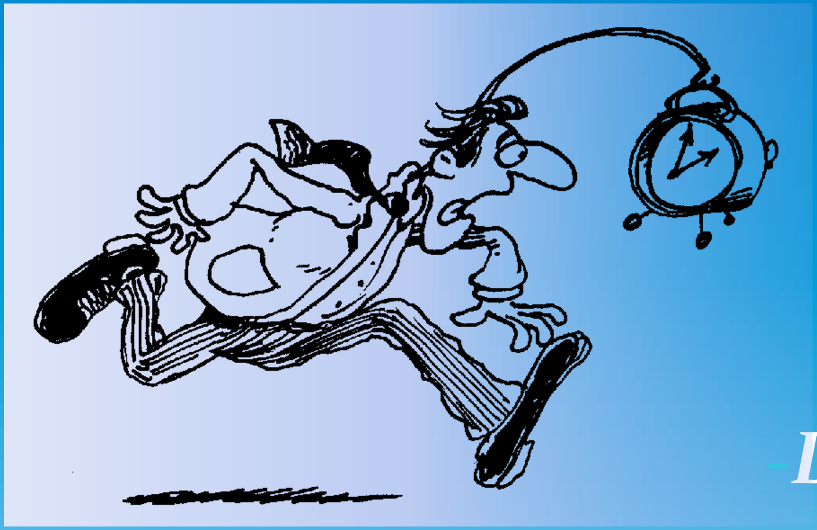
Stress and Adaptation



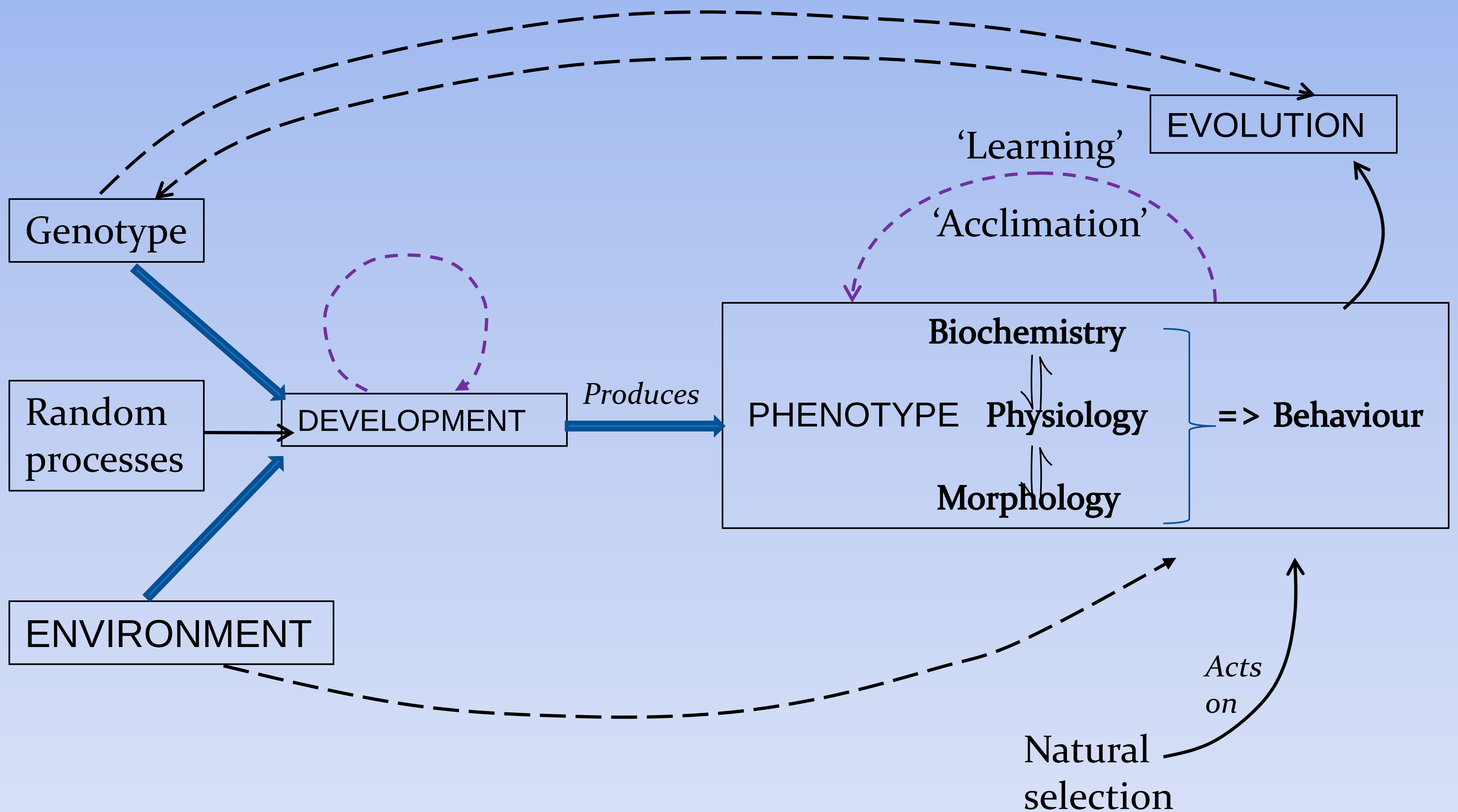
-Dr. Priyanka Halder Mallick

- Included in M.Sc. Zoology, V.U. 1st semester syllabus (2018):
  - Paper ZOO 102, Group B: Animal Physiology
- Included in NET (Life Sciences) syllabus:
  - 7. SYSTEM PHYSIOLOGY - ANIMAL

Topics to be covered :

- Basic concept regarding environmental stress
- The Nature and levels of adaptation
- Homeostasis & response of an organism.
- Environmental stressors

Schematic view of the interrelationships of genotype, environment and phenotype



Environmental stress

- Environments are enormously variable in relation to the stress that they impose on their inhabitants.
- This stress may be both
  - **Abiotic** - physical & chemical factors
  - **Biotic** - direct & indirect effects of other organisms, including competition & habitat modification.

Environmental stress

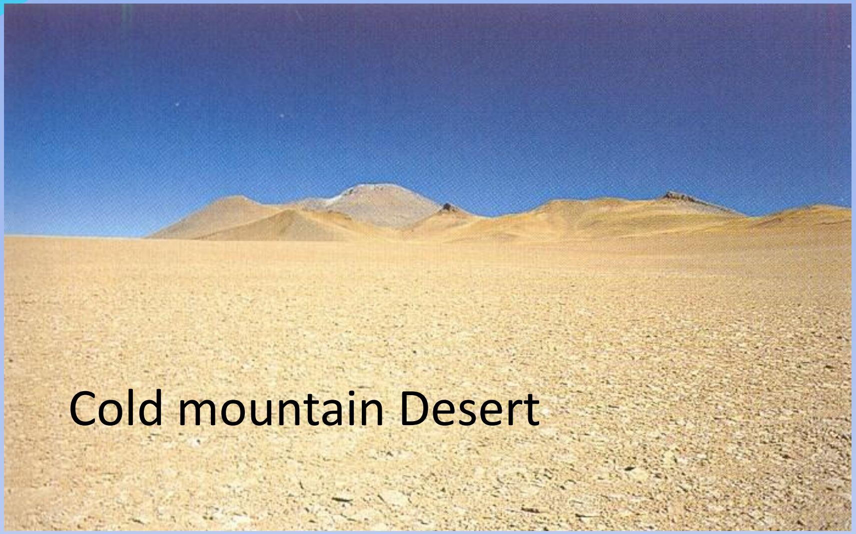
- Since life on earth evolved in seas that were thermally & osmotically relatively stable & all cellular machinery was fundamentally selected from its inception to work best in stable rather cool marine conditions, it is often useful to see the abiotic stress as being dependent on how much conditions have diverged from those starting points.

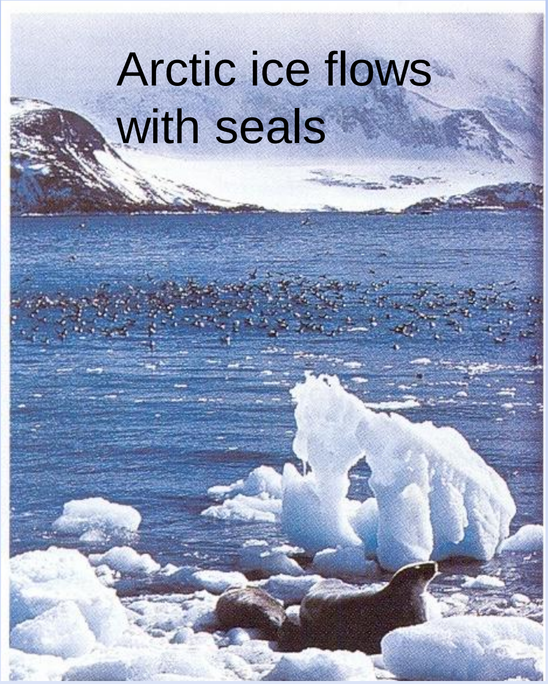
- Thus, life in -
  - Cool sea water is relatively easy
  - Seasonal pond is somewhat tricky, &
  - Hot desert conditions is spectacularly difficult.

