REVIEW OF ARTIFICIAL SUBSTRATES
FOR
BENTHOS SAMPLE COLLECTION

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EXECUTIVE SUMMARY

Under the auspices of the Aquatic Effects Technology Evaluation (AETE) program, a critical review was undertaken on the use of artificial substrates for collection of benthic invertebrate samples, and on the utility and limitations of this method as a cost-effective environmental monitoring tool for the Canadian mining industry. The review included a survey of colonization dynamics as these affect performance of artificial substrates, an assessment of the strengths and weaknesses of artificial substrate sampling compared with conventional sampling techniques, and a detailed evaluation of four classes of artificial substrates that are potentially useful for environmental monitoring in the mining industry. The advantages and disadvantages of each device were compared using a consistent set of criteria including reliability of data, ease and practicality of use, and cost.

Artificial substrates do have a place in an efficient and cost-effective biomonitoring program for the Canadian mining industry. There is no advantage to be gained from using artificial substrates in shallow streams and rivers with cobble or gravel substrata, where conventional sampling techniques provide at least as reliable data without many of the drawbacks and difficulties of artificial substrates. Rather, artificial substrates should be reserved for those locations where conventional sampling is inefficient or unfeasible, including (1) water bodies with very deep or turbid water, (2) water bodies with soft or unstable bottoms of sand, mud or organic ooze, (3) water bodies with unbroken bedrock bottoms or bottoms of large boulders and (4) rivers with torrential currents. Use of artificial substrates is not justified in shallow, rocky-bottomed streams or rivers where the variation in habitat type within the study reach is relatively minor and an abundant and diverse indigenous fauna may be expected. An exception could be made to this rule if the study area includes both hard-bottomed and soft-bottomed habitats and consistency in the sampling method were desired.

Besides permitting sampling of habitats that would be otherwise difficult to sample effectively, artificial substrates allow greater flexibility in selection of sampling sites than conventional sampling, and allow comparison of environmental effects of effluents along a watercourse where the macrohabitat is not constant, such as erosional zones upstream and depositional zones downstream. Artificial substrates provide samples with much greater numbers and

diversity of organisms than conventional samples, especially in lentic or depositional habitats, but reduce variability in organism densities among samples, and thereby increase the sensitivity of the monitoring program because smaller site differences can be detected.

The key to successful application of artificial substrates is to have a clear and precise objective beforehand, and to understand exactly what the artificial substrates are capable of measuring. The invertebrate community on an artificial substrate is an indicator of water quality during only the period of exposure. These samplers do not (1) measure the composition of the native bottom fauna, (2) indicate habitat conditions other than water quality, (3) estimate availability of food organisms, or (4) integrate long-term effects of pollution. The samplers function essentially as an on-site, multi-species toxicity test that uses the colonization success of drifting and migrating organisms as the endpoint. Careful comparison of community composition of artificial substrate samples from above and below a point source such as mine effluent can provide information on the nature, degree and extent of potential environmental effects from the effluent, one of the objectives of a biomonitoring program.

Artificial substrates do not collect a representative sample of the indigenous benthos at the site where they are placed, but rather select for mobile, drift-prone species of hard substrata. Therefore they indicate the potential effect of an effluent or disturbance, not the real effect. Moreover, they do not effectively monitor the effects of sediments or sediment-bound toxicants on aquatic biota because sediment-dwelling taxa tend to be under-represented in artificial substrate samples. This is a potentially significant difficulty in using artificial substrates to monitor mining effects because metals tend to partition onto fine sediments, which are not effectively sampled by artificial substrates.

Other limitations of artificial substrates are:

> They may overestimate the real severity of an effluent or disturbance because vagile organisms colonizing the samplers are apt to re-enter the drift, lowering the species diversity and possibly interrupting the expected successional sequence;
>
> They require a long period for colonization, and colonization dynamics, and hence optimum exposure times, are incompletely known;

They require two trips for each sample, effectively doubling the cost of field sampling compared with conventional sampling;

They are prone to loss from accidents, high flows and vandalism, which creates irreparable gaps in the data and adds to the cost of field work;

They may be bulky, heavy and difficult to handle and transport, and field deployment is often logistically complicated; and

They may lose organisms while the sampler is being retrieved, especially in deep waters were it is not feasible to use a collecting net.

