for the design of practical activities. Thus, a workshop could be organized between the teachers of the four universities to exchange content, homogenize the learning outcomes and foster reciprocal visits lectures with in-situ applications.
- The expertise of RUA (pond water quality in relation to aquaculture) and NIA (mud quality analysis) could be shared through the following approach: students in each faculty work on a video tutorial as part of an assignments, and demonstrate practical exercises in each case. The tutorials could be shared on an online platform/Dropbox folder/Teams Document Folder.

Recommendations for external support

- Support in the establishment of an online platform for shared and common teaching content. This could be done by managing a Teams SharePoint where teachers would be given access by their affiliation's emails (university email).
- Purchase of suggested handbook "Water Quality Monitoring and Management Basis Technology and Case Studies, 1st Edition, 2018, Daoliang Li & Shuangyin Liu, Elsevier.
- Support of a translator for the extraction of topics of interest from the handbook.

2.4.5. Course **B1**: Fish physiology (KNIA, NIA, RUA)

The course of Fish Physiology aims at teaching the physiological responses of fishes to their environment.

KEY ISSUES:

- Lack of a handbook in Khmer
- Outdated material
- Lack of elaborate ichthyology laboratory practices for the students

RECOMMENDATIONS:

Recommendations to universities

- The Physiology of Fishes, 4th Edition by Evans et al., 2013 is a handbook freely available online as a compressed archive file at https://vetbooks.ir/the-physiology-of-fishes-4th-edition/
- The Physiology and Ichthyology laboratories could be organized in parallel so that their practices complement one another. Example: identification of gonads of sexually mature fishes in the Ichthyology lab (anatomical basis) followed by induced spawning by hormone injection in the Physiology lab (aquaculture procedure).

Recommendations for external support

- A great resource is the Encyclopedia of fish physiology, from genome to environment (https://www.elsevier.com/books/encyclopedia-of-fish-physiology/farrell/978-0-12-374545-3 ; cost 1134,20 €). Sponsors might assist with online access by all Universities.

2.4.6. Course **B2**: Fish pathology and health management (KNIA) /Fish pathology (NIA and RUA)

The main purpose of this course is to provide basic knowledge of most common diseases among bony fish and other aquaculture organisms, as well as of infection diagnosis, pathogens identification and management of diseases in cultures. The course is well established in the faculties of fisheries of RUA and NIA, but with different depth levels. KNIA content in particular will benefit from the proposed changes.

KEY ISSUES:

- No Khmer handbook
- The course content differs a lot between the three faculties, with RUA and NIA showing more in-depth content, and the most organized structure.
- Practical activities are limited due to a lack of technical skills by teachers or laboratory technicians in some faculties.

RECOMMENDATIONS:

Recommendations to universities

- These courses should have one single title: Fish pathology
- The course content might be:
    1. Generalities on fish anatomy and physiology
    2. Pathogens that can attack fishes and host-pathogen interactions and terminology
    3. Bacterial diseases
    4. Viral infections
    5. Fungal infections
    6. Parasitic invertebrate diseases
    7. Types of diseases fresh-water fish can suffer from. Examples from Cambodia
    8. Type of diseases in marine fish? Examples from extensive aquaculture finfish cages
    9. Fish diseases and human health
    10. Disease identification. Diagnosis and differentiation between parasitic and bacterial diseases
    11. Fish pathology and climate change: how climate change affects parasite-host relationships, pathogen abundance and fish vulnerability
- Teachers in the different faculties have different facilities and equipment, and different levels of experience in lab work. It is recommended for them to share laboratory experience and explore possible visits of students with joint classes for the diagnostic of fish diseases and pathogens.
- Suggested literature: “The impact of climate change on fish infectious diseases (a review)” by Rud et al., 2020 available for free on ResearchGate

Recommendations for external support

- Teachers from NIA, KNIA or UKT could be sent to RUA to be trained in specific laboratory diagnostic practices.
- Collaboration between universities and the Post Harvest Department at FiA should be sought. Development partners could organize a workshop on practices in relation to fish pathogeny and human health.
- Content on climate change could be extracted thanks to a translator working on the suggested literature and preparing a series of slides and a short summary in Khmer for the teachers.
- At NIA laboratory some machines (see Annex 4) can be used for the amplification of DNA extracted from tissue samples (e.g. a bacterial culture or any animal tissue). This allows identifying potential pathogens in a more precise way, by selecting specific molecular markers and getting a genetic identity (a.k.a. a DNA sequence) for that specific sample. These brand-new machines are not optimally used at NIA due to human capacity constraints. The Fish pathogeny course at RUA would benefit from accessing such technology. This would in turn foster high-level research and subsequent publications in peer-reviewed journals. The presence of both a pedagogic and scientific demand (at RUA) and an availability for this equipment (at NIA) seem providential. The stipulation of an inter-university agreement for the shared use of facilities and equipment in the form of a cross-university training is a promising option.
- Sponsors might also hire an external expert in PCR machine (likely the manufacturer itself) to train both the laboratory technician of NIA and RUA teachers.

2.4.7. Course **B3**: Fish anatomy (RUA) / Ichthyology (KNIA, NIA)

Fish anatomy courses aim at giving students an understanding of fish organs and the roles that each organ plays.

KEY ISSUES:

- Lack of a handbook in Khmer
- Outdated material
- Lack of 3D models of fishes and their organs to also display the main differences between bony fishes and cartilaginous fishes

RECOMMENDATIONS:

Recommendations to universities

- As suggested for other courses, content and structure of the courses could be reassessed and redesigned during a workshop.
- Laboratory practice for the course of Ichthyology could be improved by following the free online Laboratory manual for general and special ichthyology by Marenkhov Oleh (2018), in which a series of practical activities are proposed.
- In the above Ichthyology manual a section on taxidermy is presented. This could help build a catalogue of stuffed fish species of interest.
- 3D Model of fishes and organs using basic material such as Styrofoam can be created by students as an assignment (see as example a similar exercise with the human digestive tract at https://www.youtube.com/watch?v=vhl0n_pStYg).