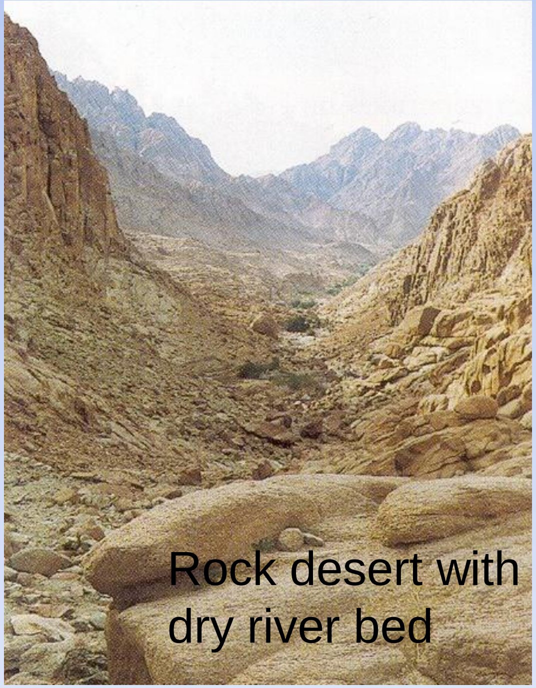
Environmental stress

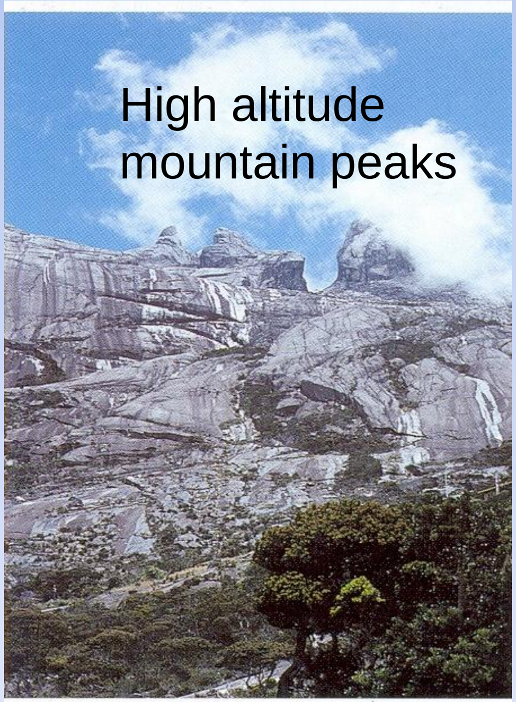
- Other extreme environments would include *(slides following)* :-
    - Polar lands
    - Mountain peaks
    - Hypersaline lakes
    - Hot springs
    - Deep sea thermal vents
- But biotic stress may sometimes work in opposite, in that ‘easy’ habitats may also have large & diverse populations of other organisms & so impose more competition & predation pressure.
- Either of these kinds of stress may put an organism at a disadvantage in having to expend more of its own energy to survive, whether in physiological regulation, or avoidance tactics, or competitive or defensive activities.

Extreme Terrestrial Environments







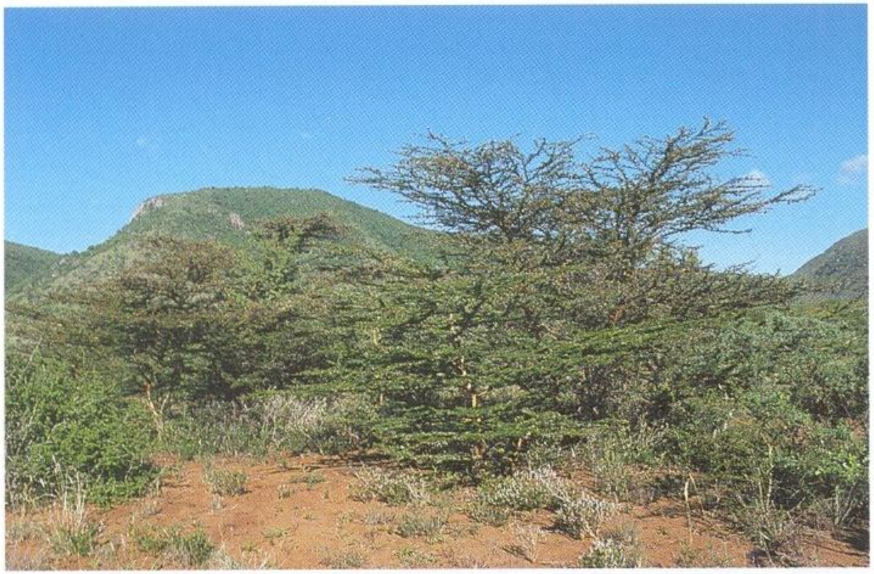


Northern Coniferous forests

More terrestrial environments

(a) (b) (c)

More terrestrial environments



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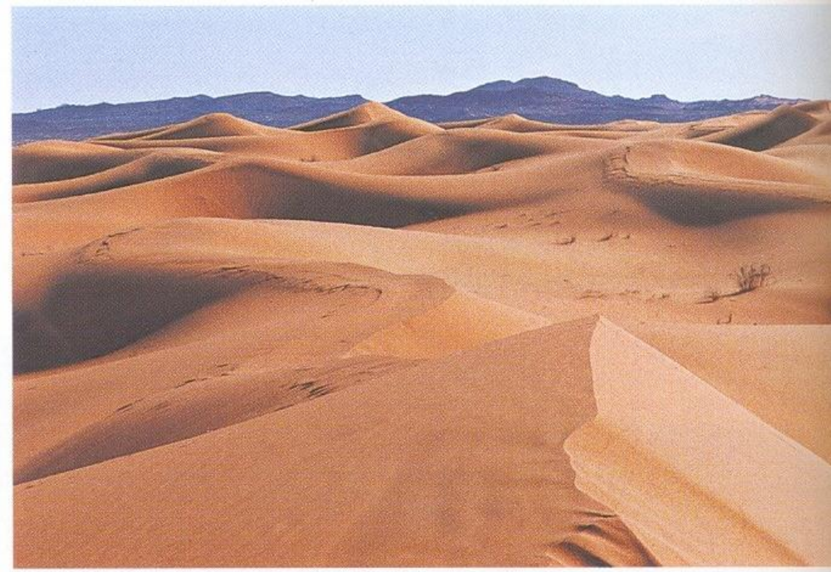
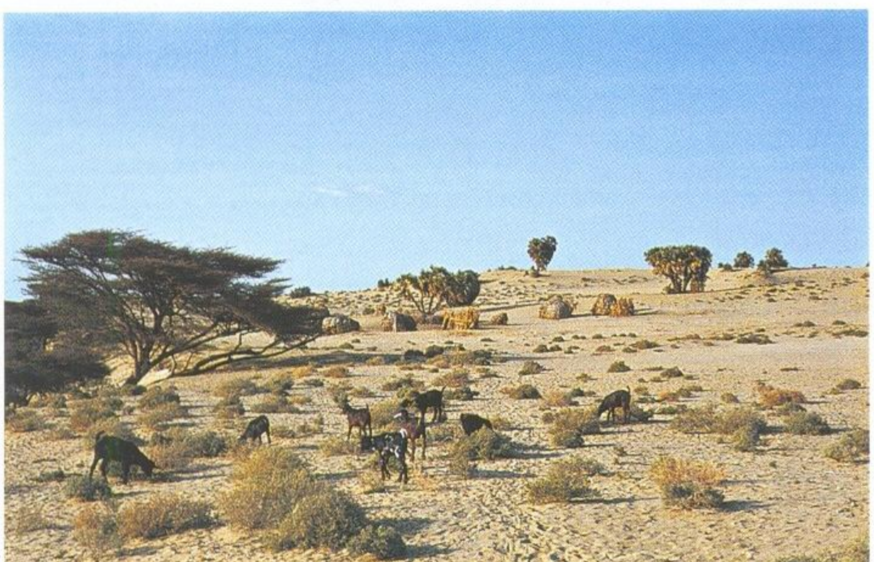




(f)

Plate 8 Terrestrial environments
(a) Tropical rain forest, New World, Ecuador. (Courtesy of J.M. Lambert.) (b) Monsoon forest, Kakadu, northern Australia. (Courtesy of P.J. Sunnucks.) (c) Temperate upland grassland ('paramo'), with llama, Ecuador. (Courtesy of J.M. Lambert.) (d) Sub-tropical savanna thorn scrub dominated by *Acacia*, Kenya. (Courtesy of G.N. Stone.) (e) Sand desert, windblown dunes, Namibia. (Courtesy of N.P. Ashmole.) (f) Semi-desert scrub with goats, Turkana, northern Kenya. (Courtesy of G.N. Stone.)