Four kinds of artificial substrate sampler are potentially useful for environmental monitoring in the Canadian mining industry: multiplate samplers, Beak trays, rock-filled baskets and rock-filled trays. Rock-filled baskets are recommended as the sampler of choice for most applications in mine effluent monitoring because (1) they closely mimic natural substrata yet (2) permit standardization of sampler area, (3) provide abundant microhabitat for colonization, (4) produce low replicate variability, (5) are reasonably stable in currents and (6) are easy and cheap to build. Beak trays are recommended for the particular application of sampling large, fast-flowing rivers with unstable substrata, where other sampling techniques would be ineffective, dangerous, or prone to failure. Though they collect less representative samples than rock-filled baskets, multiplate samplers have the advantages of small size and ease of use, and may be useful for sampling large, soft-bottomed rivers, where bottom sampling is difficult or impossible. Rock-filled trays hold considerable promise but should be considered experimental for now.

Artificial substrates are best used as one component of a multi-part program, in which measurements of indigenous fauna, water or sediment quality, and possibly laboratory toxicity tests, are combined to provide a clear picture of the state of the system and the effects of mine effluents. Sampling efficiency would be greatly improved by using smaller samplers and increasing the number of replicates. We recommend using the smallest feasible sampler, which for rock-filled baskets is 2500 cm^3, and increasing the number of replicates to at least six, with an additional allowance for lost samplers. An exposure period of six weeks is recommended as optimal for artificial substrates used for biomonitoring. The low flow period from late summer to early fall is usually the best time for benthic invertebrate sampling with any artificial substrate. Where site conditions permit, the sampler should be placed on the bottom of the water body to take advantage of all possible sources of colonization. Samplers suspended in the water column can still be effective, but are more difficult to deploy.

Fine-mesh nets or other means should be used to minimize losses of invertebrates while the sampler is being removed. A number of environmental variables (pH, dissolved oxygen, conductivity, temperature, current velocity, depth) should be measured when the samplers are placed and again when they are retrieved. Measuring the amount of periphyton growth or detritus accumulation in the samplers can aid data interpretation and is strongly recommended.

Limited data suggest artificial substrates are promising tools for assessment of environmental impacts of mining on lakes, but there are too few data for a detailed assessment. This information deficiency should be remedied by undertaking a simple study comparing benthic invertebrate populations with populations colonizing artificial substrates in a lake or lakes with different substratum characteristics. The study should include a comparison of invertebrate populations in a lake or part of a lake receiving mine effluent.

RÉSUMÉ À L'INTENTION DE LA DIRECTION

Sous les auspices du programme d'évaluation des techniques de mesure d'impact en milieu aquatique, on a entrepris un examen critique portant sur l'utilisation de substrats artificiels pour la collecte d'échantillons d'invertébrés benthiques et sur l'utilité et les limites de cette méthode en tant qu'outil économique de surveillance environnementale pour l'industrie minière canadienne. Cet examen comportait une étude de la dynamique de la colonisation, qui influe sur la performance des substrats artificiels, une évaluation des points forts et des faiblesses de l'échantillonnage effectué avec des substrats artificiels, comparativement aux techniques d'échantillonnage traditionnelles, et une évaluation détaillées de quatre classes de substrats artificiels qui pourraient se révéler utiles pour la surveillance environnementale dans l'industrie minière. Les avantages et les inconvénients de chaque dispositif ont été comparés au moyen d'une série cohérente de critères, notamment la fiabilité des données, la facilité et la commodité d'utilisation et le coût.