2.4.8. Course **B4**: Limnology (KNIA, RUA) / Limnology and oceanography (NIA)

This course is aimed at teaching the formation and main characteristics of lakes and rivers (limnology) or ocean basins and seas (oceanography). A part of this course usually overlaps with other courses such as Zoology and Botany since it also describes the biological communities inhabiting and influencing the properties of these systems.

KEY ISSUES:

- Lack of a Khmer handbook
- The course is not part of the curriculum at UKT, but could be taught by external teachers or experts.
- The understanding of limnological and oceanographic processes requires the understanding of Physics and Geology, which are not always taught within the different curricula foundation years.

RECOMMENDATIONS:

Recommendations to universities

- The course should be split into two courses: Oceanography and Limnology.
- Oceanography can be divided into i) physical oceanography, ii) chemical oceanography iii) biological oceanography, while including Physics, Chemistry (mostly inorganic) and Biology.
- A very comprehensive work covering the marine aspect of this course has been identified in the Encyclopedia of Ocean Sciences 3rd Edition 2019 by Elsevier (cost 3.455€)
- An external expert should supervise the creation of the table of content of the Oceanography course, and *ad hoc* examples from the Gulf of Thailand should be included.
- External experts could be initially invited to give specific lessons on the topic. The material could be then translated in Khmer and in collaboration with the expert and a translator, parts of the lectures being used to update the course content. Teachers would have to be trained by the expert to ensure full right understanding.

Recommendations for external support

- The work of a translator should be supported. The translator would work on the expert's course and facilitate the interaction between the expert and the interested teachers.
- Sponsors could provide budget for membership to the journals suggested above and for the suggested encyclopedia.

3. Conclusions and overall recommendations

The fisheries curricula taught in the four universities surveyed show substantial need for upgrading (both content and teaching material/methodology). The level of knowledge and skills varies between universities and exchange of knowledge and of teaching methods (e.g. via interuniversity training or via guest lecturing) is a key recommendation

For this, it is recommended to organize inter-university workshops where lecturers can share ideas, their knowledge, and agree on course content improvement and possible steps to achieve that. Both on-site and online versions of such workshops can be envisioned. External professionals from neighboring countries (e.g. Vietnam and Thailand) and Europe could be involved to help with the process.

Strengthening trainers in English is a paramount requirement and a need in all universities reviewed (in one of them none of the teachers speaks English). This, and the absence of manuals in Khmer language for all biological and ecological disciplines, is a major impediment to providing students with relevant pedagogic content -despite its availability on free-access internet resources. Teachers subject to this constraint cannot access a M.Sc. or a Ph.D. from a foreign university and in turn are less able to provide up-to-date knowledge enabling B.Sc. students to access M.Sc. and PhD levels.

- An English course could be organized in collaboration with the University of Kratie where a Bachelor in professional English is already organized and all the teachers speak fluent English. The course could be organized online, by Khmer English teacher(s). It could consist of a weekly online class, with assignments under the supervision of teachers. A part of the assignments could be online exploration of peer reviewed research and teaching content.
- Sponsors could provide a budget for the purchase of handbooks and teaching resources recommended, and also fund professors/teachers/professionals who would translate selected content from English to Khmer.

The marine-related content is extremely limited if not totally absent from most curricula. Gradual integration of marine content is recommended for specific courses and field practices (e.g. yearly Summer School) are recommended. More generally, a Marine ecology course could be developed especially for the RUA and NIA curricula. This could be achieved through:

- inviting guest lecturers from both Cambodia (e.g. from local NGOs such as Marine Conservation Cambodia or Fauna and Flora International; fisheries specialists from Fishery Administrations) and peers from Thailand, Vietnam and Belgium to give specific lectures with examples from Cambodia.
- developing linkages with International Master courses such as the International master course of oceans and lakes in Belgium (www.oceansandlakes.be) or at the UBO in France (www.univ-brest.fr/GB/menu/Research/Marine-Science). The students could be sponsored by European scholarships (e.g. VLIROUS in Belgium) and would be able to carry out a thesis on Cambodian marine matters.

Some foundation year courses should be compulsory across the different Universities -in particular Biology, Geology, Microbiology and Genetics- as they form the basis to understand ecosystems, diversity and resources. Some of these courses are featured in one faculty, but not in all of them.

A workshop (or three afternoons online) could be organized by a consultant/expert to present different online platforms to teachers. In particular ResearchGate (www.researchgate.net), Mendeley (www.mendeley.com), Zotero (www.zotero.org), Sci-Hub (www.sci-hub.se) or Edredo (www.edredo.com).

Educational programs exist for the training of technical staff. This could be ideal for a comprehensive and in-depth training of laboratory staff having a permanent position within the institution.