Semi-terrestrial environments

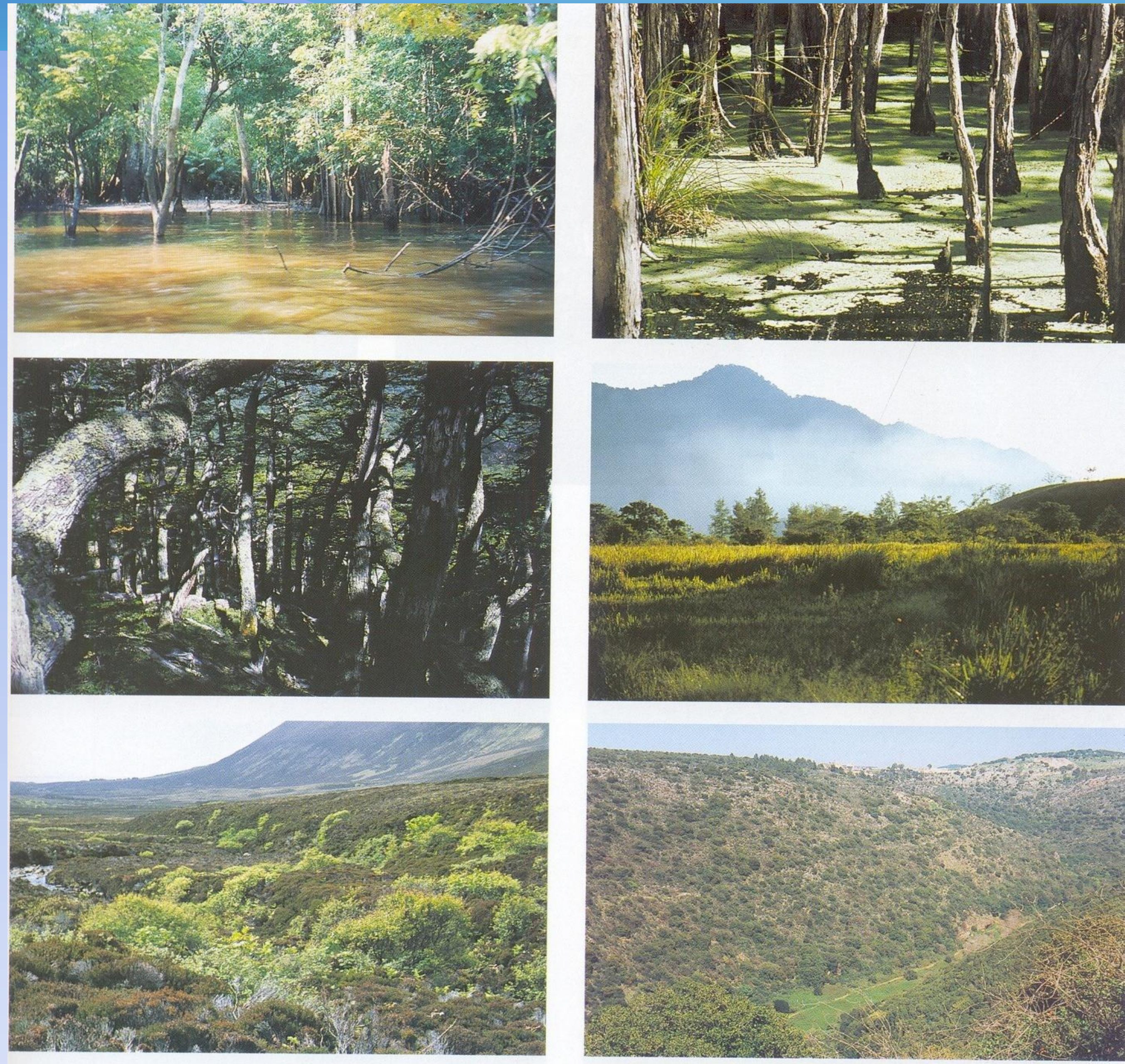


Plate 7 Semi-terrestrial and terrestrial environments
(a) Tropical flooded forest, Amazonas, Brazil. (Courtesy of I.A. Johnston.) (b) *Melaleuca* swamp (swamp cypress), southern Australia. (Courtesy of P.J. Sunnucks.) (c) Temperate southern beech (*Nothofagus*) forest, Tierra del Fuego. (Courtesy of J.M. Lambert.) (d) Tropical grassland, Mt Hagen, Papua New Guinea. (Courtesy of G.N. Stone.) (e) Temperate moorland, Isle of Hoy, Orkney, UK. (Courtesy of A.S. Edwards.) (f) Mediterranean 'garigue', Mt Carmel, Israel. (Courtesy of B. Vulliamy.)

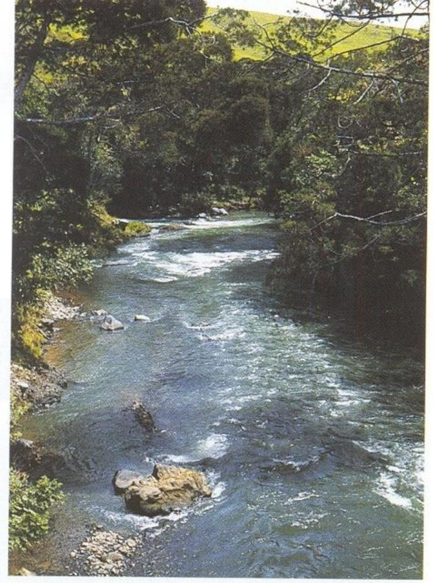
Lentic envs

Plate 5 Freshwater lentic environments
(a) Upland oligotrophic lake, Mt Rugby, New Zealand. (Courtesy of P.J. Sunnucks.) (b) Tropical lowland seasonal eutrophic lake, Dindira, Tanzania. (Courtesy of G.N. Stone.) (c) Small mesic lake, Bosherston Ponds, Pembroke, UK. (Courtesy of D.M. Paterson.) (d) Crater lake, Rinjani, Lombok, Indonesia. (Courtesy of G.N. Stone.)

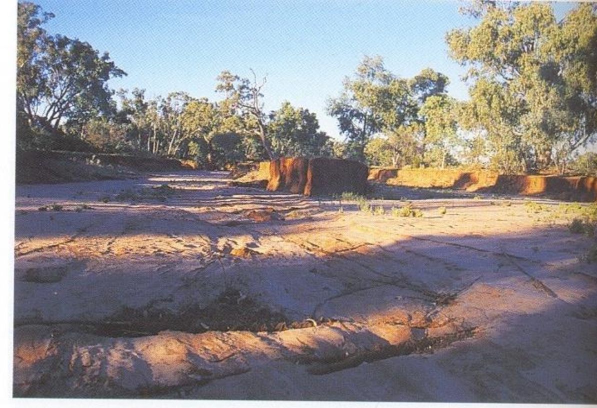
Freshwater Lotic environments

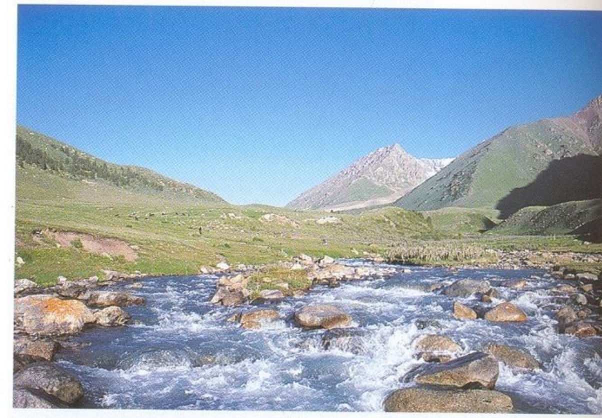
Plate 4 Freshwater lotic environments
(a) Lowland tropical river, Trauna River, Mt Hagen, Papua New Guinea. (Courtesy of G.N. Stone.) (b) Dry river bed in summer in 'Mediterranean' type climate, Mootwingee, Australia. (Courtesy of P.J. Sunnucks.) (c) Upland stream in arid zone, southern Chile.

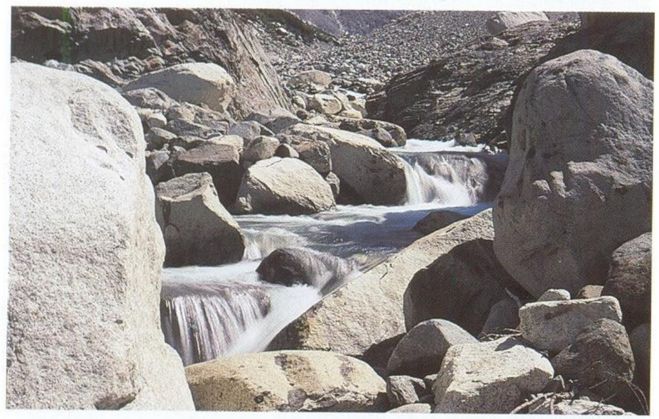
(Courtesy of J.M. Lambert.) (d) Upland stream, cool temperate Kyrgyzstan. (Courtesy of J.M. Lambert.) (e) Tropical eutrophic stream, Java, Indonesia. (Courtesy of G.N. Stone.) (f) Humic river in rain forest, northern Queensland, Australia. (Courtesy of I.A. Johnston.)