Les substrats artificiels ont effectivement une place au sein d'un programme économique de biosurveillance pour l'industrie minière canadienne. Cependant, il n'y a aucun avantage à utiliser des substrats artificiels dans les cours d'eau peu profonds ou dans les cours d'eau dont le fond est en galets ou en gravier, car dans ce cas, les techniques d'échantillonnage traditionnelles produisent des données au moins aussi fiables sans occasionner un grand nombre des inconvénients et des difficultés liés aux substrats artificiels. Les substrats artificiels devraient donc plutôt être réservés pour les endroits où l'échantillonnage traditionnel est inefficace ou impraticable, notamment 1) dans les cours d'eau très profonds ou turbides, 2) dans les cours d'eau au fond mou ou instable en sable, en boue ou en vase organique, 3) dans les cours d'eau dont le fond est constitué de l'assise rocheuse non brisée ou de gros blocs erratiques et 4) dans les cours d'eau soumis à des courants torrentiels. Par ailleurs, l'emploi des substrats artificiels n'est pas justifié dans les cours d'eau peu profonds à fond rocheux où la variation du type d'habitat est relativement mineure compte tenu du terrain étudié et où on peut s'attendre à trouver une faune abondante et diversifiée. On peut faire exception à cette règle si la zone étudiée comporte à la fois des habitats à fond dur et des habitats à fond mou et si on souhaite que la méthode d'échantillonnage soit uniforme.

En plus de rendre possible l'échantillonnage des habitats qui seraient autrement difficiles à échantillonner efficacement, les substrats artificiels permettent une sélection plus flexible des points d'échantillonnage que l'échantillonnage traditionnel et ils permettent de comparer les effets environnementaux des effluents le long de cours d'eau où le macrohabitat n'est pas constant, comme les zones sujettes à l'érosion en amont et les zones recevant les dépôts en aval. Les substrats artificiels fournissent des échantillons comportant des organismes plus nombreux et plus divers que les échantillons traditionnels, particulièrement dans les habitats lénitiques ou recevant des dépôts, mais ils réduisent la variabilité de la densité des organismes d'un échantillon à l'autre ce qui améliore la sensibilité du programme d'échantillonnage car on peut alors déceler des différences plus faibles d'un endroit à l'autre.

Pour utiliser avec succès les substrats artificiels, il faut avoir auparavant un objectif clair et précis et comprendre exactement ce que les substrats artificiels sont capables de mesurer. La communauté des invertébrés recueillis sur un substrat artificiel est un indicateur de la qualité de l'eau uniquement pendant la période d'exposition. Ces échantillonneurs ne permettent pas 1) de mesurer la composition de la faune benthique indigène, 2) d'indiquer l'état de l'habitat mis à part la qualité de l'eau, 3) d'estimer la disponibilité des organismes qui servent de nourriture ou 4) d'intégrer les effets à long terme de la pollution. Les échantillonneurs fonctionnent essentiellement comme un essai de toxicité visant plusieurs espèces, effectué sur place et qui utilise comme point final le succès de la colonisation des organismes qui dérivent et qui migrent. Une comparaison soigneuse de la composition de la communauté dans les échantillons prélevés avec des substrats artificiels, au-dessus et au-dessous d'une source ponctuelle comme un effluent minier, peut renseigner sur la nature, la gravité et l'étendue des effets potentiels sur l'environnement, ce qui constitue un des objectifs des programmes de biosurveillance.

Les substrats artificiels ne permettent pas de recueillir un échantillon représentatif du benthos indigène à l'endroit où ils sont placés, mais plutôt de choisir des espèces mobiles, susceptibles de dériver à partir de sous-couches dures. Ils indiquent donc l'effet potentiel d'un effluent ou d'une perturbation et non pas leur effet réel. De plus, ils ne permettent pas de surveiller efficacement les effets sur le biote aquatique des sédiments ou des produits toxiques fixés à des sédiments parce que les taxons qui habitent les sédiments ont tendance à être sous-représentés dans les échantillons de substrats artificiels. Il s'agit là d'un inconvénient potentiellement important de l'utilisation des substrats artificiels pour surveiller les effets de l'exploitation minière parce que les métaux ont tendance à se séparer sur des sédiments fins qui ne sont pas efficacement prélevés à l'aide des substrats artificiels.