4. ANNEX 1: TRAINING INSTITUTIONS REVIEWED

The methodology for the review consisted in:

1) Compiling a list of tertiary education institutions in Cambodia (Table 3)
2) Reviewing the web site and Facebook page of each university
3) Identifying and selecting faculties proposing fisheries-relevant topics such as fishery science, aquatic biology, environmental management, water quality, etc. Focus on these universities for the following steps (Table 4)
4) Call to each University's main office to get contacts of deans and professors
5) Email and call to deans and professors in each university whenever possible
6) Reviewing documents accessible for each institution
7) Complementary consultation of a network of teachers and academes (FiA, RUA, RUPP, Wonders of the Mekong, etc.) for additional information

Table 3: List of 54 tertiary training institutions identified during the review

City/province	Training institution (public and private)
Banteay Meanchey	Build Bright University (BBU)
	Mean Chey University (MCU)
	University of Management and Economics (UME)
Battambang	Build Bright University (BBU)
	Dewey International University (DIU)
	International University, Battambang Campus
	Khemarak University
	National University of Battambang (NUBB)
	Paññasastra University of Cambodia
	University of Management and Economics (UME)
	Vanda Institute of Battambang
Kampong Cham	Chea Sim University of Kamchaymear, Kampong Cham Branch
	Kampong Cham National School of Agriculture (KCNSA)
	University of Management and Economics (UME)
Kampong Chhnang	Bolyno Institute of Kampong Chhnang
Kampong Speu	Angkor Khemara University (AKU)
	Kampong Speu Institute of Technology
	Kirirom Institute of Technology
Kampong Thom	Angkor City Institute
	Cambodia University for Specialities (CUS)
Kampot	Angkor Khemara University (AKU)
	Regional Polytechnic Institute of Techo Sen Kampot
	University of Management and Economics (UME)
Koh Kong	University of Management and Economics (UME)
Kratie	University of Kratie
	University of Management and Economics (UME)
Phnom Penh	Institute of Technology of Cambodia (ITC)
	Prek Leap National Institute of Agriculture (NIA)
	Royal University of Agriculture (RUA)
	Royal University of Phnom Penh (RUPP)

City/province	Training institution (public and private)
Preah Sihanouk	Build Bright University (BBU)
	Khmer University of Technology and Management
	Life University, Cambodia
	Mong Reththy Agriculture Institute (MRAI)
	University of Management and Economics (UME)
Prey Veng	Angkor City Institute (ACI)
	Chea Sim University of Kamchaymear (CSUK)
Pursat	Angkor Khemara University (AKU)
	Polytechnic Institute of Pursat Province (PIPP)
	University of Management and Economics (UME)
Ratanakiri	Build Bright University (BBU)
Sien Reap	Angkor University
	Build Bright University (BBU)
	National Polytechnic Institute of Angkor
	Paññasastra University of Cambodia
	University of Southeast Asia
	Vanda Institute of Siem Reap Branch
Stung Treng	Build Bright University (BBU)
Svay Rieng	Business Institute of Cambodia (BIC)
	Svay Rieng University (SRU)
Takeo	Angkor Khemara University (AKU)
	Build Bright University (BBU)
	Saint Paul Institute (SPI)
Thbong Khmum	University of Heng Samrin Thbongkhmum (UHST)

Table 4: Faculties proposing agriculture and fisheries-related curricula

City/province	Name of University (public and private)	Curriculum accessible?	Fisheries curriculum?	Notes
Battambang	**National University of Battambang (NUBB)** Faculty of Sociology and Community Development, Faculty of Science and Technology, and Faculty of Agriculture and Food Processing.	Yes	Yes	Actually discontinued as no students enrolled in past years. Now a BSc in aquaculture
	Dewey International University (DIU) Faculty of Social Science	No	No	
	Build Bright University (BBU) Faculty of Economics and Agricultural Sciences	Yes	No	Deans or heads of departments impossible to reach beyond the central call center. No students enrolled in the Faculty of Agriculture
	Khemarak University Faculty of Agriculture and Science	No	-	Deans or heads of departments impossible to reach beyond the central call center
	International University, Battambang Campus Faculty of Agriculture and Rural Development	No	-	No response despite several calls
	University of Management and Economics (UME) Faculty of Agriculture and Rural Development	Yes	No	40-50 students in Agronomy each year (weekend classes). 54 students joined LEARN & EARN 11-month internship program in Israel (3 batches of 18)
Banteay Meanchey	**Mean Chey University (MCU)** Faculty of Agriculture and Food Processing, Faculty of Social Science and Community Development	No	No	No classes in fisheries
	University of Management and Economics (UME) Faculty of Agriculture and Rural Development	Yes	No	No classes in fisheries
Kampong Chhnang	*No university teaching agriculture, fisheries, environment or rural development*			
Kampong Cham	**Kampong Cham National Institute of Agriculture (KNIA)** Department of fishery science	Yes	Yes	**Identified for partnership**
Kampong Thom	*No university teaching agriculture, fisheries, environment or rural development*			
Kampot	**University of Management and Economics (UME)** Faculty of Agriculture and Rural Development	Yes	No	No classes in fisheries
Koh Kong	**University of Management and Economics (UME)** Faculty of Agriculture and Rural Development	Yes	No	No faculty of agriculture and rural development. Student in Bachelor of Management and Accounting instead

Kratie	**University of Kratie** Faculty of Agronomy (program Agriculture and Community development), Institute of Ichthyology	Yes	Yes	**Identified for partnership**
Phnom Penh	**Institute of Technology of Cambodia (ITC)**	Yes	No	Already a UNIDO partner for post-harvest
	Royal University of Agriculture (RUA) Faculty of Fisheries Science; Faculty of Agricultural Economics and Rural Development	Yes	Yes	**Identified for partnership**
	Royal University of Phnom Penh (RUPP)	Yes	No	Biodiversity program but no specific program in fisheries; already collaborating with MCC and FFI
	Prek Leap National Institute of Agriculture (NIA) Department of fishery science	Yes	Yes	**Identified for partnership**
Preah Sihanouk	**Mong Reththy Agriculture Institute (MRAI)** Animal Science and Agriculture Science	No	No	
	Build Bright University (BBU) Faculty of Economics and Agricultural Sciences	Yes	No	
	University of Management and Economics (UME) Faculty of Agriculture and Rural Development	Yes	No	
Prey Veng	**Chea Sim University of Kamchaymear (CSUK)** Faculty of Agriculture	Yes	No	No classes in fisheries
Pursat	**University of Management and Economics (UME)** Faculty of Agriculture and Rural Development	Yes	No	No faculty of agriculture and rural development. Student in Bachelor of Management and Accounting instead
	Build Bright University (BBU) Faculty of Economics and Agricultural Sciences	Yes	No	Only Bachelor in Finance and Accounting
	Angkor University Faculty of Agriculture	No	-	Deans or heads of departments impossible to reach beyond the central call center
Thboung Khmum	**University of Heng Samrin Thboung Khmum (UHST)** Faculty of Agriculture	No	No	No classes in fisheries

