We study the **economics of water and bio-resources** as they are **highly valuable to society**.
Examples of **dynamic natural systems** include **fisheries**, **forests**, **groundwater**, **surface water**, **ecosystems (biodiversity)**, and **stock pollution**.
Stocks are static quantities measured at a single point in time whilst **flows** are variables measured over an interval of time such as per year.
Private economic agents such as farmers, loggers, or hunters tend to **only account for private costs and benefits over a short time period** and **ignore the significant social benefits of actions** such as conservation, reforestation, native vegetation that imply net private cost.

- This results in i**nefficient (suboptimal) management of dynamic natural systems**.
- **Overpopulation** has placed greater stress on natural systems and the ability for replenishment of stocks.

The **two major forces affecting natural system dynamics** are:

- **Bio-Physical forces** such as changes of stocks over time e.g. changes of biomass, or physical quantities over time.
- **Economic forces**, that is what governs human behaviour in regards to the extraction of natural resources such as water.
  - This includes understanding **markets** for products and services derived from nature systems which provides incentive for extraction.

The key economic issue is how to manage **optimal use of a resource** over time as use now implies reduced use in future time periods.

- Simply using the resource now due to positive resource rent will lead to **rent dissipation and possible collapse of the stock** and therefore natural system due to inadequate stock levels resulting in **social and environmental problems**.
- We solve this issue through use of **standards and restrictions**, the creation of **price signals** such as taxes and subsidises that value the use of disuse of a natural system, and the **creation of markets** such as through tradeable permits.

Fisheries economics revolves around the key state variable of the stock of fish combined with economic behaviour (harvesting) to provide a simply model of the interface between natural and economic systems in order to **derive optimal rules for harvesting**.
Forestry economics explores how to manage a forest in order to derive maximum private and social benefits through understanding the optimal time to harvest timber from an economic standpoint **based upon NPV**.
There are **two types of forests**:

- **Old growth forests** which are naturally occurring.
- **Even aged forests** which are established by people.

A key issue in **water economics** is that water is priced as a necessity and therefore at a low value, even though it has a relatively higher economic value and should be considered as a commodity.

- **People have inelastic demand for water at low quantities**.
- The confusion between water as a necessity and as a commodity is the **Diamond-Water Paradox** whereby water is an essential but priced very low, whilst diamonds are relatively useless but are priced very high.
- Water quality is a major issue in many countries due to **agricultural runoff**, **increased human population** leading to increase **wastewater**, and **increased manufacturing activities**.

Two major forces determine natural system dynamics:

- **Biological/physical system dynamics** are the changes of stock (**population**, **biomass**, **pollutant**) over time.
  - This is dependent on the **natural growth of the system** due to **inflows** (e.g. **recruitment**) or **growth in existing stock** (e.g. **growth in biomass**), **natural loss in stock** (e.g. **natural mortality**), **economic use** (e.g. **harvest mortality**).

- Economics factors such as human use (harvesting) dependent bio-physical factors such as stock size and economics factors such as effort, prices and the market.

Xt and X(t) state that X is a function of t and denotes stock, the state variable.

- Xt refers to discrete time.
- X(t) refers to continuous time.

Change in stock is a key characteristic of dynamic natural systems and is denoted by ΔXt/Δt, Xt-Xt-1, dX/dt, and $\dot{X}$.

- Can be mathematically modelled in a variety of ways e.g. logistic function (Schaefer model of fisheries), Sigmoid function (P pollution in lakes), and polynomial volume function (forestry).

Stock-recruitment models such as the Ricker Curve have a density dependent between the recruits and current stock.

- Depensation is a rapid decline in recruitment, whilst critical depensation refers to no recruitment meaning that the stock will collapse.

Dynamic Pool models distinguish between various cohorts and the linkages between them within a given population and are useful in determining the age or size at which a given cohort becomes vulnerable to fishing.

Surplus Yield models such as the Schaefer model are bell shaped functions for the growth in stock of fish biomass.

An equilibrium is a point at which there is non change in stock size from one time period to another i.e. $\Delta \boldsymbol{X(t)}/\Delta(\boldsymbol{t}) \ = \ \mathbf{0}$.

- The environmental carrying capacity (k) is the naturally occurring equilibrium point.
- The minimum viable population (K_0) is an unstable equilibrium.

The Predator-Prey model is used to understand system dynamics with two stocks where the population of one species depends on the population size of another species.

The Sigmoid function where X is the state variable (e.g. water pollution), IN denotes some inflow, u is a control variable, and the others are given parameters.

$$\dot{X}(t) = IN(u(t)) - \phi X(t) + \psi \frac{X(t)^q}{m^q + X(t)^q}$$

Human use of natural systems through harvesting diminishes the stock and can have long ranging consequences on the stock.

Harvesting is removing biomass from its natural habitat for the purposes of its economic use.

- The amount of harvest depends on the stock of the resource and the effort devoted to harvesting (e.g. days at sea, number of hours, number of boats).

Trawling is the most cost effective method of fishing however is environmentally and ethically controversial.

The harvest function is given by $\boldsymbol{H(t)} = \boldsymbol{F(e(t),\ X(t))}$, this is the effort put into catching fish and the stock of fish.

- An increase in the stock will increase the quantity harvested at any given level of effort.
- The marginal physical product of effort is positive but with decreasing returns, this is the stock effect.
- At higher level of effort sustained over long periods of time, the stock declines and the harvest ultimately declines.

The catchability coefficient q, therefore $\boldsymbol{H(t)} = \boldsymbol{qX(t)E(t)}$ captures that some species are easier to catch than others.

The Cobb-Douglas function $\boldsymbol{H(t)} = \boldsymbol{qX(t)aE(t)b}$ reflects stock elasticity (a) and effort elasticity (b).

A sustainable yield of harvest is defined as a rate of harvest that will maintain the population stock at equilibrium.

- $\boldsymbol{Natural\ increase\ in\ biomass - Natural\ mortality - Harvest\ mortality = 0}$.