Les autres limites des substrats artificiels sont les suivantes :

> Ils peuvent conduire à une surestimation de la gravité réelle d'un effluent ou d'une perturbation parce que les organismes vagiles qui colonisent les échantillonneurs peuvent se mettre de nouveau à dériver, ce qui réduit la diversité des espèces et risque d'interrompre la séquence prévue ;
>
> Ils nécessitent une longue période de colonisation et la dynamique de la colonisation, et donc les temps d'exposition optimaux, ne sont pas complètement connus ;
>
> Ils exigent deux voyages pour chacun des échantillons, ce qui double en fait le coût de l'échantillonnage sur le terrain comparativement à l'échantillonnage classique ;
>
> Ils sont sujets à des pertes causées par des accidents, des crues et du vandalisme, ce qui crée des lacunes irréparables dans les données et se rajoute au coût des travaux sur le terrain ;
>
> Ils peuvent être encombrants, lourds et difficiles à manutentionner et à transporter ; la logistique du déploiement sur le terrain est souvent compliquée ;
>
> Des organismes peuvent être perdus au moment de la récupération de l'échantillonneur, particulièrement en eau profonde où il n'est pas possible d'utiliser un filet.

Quatre types d'échantillonneurs à substrat artificiel peuvent être utiles pour la surveillance environnementale de l'industrie minière canadienne : les échantillonneurs à plaques multiples, les plateaux Beak, les paniers garnis de roches et les plateaux garnis de roches. Les paniers garnis de roches sont particulièrement recommandés pour la plupart des applications liées à la surveillance des effluents miniers pour les raisons suivantes : 1) ils reproduisent de très près le comportement des sous-couches naturelles, mais 2) ils permettent de normaliser la surface parcourue par l'échantillonneur, 3) ils fournissent un microhabitat abondant pour la colonisation, 4) ils produisent une faible variabilité entre des échantillons identiques, 5) ils sont raisonnablement stables dans les courants et 6) ils sont faciles et peu coûteux à construire. Les plateaux Beak sont recommandés dans le cas particulier de l'échantillonnage de gros cours d'eau rapides avec des sous-couches instables, pour lesquels les autres techniques d'échantillonnage seraient inefficaces, dangereuses ou risqueraient d'échouer. Bien qu'ils permettent de recueillir des échantillons moins représentatifs que les paniers garnis de roches, les échantillonneurs à plateaux multiples ont l'avantage d'être petits et faciles à utiliser et ils peuvent se révéler utiles pour échantillonner de gros cours d'eau à fond mou lorsque l'échantillonnage du fond est difficile ou impossible. Les plateaux garnis de roches sont très prometteurs, mais ils devraient être considérés comme étant au stade expérimental pour le moment.

La meilleure façon d'utiliser les substrats artificiels consiste à en faire un élément d'un programme en plusieurs parties comportant des mesures de la faune indigène, de la qualité de l'eau ou des sédiments et peut-être des essais de toxicité en laboratoire, ces parties étant combinées pour tracer un tableau clair de l'état du système et de l'effet des effluents miniers. L'efficacité de l'échantillonnage serait améliorée de beaucoup si on utilisait des échantillonneurs plus petits et si on augmentait le nombre d'échantillons identiques. Nous recommandons l'utilisation du plus petit échantillonneur possible, dont la capacité dans le cas des paniers garnis de roches est de 2500 cm^3, et d'augmenter le nombre de portions identiques à six, en prévoyant un nombre plus élevé au cas où des échantillonneurs seraient perdus. On recommande une période d'exposition de six semaines, considérée optimale pour les substrats artificiels servant à la biosurveillance. La période d'étiage qui va de la fin de l'été jusqu'au début de l'automne est habituellement le meilleur moment pour effectuer l'échantillonnage des invertébrés benthiques, quel que soit le substrat artificiel. Lorsque les conditions le permettent, l'échantillonneur devrait être placé sur le fond du plan d'eau pour qu'on puisse profiter de toutes les sources de colonisation. Les échantillonneurs suspendus dans la colonne d'eau peuvent encore être efficaces, mais ils sont plus difficiles à déployer.