5. ANNEX 2: List of recommended pedagogic resources

List of recommended handbooks and resources to support course content upgrading:

Fisheries ecology

- Fresh water ecology: concepts and environmental applications of limnology" 3rd Edition by Water Dodds and Matt Whiles
- Elements of Marine Ecology 5th Edition, Dipper 2022, Elsevier
- Practical Handbook of Marine Science, 5th Edition, Michael J. Kennish, 2020, CRC Press

Fish physiology

- The Physiology of Fishes, 4th Edition by Evans et al., 2013 (free online at https://vetbooks.ir/the-physiology-of-fishes-4th-edition/)
- Fish Physiology (free online at https://www.elsevier.com/books/encyclopedia-of-fish-physiology/farrell/978-0-12-374545-3)

Zoology, biology

- "Invertebrates" by Brusca, Giribet and Moore, 3rd or 4th Edition
- Vertebrate Life" by Pough et al., 11th Edition 2022.
- Manual for General and Special Ichthyology (Oleh 2018)
- Handbook of Biology ((926 pp), free online at https://open.umn.edu/opentextbooks/subjects/biology)

Water quality

- Water quality monitoring and management bases. Technology and Case Studies, 1st Edition, 2018, Daoliang Li & Shuangyin Liu, Elsevier.

Research resources

- ResearchGate (https://www.researchgate.net). ResearchGate is a networking site where scientists from all disciplines share their research in the form of PDF files and can ask questions and start discussions on theoretical, practical or statistical matters.
- Sci-Hub (http://www.sci-hub.se/). Sci-Hub is a pirate repository of millions of science papers in PDF format highjacked from journals, until 2021. In 2018, Sci-Hub's database contained 68.9% of the 81.6 million scholarly articles registered. Search is done using the DOI number of these articles.
- Zotero (https://www.zotero.org) and Mendeley (https://www.mendeley.com). Mendeley and Zotero are two online library depositories that allow collecting and cataloguing literature found online. They also allow for online collaboration (library collection, writing of papers, sharing of teaching material with students).
- Online education resources Microsoft Teams (https://www.microsoft.com/en/microsoft-teams/group-chat-software)
- Google Education (https://edu.google.com).
- Google Classroom (https://www.youtube.com/watch?v=XQ0Ja_vaM0o)

6. ANNEX 3: Additional courses reviewed

The courses reviewed below are not part of the eight courses identified by deans and professors as requiring priority support; however, they are an important part of any curriculum in fisheries and have also been reviewed at the request of some professors.

Fisheries Ecology (NIA)/ Ecology of Aquatic Ecosystems (KNIA) / Fisheries (RUA, UKT)

The two courses deal with the same content and hence similar learning outcomes. Yet, this training is given different titles in the universities teaching it.

The main goal of a course on the Ecology of aquatic ecosystems is to provide the basic understanding of the ecological features of the different habitats that finally support fisheries (e.g. lakes, rivers, wetlands, marine coastal areas, open ocean systems and the deep sea). This is achieved by discussing generalities on food webs and energy flows, notions of element cycling (biogeochemical cycles) and basic elements of biology and phenology (e.g. the study of periodic events in biological cycles) of primary producers, bony fishes and other organisms of interest (e.g. seafood, seaweeds).

The lectures are given using Power Point presentations prepared by the lecturers based on material handed by previous lecturers, and recent online sources. Practical teaching consists in a field excursion to nearby locations to gather field data, process data during group assignments and produce a PowerPoint presentation to generate discussion.

KEY ISSUES:

- Lack of Khmer handbooks
- Different course titles for similar course content
- Outdated material: most literature is older than 2010
- UKT does not have teachers who can give this course as required: the university requests external teachers from RUA or other institutions to teach this course as guest lecturers. However, this may be difficult given the very detailed content of this course requiring a large number of teaching hours.
- Very minimal content on marine ecosystems; RUA and NIA request improvement of marine science content
- Limited funds for field excursions; many students cannot afford distant travel.

RECOMMENDATIONS:

The following suggestions are listed by order of importance and urgency.