(a)

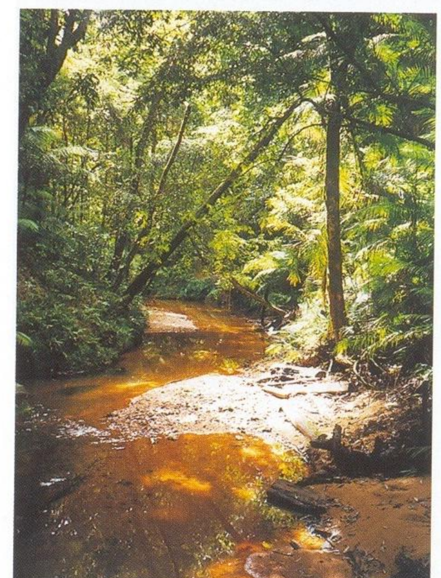






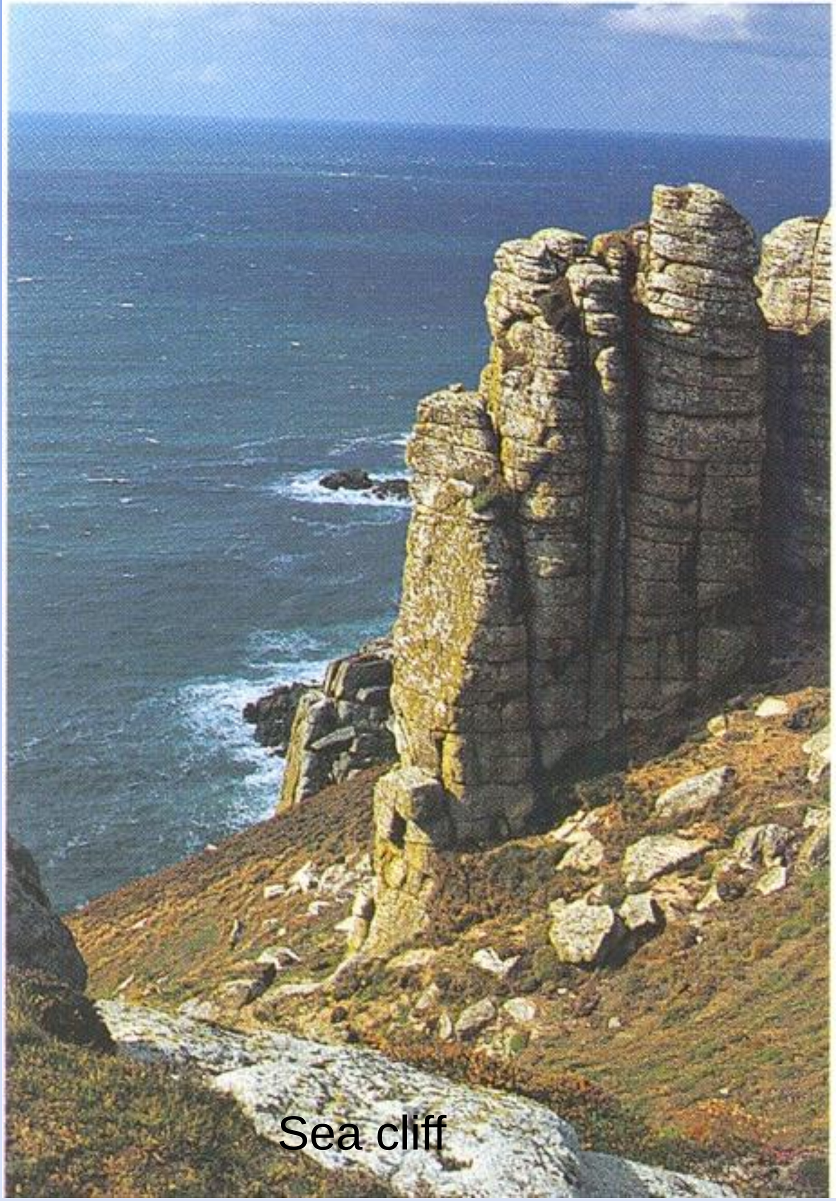
(c)

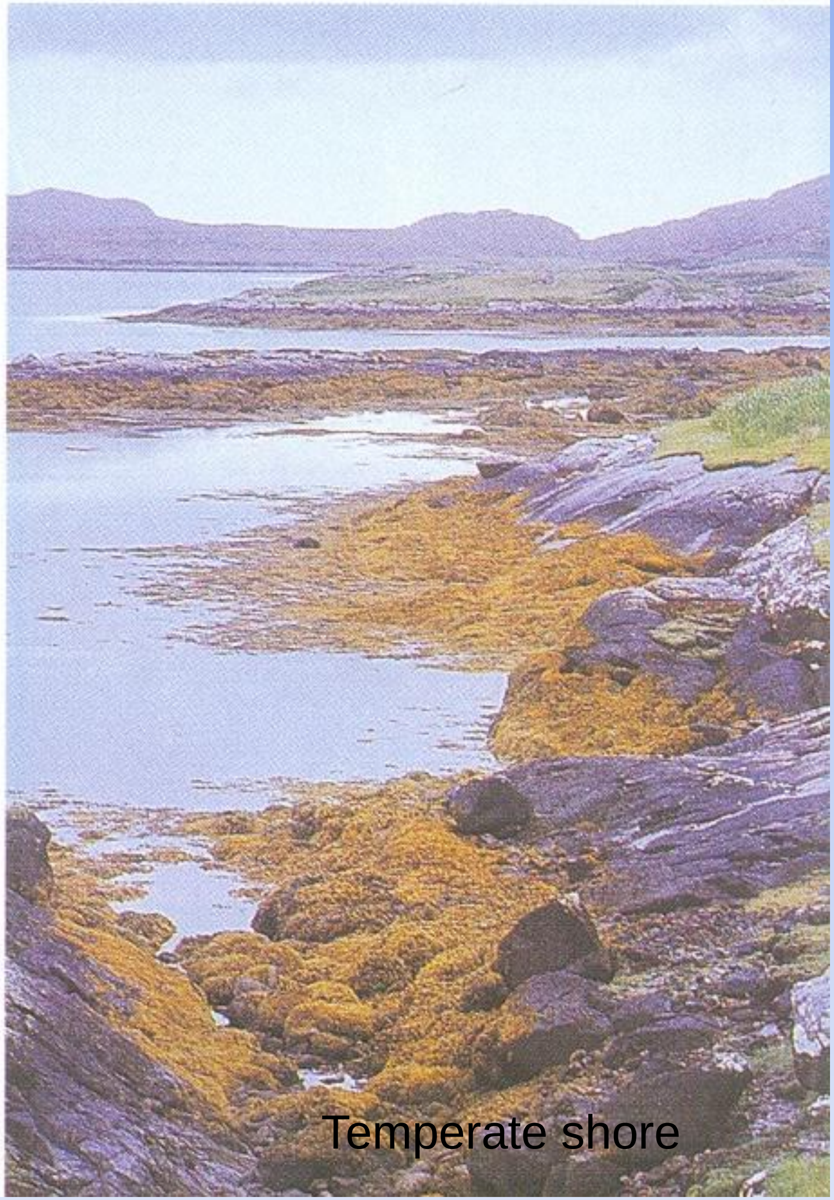
(e)



(f)

Littoral environments





Littoral environments

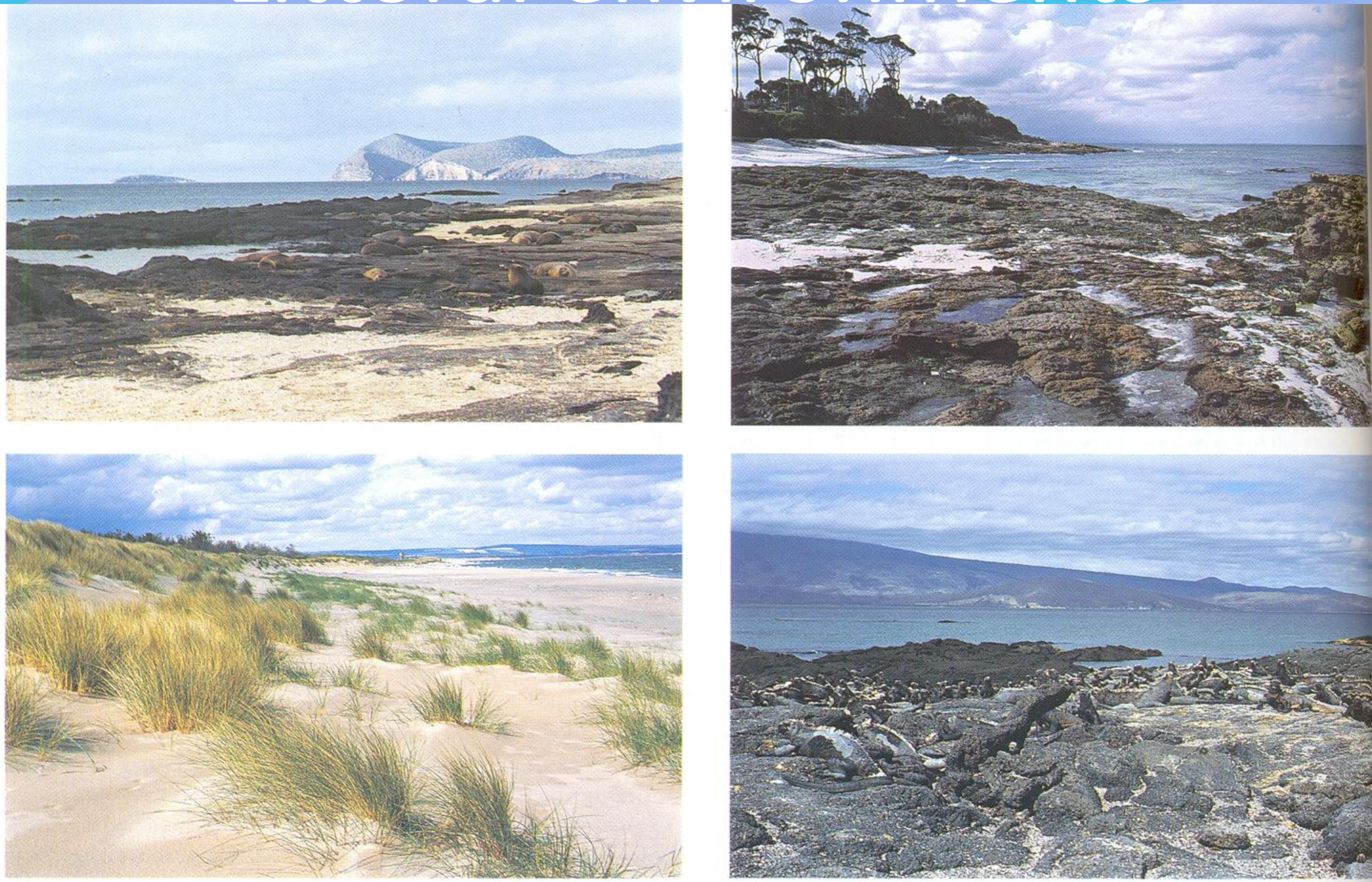


Plate 2 Littoral environments

(a) Sea cliffs, Lundy Island, UK. (Courtesy of A.S. Edwards.) (b) Vertical zonation on a moderately exposed temperate shore, Devon, UK. (Courtesy of P.G. Willmer.) (c) Mixed sandy/rocky shore with sea lions, southern Australia. (Courtesy of P.J. Sunnucks.) (d) Rock pools and rocky shore, Jervis Bay, southern Australia. (Courtesy of P.J. Sunnucks.) (e) Sand-dunes with marram grass, South Wales, UK. (Courtesy of P.G. Willmer.) (f) Volcanic lava shore, with basking iguanas, Fernadina, Galapagos. (Courtesy of N.P. Ashmole.)