Les filets à maille fine ou d'autres moyens devraient être utilisés pour réduire au minimum les pertes d'invertébrés pendant le retrait de l'échantillonneur. Un certain nombre de variables environnementales (pH, oxygène dissous, conductivité, température, vitesse du courant, profondeur) devraient être mesurées lorsque les échantillonneurs sont mis en place et de nouveau, lorsqu'ils sont récupérés. La mesure de la croissance du périphyton ou de l'accumulation des détritus dans les échantillonneurs peut faciliter l'interprétation des données et elle est fortement recommandée.

Les données limitées dont on dispose donnent à penser que les substrats artificiels sont des outils prometteurs pour évaluer l'impact environnemental de l'exploitation minière sur les lacs, mais il existe trop peu de données pour permettre d'effectuer une évaluation détaillée. Ce manque d'information devrait être comblé grâce à une étude simple consistant à comparer les populations d'invertébrés benthiques à des populations colonisant des substrats artificiels dans un lac ou dans des lacs dont les sous-couches possèdent des caractéristiques différentes. Cette étude devrait comporter une comparaison des populations d'invertébrés dans un lac ou dans une partie d'un lac recevant un effluent minier.

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1.0 INTRODUCTION

Effluents from metals mines in Canada are regulated by the Metal Mining Liquid Effluent Regulations. Currently, these Regulations are being reviewed to assess whether they provide adequate mitigation of mine effluent effects on receiving water ecosystems. In parallel with this review, the Aquatic Effects Technology Evaluation (AETE) program was established to review appropriate technologies for assessing the effects of mine effluents on aquatic ecosystems. AETE is a co-operative program among the Canadian mining industry, several federal government departments, and eight provincial governments. The program is co-ordinated by CANMET, the Canadian Centre for Mineral and Energy Technology. The program has two stated objectives: to help the Canadian mining industry meets its obligations for environmental effects monitoring in the most cost-efficient manner; and to evaluate new and established monitoring technologies that could be used for assessment of environmental effects of mining.

As one component of the AETE program, a field evaluation of selected biomonitoring methods is planned for three mine sites in 1996 and three others in 1997. A preliminary field program, to be carried out at one mine only, is planned for 1995 to perfect the study design. Community structure of benthic invertebrates, the insects, worms, molluscs and other organisms living on the bottoms of rivers and lakes, will be included in the pilot field study as an indicator of environmental quality and mine effluent effects.

Artificial substrates are one of several approaches available for collecting samples of benthic invertebrates from a wide variety of environments. CANMET has undertaken to determine whether artificial substrates should be included in the preliminary field program by initiating a review of the literature. The formal objective of the review is to critically examine the use of artificial substrates for collecting benthos samples, and to make recommendations on the utility and limitations of this method as a cost-effective monitoring tool for the Canadian mining industry. Golder Associates Ltd. was retained to the review on behalf of CANMET.

The literature review had several specific objectives. First, we set out to summarize the literature on the use of artificial substrates for benthic invertebrate sampling, and to evaluate the usefulness of this sampling method for environmental monitoring. This part of the work essentially involved a comparison of artificial substrates against direct sampling methods with nets, grabs, and dredges. To be useful, the literature review had to be directed squarely at benthos sampling for biomonitoring, as opposed to sampling for research in aquatic ecology. While not originally an objective, a brief review of colonization dynamics is included in the report because colonization by benthic invertebrates is central to the functioning of artificial substrates. We then undertook a detailed evaluation of four classes of artificial substrates that are potentially useful for environmental monitoring in the Canadian mining industry. The strengths and weaknesses of each device were compared using a consistent set of criteria including reliability of data, ease and practicality of use, and cost. The final objective was to make defensible conclusions on the utility of artificial substrates for mine effluent monitoring and to recommend the best device(s).