Recommendations to universities

a) The course title should be: Ecology of aquatic systems. Courses entitles "Fisheries ecology" deal with more practical and quantitative aspect of aquatic ecology in relation to fisheries, such as mathematical methods to link biological characteristics with fisheries management or quotas.

b) Split the content of the Ecology of aquatic systems into two courses: 1) Ecology of freshwater systems and B) Ecology of marine systems. Both courses would be taught at RUA and NIA, while KNIA and UKT would might only teach Ecology of freshwater systems.

c) The content should be produced in English in the teaching slides and explained in Khmer by the teacher in the class. A "presenter's notes" handbook in Khmer would accompany the slides and help the students understand the English material and help acquire the theory behind the slides. The basics of aquatic ecology and of English terminology should be acquired by the students to facilitate their access to outside online available resources.

d) Below is a suggested Table of Content for the two courses options:

A) Ecology of Fresh Water Aquatic Ecosystem

- Concepts of ecology, habitat, ecosystem
- Properties of water (e.g. alkalinity, oxygen concentration, temperature, density, turbidity)
- Properties of light and light penetration in water
- Hydrological cycles and physiography of groundwater habitats and wetlands
- Physiography of flowing water systems
- Hydrology and physiography of lakes and ponds
- Biogeochemical cycles in fresh water systems: water, carbon, nitrogen, phosphorous and other nutrients
- Microbes and plants
- Multicellular organisms and fishes
- Generalities of fresh water food webs (predation, grazing, plants interactions, microbial-invertebrate interactions)
- Trophic state, oxygen and eutrophication
- Importance of water quality and trophic state for fisheries
- Ecology of the Tonle Sap system

B) Ecology of Marine Ecosystems

- Concept of ecology, habitat, ecosystem
- Marine, brackish and estuarine coastal habitats; properties of seawater
- Zonation of oceans: shallow coastal waters, continental shelf, continental slope, deep-sea, abyssal plain.
- Properties of water and water masses: salinity, pH, alkalinity, temperature, density, turbidity
- Euphotic zone
- Oxygen depth zones: in water and in the sediment (RedOx potential)
- Basics of physical oceanography and water masses circulation: water mass

properties (salinity, temperature and density), winds and marine currents (Ekhman and Coriolis effect, geostrophy)

- Upwelling and downwelling systems: hotspots of productivity and biodiversity
- Coastal marine habitats: estuaries, mangroves, seagrass, salt marshes
- Off-shore ecosystems: coral reefs and atolls, pelagic ecosystems, sargassum habitats
- Deep-sea ecosystems (e.g. hydrothermal vents, cold seeps, seepages, brines, trenches and canyons, sea mounds and deep coral reefs)
- The plankton: phytoplankton and zooplankton
- Nutrient cycles and phytoplankton
- Microbial loop and oxygen concentration in water and sediments
- The benthos: hard substrate versus sediment assemblages
- Fisheries of the world: a brief overview of main landing regions and hotspots of biodiversity in oceans
- The Economic Exclusive Zone (EEZ) and marine fisheries: the nutrient paradigm
- Marine coastal protection and management: The Kep Archipelago and the Marine Fishery Management Area of Kep

e) In the case of UKT, being able to host a full course without any assigned resident lecturer may be unrealistic, and the same applies to the request to have a series of guest lecturers to teach a full course (difficult logistically and pedagogically). A solution could be to implement a wrap-up of the two courses (fresh water and marine systems) with three lectures in total dealing with: i) the aquatic ecosystem: water as a medium for life; ii) fresh water ecology; iii) marine ecology. These lectures can be rather superficial but touch upon primary productivity in water, influence of light, nutrients and microbes in water quality, main differences between fresh water and marine habitats.

f) For new content on fresh water habitats ecology the handbook "Fresh water ecology: concepts and environmental applications of limnology" 3rd Edition by Water Dodds and Matt Whiles is suggested;

g) For new content on Marine Ecology two handbooks are very comprehensive: 1) "Elements of Marine Ecology 5th Edition, Dipper 2022, Elsevier" 2) "Practical Handbook of Marine Science, 5th Edition, Michael J. Kennish, 2020, CRC Press";

h) The field visits could consist of i) one Marine ecology visit for RUA and NIA with external lecturers from Europe, Thailand and Vietnam to foster international collaboration (similar to what has already been organized by RUA and the NGO Marine Conservation Cambodia in collaboration with Ghent University); ii) one for the Freshwater system course consisting of a field trip to the Tonle Sap system. These activities could be organized as a "University networking joint field trip" with students and professors.

Recommendations for external support

- Purchase of the handbooks recommended.
- The updated material should be produced (in the form of a written translation, summary, or slides with scans of handbook figures) in English and then presented in Khmer in the class. The requirement of a translator for the implementation of such content should be considered a priority.

- For the course on Marine systems, experts from neighboring countries could be invited to give specific lectures on marine processes (e.g. water masses and oceanic circulation), coastal and open ocean marine habitats (e.g. estuaries, coral reefs).
- The establishment of the Marine Management Fishery Area of Kep Archipelago (e.g. Marine Conservation Cambodia, Fauna and Flora International) is an outstanding local example of good marine management practice. Donors could sponsor guest lecturers from abroad and from local NGOs to cover such topics within the course.
- Marine ecology is taught in English at Ghent University as part of the international Master courses of IMBR Sea and Oceans and Lakes. There is a possibility to partially share already available content in the form of expert visits and guest lecturing. Sponsors could support the costs of such visits (travel, hotel and per diem) or arrange online workshops in the form of guest lectures covering the expense of the external expert.

Systematic Aquatic Zoology (KNIA, RUA)

The main course learning outcome is to learn what groups of the animal kingdom are present in marine and freshwater ecosystems, and what is their role in relation to their habitat. The course upgrade was requested by RUA and KNIA. The course has a strikingly different structure in terms of credit/hours of teaching, with 64 h for 2 credits at RUA and 3 credits for 48 h of teaching at KNIA. The content is different too, with much more details at RUA despite a less organised structure.

KEY ISSUES:

- Lack of a handbook in Khmer
- Outdated material
- Bad visual presentation with often chaotic PowerPoint material
- Confusing structure of the teaching material

RECOMMENDATIONS:

Recommendations to universities

- The course should be divided in two courses: 1) Aquatic vertebrate zoology (which could also include principles of Comparative anatomy) and 2) Invertebrate zoology.
- The course(s) outline and content should be homogenized across the two universities by means of workshops with the help of external experts.
- Handbooks suggested: i) “Invertebrates” by Brusca, Giribet and Moore, 3rd or 4th Edition; ii) “Vertebrate Life” by Pough et al., 11th Edition 2022.