Unusual aquatic environments

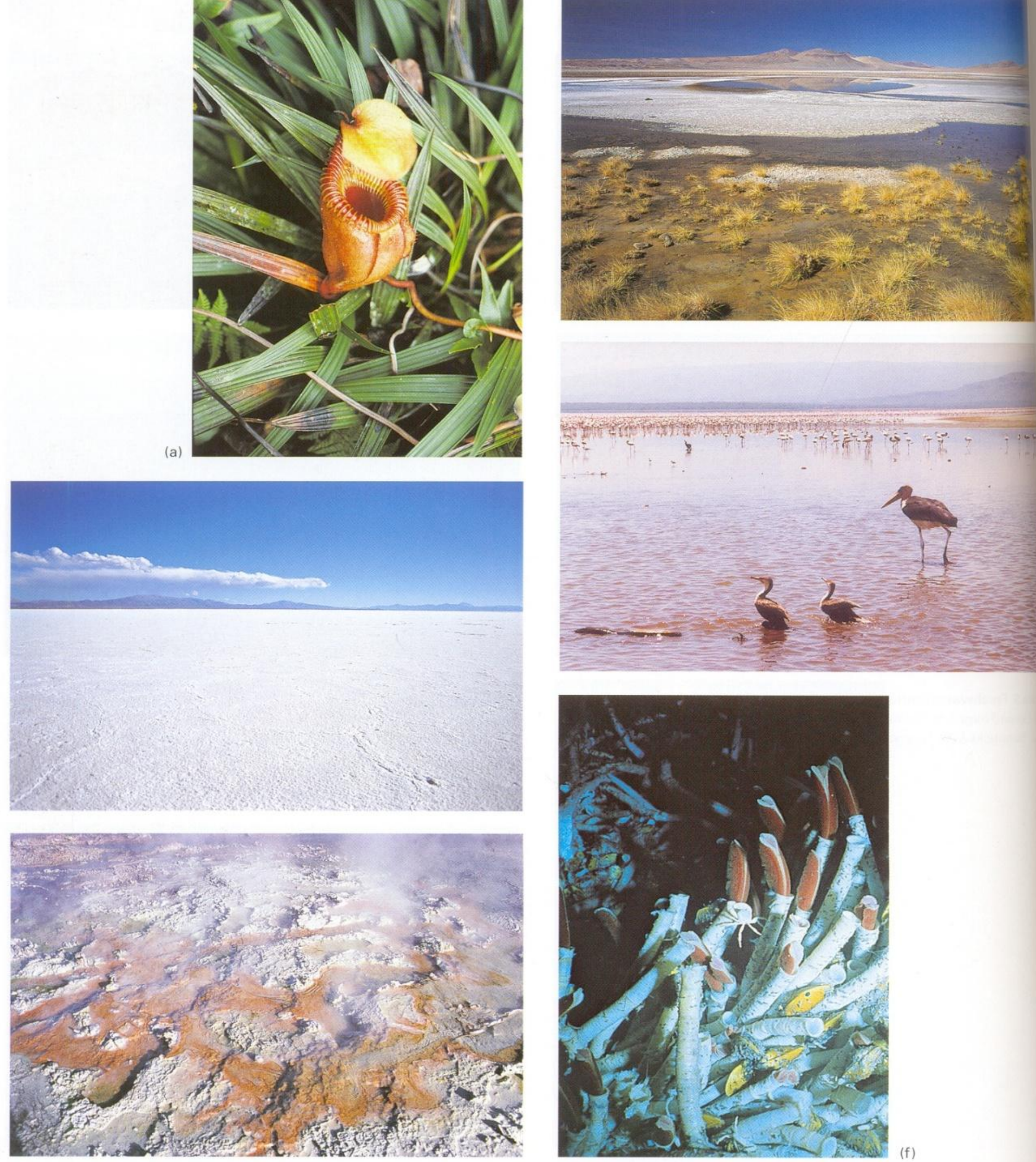
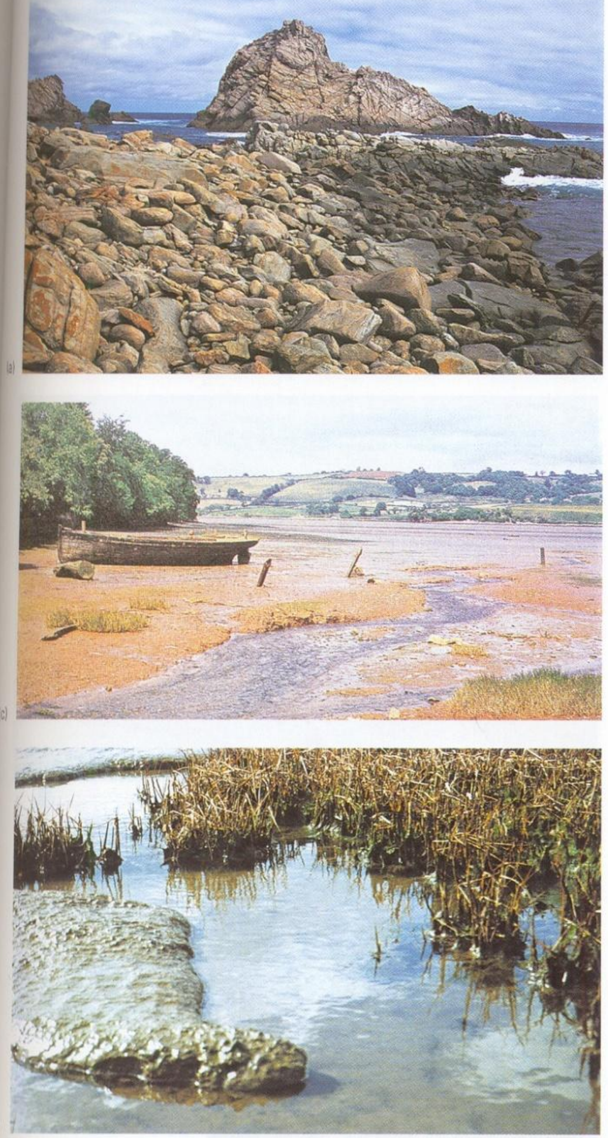


Plate 6 Unusual aquatic environments
(a) Pitcher plant, Mt Kinabalu, Borneo. (Courtesy of J.M. Lambert.) (b) Soda lake, hypersaline and sulphurous, northern Chile. (Courtesy of J.M. Lambert.) (c) Salt flat (resulting from completely dried out salt lake), northern Argentina. (Courtesy of J.M. Lambert.) (d) Rift Valley soda lake, Lake Magadi, Kenya, dominated by flamingos. (Courtesy of I.A. Johnston.) (e) Hot-water springs and small geysers feeding soda lake, with thermophilic algae, El Tatio, Chile. (Courtesy of J.M. Lambert.) (f) Deep-sea vent fauna. Giant, tubicolous, pogonophoran worms, *Riftia pachyptila*, found abundantly around deep-sea fumaroles. (Courtesy of R.R. Hessler.)

Estuarine environments



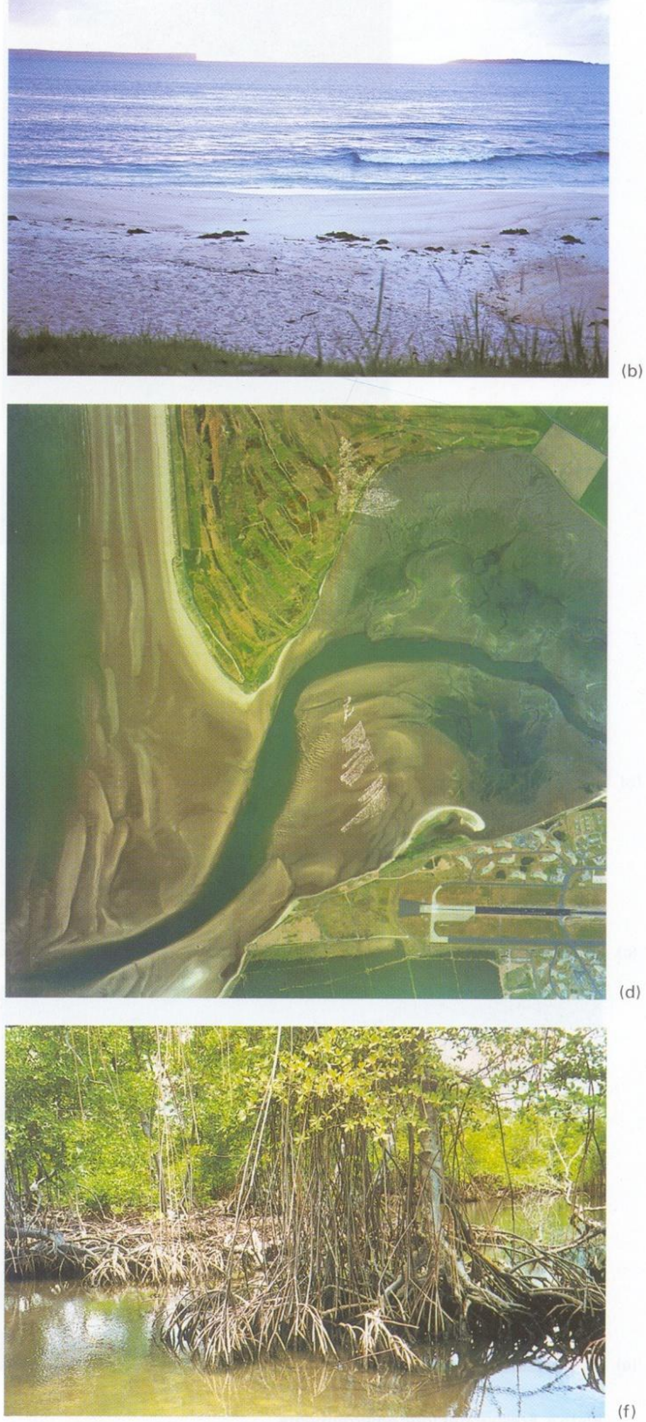


Plate 3 Littoral and estuarine environments
(a) Boulder beach, Cape Nat, Australia. (Courtesy of P.J. Sunnucks.)
(b) Muddy shore, Jervis Bay, Australia. (Courtesy of P.J. Sunnucks.)
(c) 'Ria' type estuary (drowned river valley), South Devon, UK. (Courtesy of P.G. Willmer.) (d) Aerial view, River Eden estuary, Scotland, UK, with sand spit at mouth and enclosed mudflats and salt marsh. (Courtesy of D.M. Paterson.) (e) Mudflats, intertidal creeks and salt-marsh formation, Skeffling, Humber estuary, UK. (Courtesy of D.M. Paterson.) (f) Mangrove swamp with emergent roots (pneumatophores), northeast Brazil. (Courtesy of I.A. Johnston.)

Marine environments

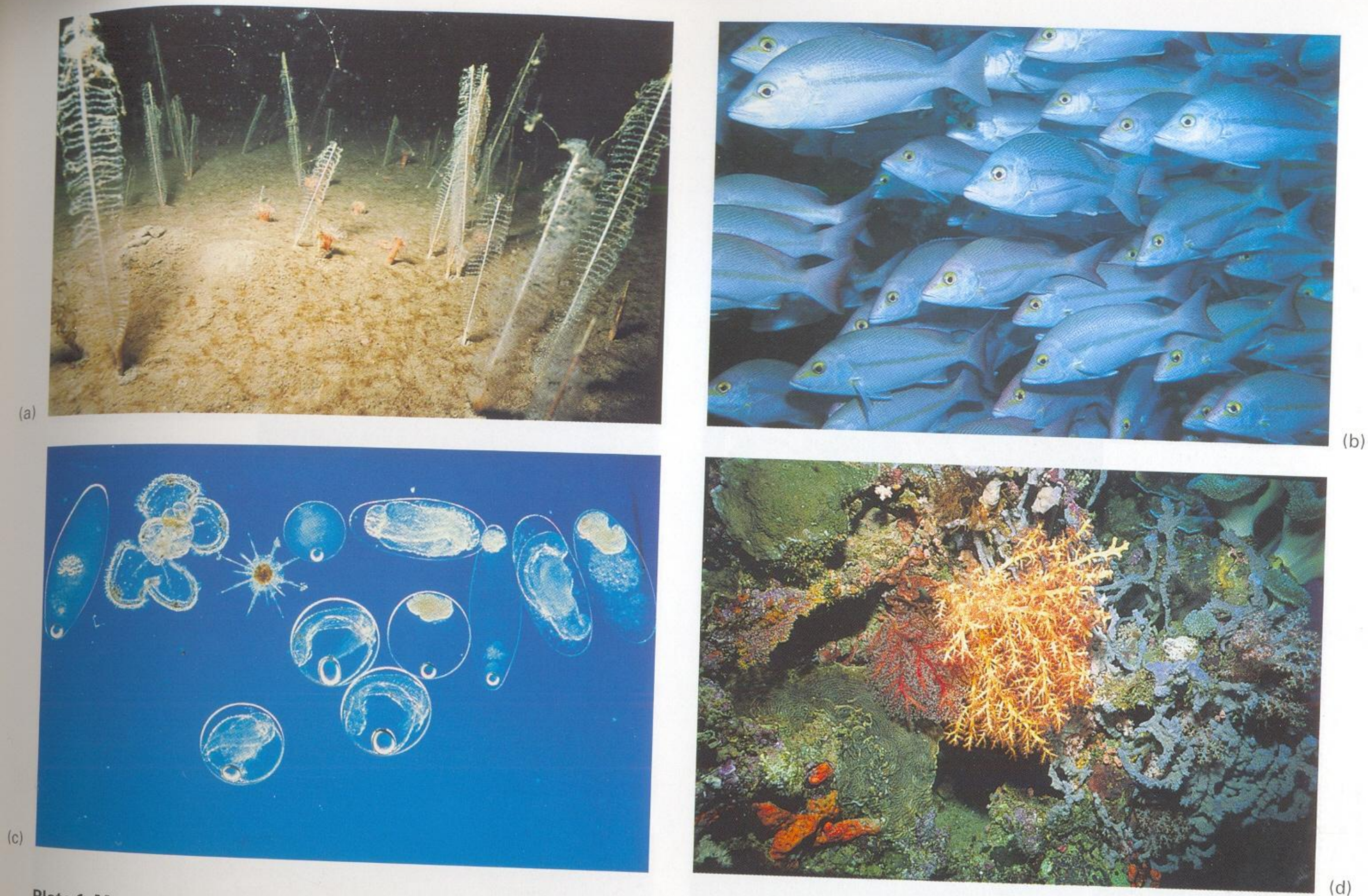


Plate 1 Marine environments
(a) Marine benthos. Shallow soft mud with sea pen *Virgularia mirabilis* and the anemone *Sagartiogeton laceratus*, Loch Laxford, Scotland, UK. (Courtesy of R. Holt/Joint Nature Conservation Council.) (b) Marine nekton. A shoal of fish (hussars *Lutjanus amabilis*), Heron Island, southern Great Barrier Reef. (Courtesy of L. Newman & A. Flowers.) (c) Marine plankton, including invertebrate larvae, fish eggs and phytoplankton. (Courtesy of P. Parks, Imagequest.) (d) Coral reef. Underwater scene with soft corals, off Madang, Papua New Guinea. (Courtesy of L. Newman & A. Flowers.)

Selection and Environment

- Interactions between all 3 components of an environment :
  - basic stress intensity,
  - the magnitude and time scale of fluctuations, &
  - the energy or resource availability;

  tend to determine the kinds and diversity of animals plus the type of selection that occurs.

- Traditionally 2 main types of selection are recognized, representing either end of a continuum:
  - ***r-selection*** = occurs in unpredictable environments
  - ***k-selection*** = occurs in more predictable environments

Selection and Environment

- ***‘r’*** => rate of population increase i.e. maximised in the former.
- ‘k’ => carrying capacity of the environment

- Many animals don’t fit into above 2 categories, rather have some combined features.
- Thus in a 3 way model, k- selection is the norm in predictably favourable habitats but is replaced by ***A-selection*** (adversity selection) in more extreme & predictably unfavourable environments.

What is Adaptation?

1. A term used for the **characters** or **traits** observed in animals that are a result of selection. E.g. Haemoglobin (Hb) to allow greater O2 carriage.
2. Correctly, defined as a **process**; the means by which natural selection adjusts the frequency of genes that code for traits affecting fitness. Adaptation, in this sense, is a process that normally occurs very slowly , over 100s or 1000s of generations, & its not usually reversible. E.g. Increasing Hb concentrations within a taxon => adaptation to hypoxic environments.
3. Also used to describe short term **compensatory changes** in response to environmental disturbance i.e. The outcome of **phenotypic plasticity**; so the terms **acclimatization** are technically more correct.

Physiological response on different scales

1. **Different time scales:**
   i. Short term changes: e.g. acclimation - rapid phenomenon of physiological or biochemical change resulting from exposure to new conditions, & is reversible.
   ii. Developmental effects
   iii. Longer term genotypic/evolutionary effects

2. **Different spatial levels:**
   i. At the outside surfaces (skin)
   ii. Between circulating fluid & ECF
   iii. Between ECF & cells
   iv. Within cells

Physiological response on different scales

3. **Different functional levels:** When an animal is confronted with changes in its environment. It normally shows following 3 categories of responses: -
   i. **Avoidance** – mechanism for getting away from an environmental problem either in space or in time.
   ii. **Conformity** – changes of internal state similar to the changes of state imposed externally. ∴ sometimes termed '**tolerators**', & such animals don't attempt to maintain a homeostatic condition for the whole body.
   iii. **Regulation** – maintenance of some or all components of the internal environment close to the original or 'normal' level, irrespective of external conditions.