Recommendations for external support

- Sponsor a workshop to have teachers from agree on the table of content of the two courses.

Biology (UKT)

This course upgrade was requested by UKT only. The content is aimed at explaining the bases of biological processes at the level of the cell, while distinguishing between the different types of living organisms (from viruses and prokaryotic cells to eukaryotic to plant cells). This course should be a basic course for all life sciences and curricula dealing with biological organisms.

KEY ISSUES:

- Lack of a handbook in Khmer
- Lack of more detailed knowledge on enzymes and protein functions
- Lack of expertise in the use of light microscopes
- Lack of expertise in the preparation of tissues for examination during practical activities
- Lack of 3D models of cells

RECOMMENDATIONS:

Recommendations to universities

- Workshop at NIA to share the already available knowledge with the teachers of UKT could be the fastest way to homogenize the course content and favor interaction.
- Practical activities would benefit from training UKT teachers with access to good histological samples to show students the use of light microscopes.
- 3D models can be done by students as part of a practical activity (this was already suggested by the consultant to the teacher and achieved during this past academic year, see figure below)
- All knowledge necessary at this level is present online and freely available but in English.

Recommendations for external support

- Handbook (926 pp) of Biology freely downloadable at https://open.umn.edu/opentextbooks/subjects/biology
- Salary of a translator to support the translation of online available handbooks
- Sponsors could pay the salary to an expert to teach UKT teachers how to make histological samples from different organisms (e.g. plant versus animal tissue). The training should take not more than one week.

Figure 1: Examples of 3D cell models built by UKT students as part of the Biology course.

7. ANNEX 4: Equipment, opportunities and needs in laboratories

Between June and August 2022, we visited and reviewed the laboratories of the four Universities for which this syllabus revision was ongoing. In the following paragraphs the main observations are reported for each laboratory visited, and recommendations are issued accordingly.

Equipment and issues common to all universities, and generic recommendations

Microscopes are available in the facilities; they range from basic stereomicroscopes (binoculars used for macrofauna such as polychaetas, meiofauna such as nematodes and plankton) to light microscopes with 40x and 100x magnification lenses (used for instance to count otolith rings in fishes or identify meiofauna down to genus and species level) and to an inverted light microscope with a fluorescence option, used to count bacteria in water and/or sediment samples. Interviews indicated that the potential use of elaborate microscopes was not known to most teachers and technicians present, technicians underlining that they had never been trained in their maintenance or use. One way to address this challenge is to hire professionals from the health sector to train university technicians in the use and maintenance of microscopes and lab equipment.

In fact, the use of this type of equipment requires training on i) how a specific microscope model works; ii) how to prepare samples for each possible analysis (protocols for different sample processing; extraction of organisms from their matrix such as sand or water, slides preparation etc.), iii) how to properly use the microscope (e.g. use of immersion oil for 100x magnification) and iv) how to maintain this equipment (e.g. regular complete cleaning of lenses and other parts etc.).

Toxic or harmful chemicals such as formalin, ethanol and acids are used without specific waste collectors nor waste management (to date, most waste is simply drained down the sink then down to the ground or a river). Laboratory technicians should be trained on the proper storage, use and waste management of all classes of chemicals. The training of laboratory technicians is a high-priority and should be supported. Such specific training can be pursued in other institutions within Cambodia. Medical or industrial laboratory operators could be hired to train the university lab technicians in the use and maintenance of various instruments and in toxic waste management. Thus, a coordinated management of toxic and dangerous waste common to all university labs could be prepared in collaboration with health lab professionals.
Grants for technical staff from least advanced countries were offered in the past by VLIROUS (www.vlirous.be) for training at Ghent University in Belgium. A Global Mind Fund Capacity Building program could be a good funding opportunity to sponsor such training.

Unused high-tech instruments are of interest for research topics at other institutes, labs or faculties. They could become part of a “Inter-university service network” with agreements by which the use of these machines would be granted against reasonable remuneration and training of lab staff. In the long run, this could lead to providing paid services (sample analysis) to external institutes or clients (research institutes, food safety analyses, private companies).
The specific equipment and issues in each university reviewed are detailed below.

Preak Leap National Institute of Agriculture (NIA)

NIA features a series of laboratories on two floors. A large part of the equipment was donated by Chinese sponsors in 2015. One of the issues encountered NIA is the lack of sustainability in most projects that donated this highly specific and complex equipment. The lack of an ongoing research projects requiring and funding the use of these instruments makes it impossible to retain staff knowledgeable in use and maintenance of these instruments (some of the instrumentation present at NIA require a very high level of technical knowledge; e.g. gas chromatography mass spectrometer; DNA amplification PCR; atomic absorption spectrometer). Yet, some of these instruments detailed below represent an invaluable asset for research in Cambodia.

Gas Chromatography (GC) and Gas Chromatography Mass Spectrometer (GC-MS)

Gas chromatography allows the separation of compounds into their elements without decomposing them, by vaporization. This technology can be used to test the purity of a substance or separate the different components of a mixture. Applications range from industrial analysis of chemical products to measuring chemicals (including gases) in soil, air and water. Gas chromatography can also be used in forensic science. The accuracy of the measurements can be extremely high.
A series of practical activities can be envisioned for students to get acquainted with the functioning of the machine, among which the analysis of oils from plants.