Homeostasis

Physiological response on different scales

- Traditionally physiology has concerned itself with the mechanisms of regulation *vis-a-vis* **Homeostasis =>** maintenance of a constant internal environment.
- But *homeostasis* can often be achieved more cheaply by avoidance & behavioural tricks; & it may not need to be achieved at all, involving much less energy & resource expenditure
- However these categories aren't absolute & merge into each other. There are limits to both regulating & conforming, & there are no perfect cases. E.g. Osmoconforming animals tend to show some regulation at extremely low salinities while osmoregulators sometimes lose an ability to regulate at low salinities & become conformers.

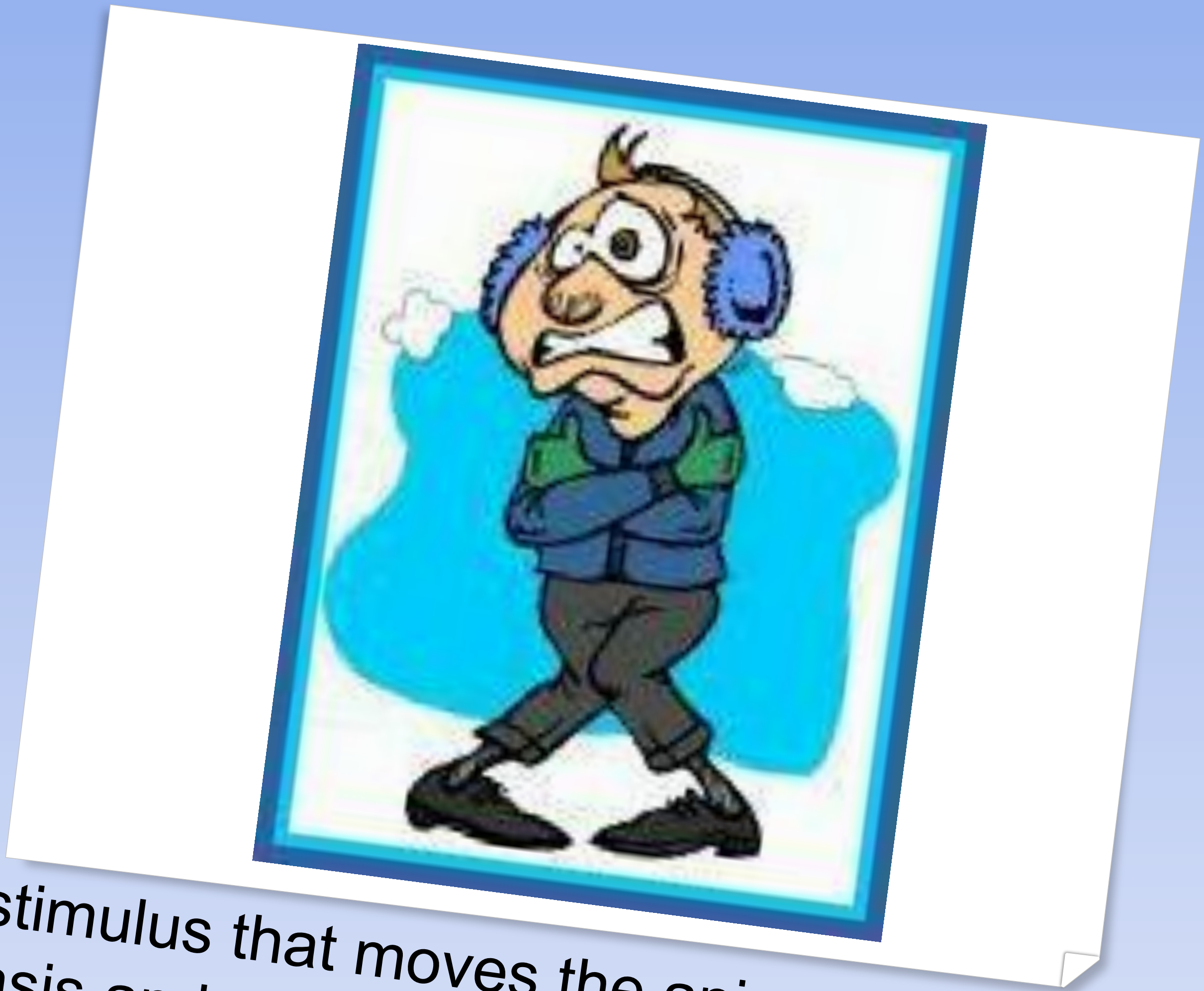
Environmental stress

Environmental components like temperature, noise, chemical pollutants etc. are capable of changing biological variables of an animal.

At normal condition, specific adjustments operate in animal's body against these environmental factors i.e. internal constancy or **Homeostasis** & when such constancy is vibrated, these are known as environmental stressors.

Stress elicits physiological changes in invertebrate species as well as in mammals, suggesting that stress response pathways are ancient, evolutionarily conserved coping mechanisms.

Macro environment = Physical + Chemical + Biotic components



Stress = any stimulus that moves the animal away from homeostasis and evokes general response facilitating a return to the steady state.

STRESS: INTEGRATION OF THREE OPEN SYSTEMS

- Each interacting system can be termed an "open system."
- At the highest-level Environmental/Social (I) stress includes such concepts as environmental and social conditions (heat, cold, chemicals, income, water, etc.), as well as work organization & psychosocial factors of the job. At this level (I) the stress is independent of the individual in which it influences. The human subjected to this level of stress senses the stress and stress at this level will create changes at the other two levels.

STRESS: INTEGRATION OF THREE OPEN SYSTEMS

- The next level is External Interactive (II) and refers to an individual interacting with their environment. At this intermediary level the human is required to not only sense the environment, but to directly attempt to change it. The change is either physical work or perhaps adding information (after processing information) as with exercise or mental tasks.

STRESS: INTEGRATION OF THREE OPEN SYSTEMS

- Finally, the last level is the Internal Organism (III)- perhaps the most complicated level as there are a tremendous number of feedback loops and a rich hierarchical structure of subsystems. The basic premise of the internal organism level of stress is that internal changes to the human are then, independent of the external stress, a stress in and of themselves. An obvious example is a constraint on mobility in humans with disease and impairment of an organ system. The diseased organ system constrains (stresses) other systems. Additionally, the resultant loss of mobility increases stress from level II (external interaction).

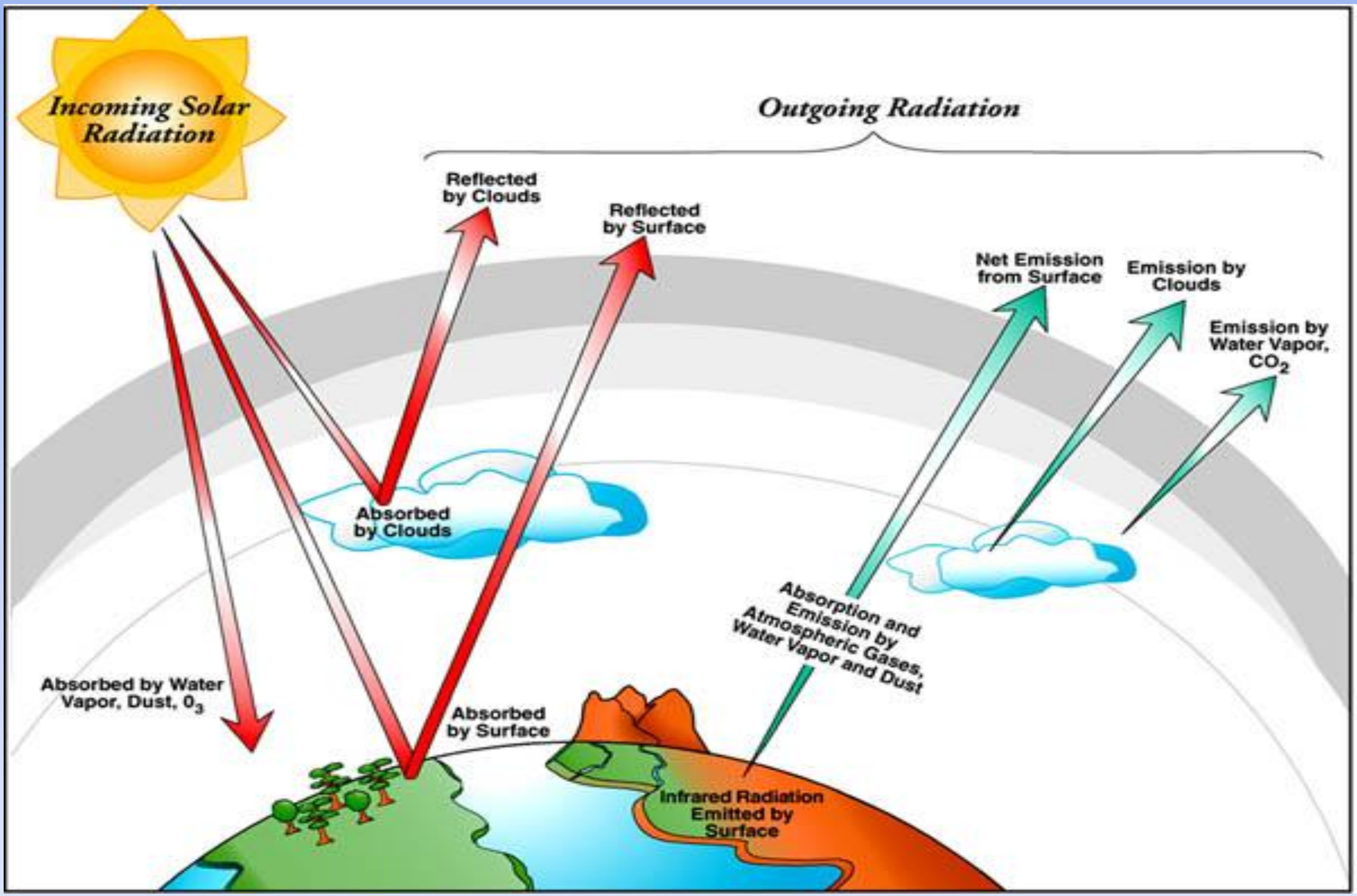
Types of Environmental stressors

a) **Physical stressors:**

i. Heat
ii. Cold
iii. Moisture
iv. Oxygen levels
iii. Noise
iv. Vibration

a) Physical stressors:

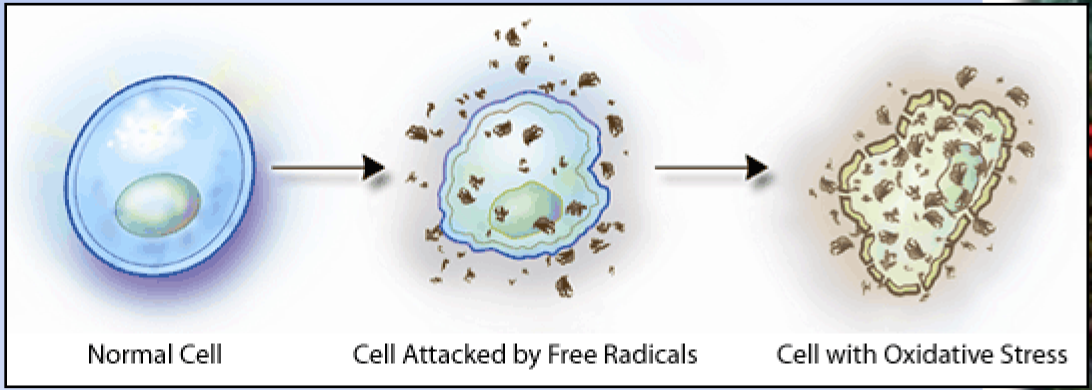
v. Radiation



Types of Environmental stressors

a) Physical stressors:

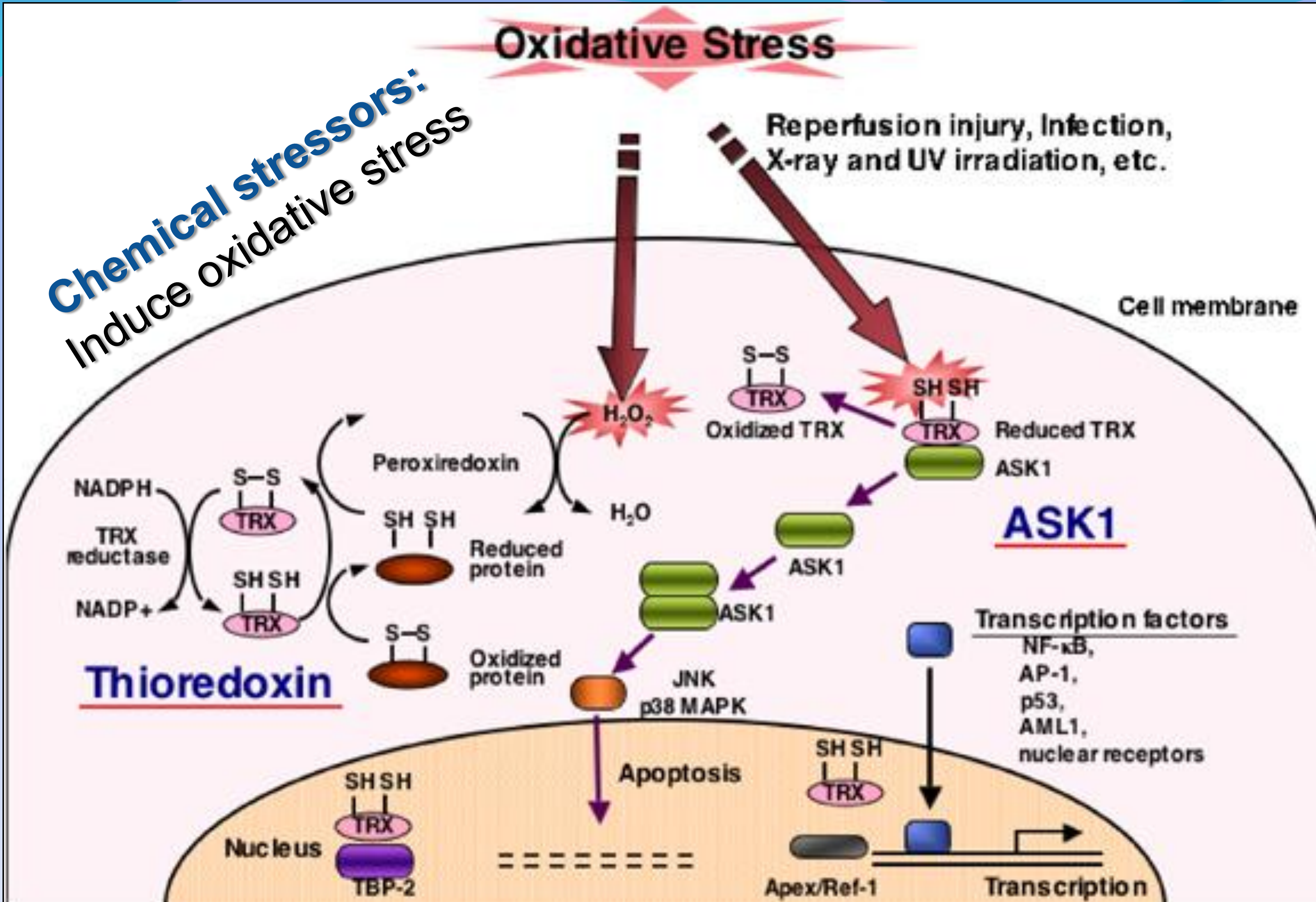
- Influence cellular homeostatic organisation
- Induce oxidative stress in different organs



Types of Environmental stressors

b) Chemical stressors:

i. **Drug injection**
ii. **Heavy metal pollution**


Chemical stressors:
Induce oxidative stress
Oxidative Stress
Reperfusion injury, Infection,
X-ray and UV irradiation, etc.
Cell membrane
S–S
TRX
Oxidized TRX
SH SH
TRX
Reduced TRX
ASK1
ASK1
ASK1
ASK1
H_2O_2
Peroxiredoxin
H_2O
NADPH
TRX reductase
NADP+
S–S
TRX
SH SH
TRX
SH SH
Reduced protein
S–S
Oxidized protein
Thioredoxin
JNK
p38 MAPK
Transcription factors
NF-κB,
AP-1,
p53,
AML1,
nuclear receptors
Apoptosis
SH SH
TRX
SH SH
TRX
Nucleus
TBP-2
Apex/Ref-1
Transcription

Basic Mechanism

Stress

activates → **Neural Pathways**

- Increased arousal
- Attention

inhibits → **Non-adaptive functions**

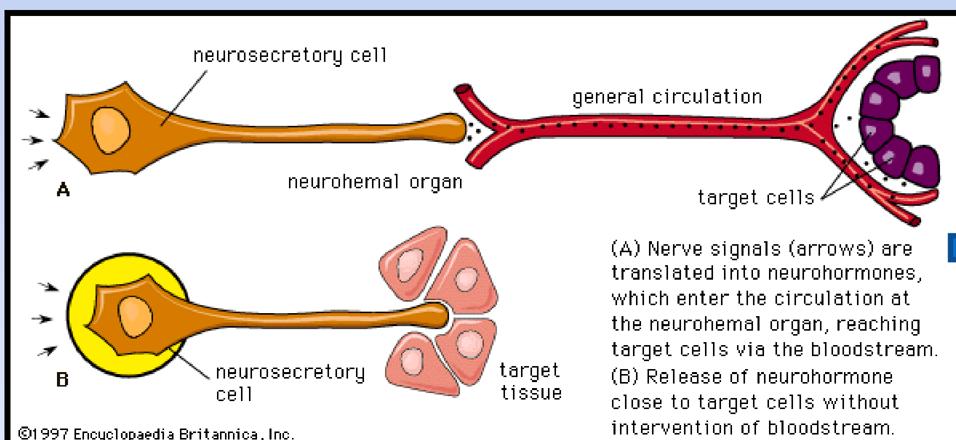
- Feeding
- Sexual behaviour
- Reproduction

Counteract ↑

Neural system + Endocrine system

(A.N.S.) – Vital role – (Adrenal gland)

Reactions start at cellular level →



(A) Nerve signals (arrows) are translated into neurohormones, which enter the circulation at the neurohemal organ, reaching target cells via the bloodstream. (B) Release of neurohormone close to target cells without intervention of bloodstream.

→ **Ultimate reflection in the system**

References

- **Environmental Physiology of Animals -** Pat Willmer, Graham Stone and Ian Johnston. Wiley-Blackwell Publishers
- **Stress Physiology** - D.P. Singh. New Age International Publishers
- **Animal Physiology** - Richard W. Hill, Gordon A. Wyse, Margaret Anderson. Sinauer Associates Inc. Publishers