The Gas Chromatography Mass Spectrometry (see Figure 2) is a hybrid analytical technique that couples the separation of compounds by *gas chromatography* with the detection properties of mass spectrometry; this leads to the identification of compounds on the basis of their mass. Applications are various, from medical science (e.g. detection of trace compounds in urine of patients with genetic metabolic disorders) to environmental applications (e.g. detection of pollutants such as pesticides in air, water and soil) and food web ecology (e.g. to trace the relative proportion of various stable isotopes diagnostic for specific food sources and trophic levels within the food chain). One of the main issues at NIA is that password-protected software associated with the machine is not mastered any longer, as the professor in charge left the institute.

Figure 2: Gas chromatography GC 400A with its nitrogen tank (left) and Gas chromatography mass spectrometer with the its helium tank (right) at NIA.

Such instrumentation (whose commercial value reaches USD 150 000 per machine) represents an invaluable technological strength and opportunity for NIA. It could be used or rented out for external research analyses. The revenue could be used to maintain the machine, pay the technical staff and also support research within the faculty. Training of technical staff or research staff is a high priority. This could be achieved by either sending the technical staff to courses on the technology, or by hosting technicians/experts who could train the local staff and appointed academic staff.

Ultraviolet-visible Spectrophotometer UV-1200 (UVS), Atomic Fluorescence Spectrophotometer (AFS) and Atomic Absorption Spectrometer (AAS)

Electromagnetic spectroscopy is the study of the interaction of light and matter. It measures how different atoms of molecules absorb and/or emit light across different electromagnetic wavelengths.
Ultraviolet-Visible Spectrophotometry (UVS) uses the properties of specific molecules to absorb ultraviolet (UV) or visible light at specific wavelengths and relate that absorption to their concentration in a solution which is measured against a standard. UV Spectrophotometer is used in ecological studies to estimate the productivity of a water or sediment systems. Water samples can be analyzed - after specific extraction protocols - for chlorophyl-a and phaeophytin concentrations which can be a proxy for primary productivity and ageing of the organic matter produced by the primary producers, in both seawater and freshwater.
The Atomic Fluorescence Spectrophotometer (AFS) uses light to excite atoms in a solution, which once excited are converted in a gaseous form, and finally the fluorescent radiation generated by the excited atom is measured by a fluorescence spectrophotometer. The Atomic Absorption Spectrometer (AAS) uses the same concept of absorption of wavelengths by different elements and the atomic states changes that happen during the excited and relaxed states of the atoms to detect different elements and measure their concentration in water or solids, with specifically the detection of metals in samples. There are many applications for these AFS and AAS technologies, in particular in agriculture where it is utilized to measure the presence of phosphorous and nitrogen in soil samples. Another application can be the detection of trace amounts of harmful chemicals, such as mercury or rhodium, in water samples.

Figure 3: UV spectrophotometer (left) and atomic absorption spectrometer (right) at NIA.

Freezing microtome and accessory microscopy

The freezing microtome (cryostat) can be used in histopathology to freeze specimen samples (e.g. organ tissue of fishes with parasite damage, plant tissue with laceration of parasites) which are hardened and then cut as microscopic slices. The slides created can be then analysed under light microscopy. This technology is used in quick diagnostic of cancers in medicine, but it can be used to investigate the infection of fish and plants by parasites such as nematodes. The pedagogic potential is obvious given the presence of light microscopes and inverted light microscopes at NIA. Training of the lab staff in this technique could improve the laboratory practice of the faculty, especially in relation to the Fish pathology course.

Figure 4: Freezing microtome (cryostat, left), light microscopes (center) and inverted microscope (right) at NIA

DNA analysis instrumentation, Thermocycler (PCR) and Real-time PCR (qPCR)

The genetic material of cells or DNA can be used for a series of applications including medical, environmental, ecological fields and even forensics.

The Nucleic Acid Extraction System (see Figure 5) allows extracting DNA from cells and processing it to be sequenced then amplified. A thermocycler is a simpler version of a PCR machine, where the amplified products then need to be quantified and isolated by following procedures and protocols.

Figure 5: Some machines present at NIA and currently not in use: nucleic acid extraction system (left); thermocycler (center); and real-time Polymerase Chain Reaction (PCR) machine (right).

In short, NIA is in possession of a series of very advanced machines that have the potential to establish within the institute a molecular laboratory. The latter could not only serve to teach molecular approaches to students, but also become a service laboratory in the field of environmental monitoring (e.g. using environmental DNA to search for the presence of invasive species in rivers or open waters) and biodiversity assessment or species cataloging (barcoding). Training professors and technicians in these techniques is therefore a priority to develop not only the *inhouse* skills to make use of the potential of genomics for ecological and scientific investigations, but also to establish within NIA a molecular laboratory that could become available outside the Institute.

Table 5: List of scientific analytical equipment of the NIA

Instruments	Training required?
Atomic absorption spectrophotometer	Yes
Atomic fluorescence spectrophotometer	Yes
Gas Chromatograph with Electron Capture Detector	Yes
Ultraviolet High Performance Liquid Chromatography	Yes
High Performance Liquid Chromatography RSD (HPLC-5500)	Yes
Viscometer DV-2T	Yes
Freezing microtome	Yes
Digital microscope	Yes
Inverted fluorescence microscope	Yes
Nucleic acid isolation machine	Yes
In Situ Hybridization Instrument	Yes
Ultraviolet-Visible Spectrophotometer UV-1200	No
Gas chromatograph-mass spectrophotometer GCMS-3100	Yes
Automatic microplate reader	Yes
Real time fluorescent PCR and Thermocycler PCR	
Others: Azotometer; Centrifuges (ordinary, high and low speed); Constant temperature water channel and bath; Cryogenic refrigerator; Digestion furnace; Distilling apparatus; Dry incubator and dry oven; Electro-heating cultivator; Electronic scales; Electrophoresis system + Gel; Evaporator; Gas flowmeter; High-speed refrigerated centrifuge; Ice machine; Incubators (biochemistry and carbon dioxide); Light microscopes and dissection microscopes; Oscillator, vibrator, mixer, agitator and stirrer; pH meters; Precision pipettes; Pressure steam sterilizer; Sand core filter; Sieve shaker; Soxhlet extractor & bottle; Thermostatic dry oven; Tissue dehydration processor; Ultra-pure water system; Ultrasonic cleaner; Vacuum pump; Vertical pressure propped sterilizer	

Royal University of Agriculture (RUA)

The Faculty of Fisheries is managing one clean and organized laboratory. A closet with glass sliding doors (Figure 6) is used as chemical storage for non-corrosive nor inflammable chemicals.

Figure 6: Chemical product closet at RUA laboratory.

Another metallic closet is used to store those corrosive and flammable liquid products (the order of the products is alphabetical across the different shelves).

Figure 7: Metallic closet for acid, corrosive and flammable products at RUA laboratory.

Other highly toxic chemicals (e.g. formalin) are stored on the floor, below benches. Although those chemicals are handled with the highest care, the needed safety measures are not in place: i) no use of nitrile gloves and protection masks (with filters for formalin fumes) while handling chemicals; ii) no properly labelled plastic barrel for the disposal of the waste of toxic solutions; iii) no suction arms to collect the fumes of samples previously stored in formalin and processed in the open space of the lab.

Figure 8: Air suction arm.

Source: https://www.tolkim.com.tr/en/alsident-air-suction-arms-system-50-77/

Table 6: Short list of main equipment present at RUA

Instruments	Training required?
Stereo microscope (A)	Yes
Light microscope (B)	No
Light microscope with camera system and integrated screen (C)	Yes
Oven; Furnace; Autoclave (F); Continuous flow bench (E); Centrifuge; Photometer (D); Oxygen probe (G)	

Figure 9: Pictures of some of the equipment present at the RUA laboratory

Kampong Cham National Institute of Agriculture (KNIA).

The KNIA has one laboratory with a series of light and stereomicroscopes, a few balances, a pH meter, an autoclave, an incubator with mixing plate. The laboratory is kept very clean and organized, but with some maintenance issues (storage solutions, expiry dates, etc.). The person in charge shared his interest in being trained in the use of microscopy and other instruments. KNIA features the simplest lab facilities across all universities investigated.

Table 7: Short list of main equipment present at KNIA

Instruments	Training required
Stereo microscope	Yes
Light microscope	No
Light microscope with camera system and integrated screen	Yes
Oven; Autoclave; Centrifuge	

University of Kratie (UKT)

The facilities are large, with four laboratories dedicated mostly to culturing young plants for aquaponic, for fish cataloging (previously a taxidermist process) and for microbiology. The laboratory equipment is basic but used and the technicians know how to use and maintain it. The laboratories are clean and well organized.

A request was made for training in making slides for the observation of plant and animal samples under the microscope. Some equipment is left unused due to a lack of purpose or knowledge of its application for either teaching or research purposes. A basic training in these instruments should be provided to all teachers and the various responsible personnel of the laboratories.

Figure 10: Light microscope with direct imaging (A); air flow bench for working in sterile conditions (B) and various cultures of hydroponic baby plants (C).

Table 8: Short list of main equipment present at UKT

Instruments	Training required?
1 light microscope	No
1 light microscope with camera system and integrated screen	Yes
Flow bench; oven; autoclave; microplate reader; cell counting lamp with grid; shaker and temperature incubator; pH meter; thermic plate; scale	

TEXT BOX 2

Recommendations regarding health and safety in laboratories

Below is a list of points for improvement:

- Glass containers should be kept (after having been properly washed and rinsed) in a closet or closed container to avoid dust and breakage;
- Electric cables of bench instruments should not be left entangle. This is tidier but also prevent fire and electrocution;
- pH meter equipment should be kept on a separate bench. The use of such equipment requires the use of solutions that often produce corrosive salts;
- Solutions used for calibration of pH meters, the probe electrolytes solution and the solution used to store the probe of the pH meter should be purchased timely (solutions observed were long expired). The use of expired solutions may lead to erroneous calibrations and potentially damage the probe;
- A proper rinsing of the pH probe should be carried out after each usage. This should be done with distilled or milliQ water to avoid algae growing inside the probe.
- The pH probe in all laboratories visited lacked the electrolyte fluid inside the probe and were stored in expired storage solution. It is doubtful the probes are still functioning properly.
- Each collector of toxic and hazardous waste should be labelled with a specific sign (see example for formalin in Figure 11). The possible mixture of chemicals in one common container would need to be assessed for the risk of unwanted and hazardous chemical reactions.

Figure 11: Some hazard symbols to be used on containers

Example of formalin: a toxic and hazardous chemical also flammable, toxic, carcinogenic and corrosive.

- Each laboratory should have a list (inventoried on a regular basis) of the chemicals present in the laboratory. This list could be compiled in alphabetical order for all the chemicals. Details should include: name and chemical formula of the chemical; its form (liquid/powder); type of container and volume/weight; how many units are there; possible hazard for the chemical; where it is stored.
- Each laboratory should have a Code of Conduct to be signed by the students and/or any person working in the laboratory where the basic laboratory safety protocols and emergency procedures are outlined, including the presence of the emergency contact in case of any accident.

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No. 186, Norodom Boulevard, Tonle Bassac, Chamcar Mon, Phnom Penh, Cambodia, P.O. Box 582
Tel: (855) 23 215 470 Facebook: https://fia.maff.gov.kh/