A comprehensive review of artificial substrates, including a detailed examination of the strengths and weaknesses of the approach and a brief comparison of different samplers was published by Rosenberg and Resh (1982). They covered the published literature up to 1980. Given the thoroughness of that review, we relied on Rosenberg's and Resh's work to provide a summary of the earlier literature, and have concentrated instead on work published since 1980. However, many of Rosenberg's and Resh's conclusions were re-evaluated in light of the narrower objective of evaluating artificial substrates specifically for biomonitoring.

"Substrate" as a term replacing substratum is a misnomer that we are loathe to perpetuate. However, the terms *artificial substrate* and *artificial substrate sampler* are established in the literature and will be used in this report for consistency. In ordinary use the *substratum* is the bottom layer of a river, lake or other water body. A good general definition of artificial substrates is provided by Klemm et al. (1990): "Artificial substrate samplers are devices made of natural or artificial materials of various composition and configuration that are placed in water for a predetermined period of exposure and depth for the colonization of indigenous macroinvertebrate communities. They are used to obtain qualitative and quantitative samples of macroinvertebrates in rivers, streams, lakes and reservoirs." Following a convention established by Rosenberg and Resh (1982) artificial substrates are divided into two major categories: *representative* artificial substrates that closely resemble the natural substratum of streams and lakes (e.g., rock-filled baskets), and *standardized* artificial substrates that differ from natural substrata but provide a uniform surface area for colonization (e.g., multiplate samplers). *Conventional* sampling is used in this report to mean sampling of the indigenous benthic invertebrates using grabs, dredges, or other devices such as the Surber sampler.

2.0 GENERAL REVIEW

The use of artificial substrates as a means of sampling benthic invertebrate populations arose from the realization that many aquatic habitats are not amenable to quantitative sampling with grabs, dredges, nets and similar sampling devices (Rosenberg and Resh 1982). Artificial substrates have also been promoted as a means of reducing the variability in macroinvertebrate density estimates, by providing a uniform habitat for colonization (Weber 1973, Hellawell 1978). Sampling problems and variability are key issues in the use of benthic invertebrate to assess the effects of pollution or other disturbances on aquatic ecosystems; consequently artificial substrates are particularly attractive for environmental quality monitoring.

The various kinds of artificial substrates (rock baskets, multiplates, trays) are described in Section 2.2. The general approach to sampling with artificial substrates is the same for all types of samplers. Samplers containing gravel or cobbles, or constructed to simulate such material, are placed in the water body to be sampled and colonization by periphyton and benthic invertebrates is allowed to proceed naturally. After a set time, usually several weeks, the samplers are retrieved and the invertebrates on or in them are removed, counted and identified. Effects of effluents or other point-source disturbances are evaluated by comparing community composition on samplers above and below the effluent outfall.

Most routine methods for environmental monitoring with benthic invertebrates have evolved from approaches designed for assessment of organic pollution in fast-flowing, shallow streams and rivers. They therefore assume the presence of a diverse, numerically abundant fauna dominated by sensitive insect groups (Ephemeroptera, Plecoptera, Trichoptera), the typical fauna of cobble-bottomed riffles in unpolluted watercourses. Inevitably, however, many industrial effluents in Canada are discharged into lentic environments such as lakes, large, deep rivers or slow-moving streams, where the natural fauna may be both species-poor and of very different taxonomic composition from those in fast-flowing waters. The difference is all the greater if the benthic strata of the sampled water body is composed of soft, fine particles typical of depositional zones (sand, mud, organic ooze) as opposed to rocks or cobbles.

Artificial substrates circumvent the problem of unsuitable benthic habitats by creating uniform islands of hard-bottom habitat that can be placed wherever they are needed. The underlying assumption of this approach is that the community composition of organisms that colonize the artificial substrates can be used to assess effects of effluents or anthropogenic activity in the same way as benthic grab samples (Weber 1973, Hellawell 1978). But because the artificial substrates provide habitat for more varied and sensitive organisms, environmental degradation can be more readily detected and established analytical methods for lotic habitats can be applied.

Counter arguments can be raised against each of these putative benefits, and the advantages and drawbacks of artificial substrate sampling have been the subject of lively debate in the scientific literature. Much of the debate, however, has centred on the utility of artificial substrates for studies of colonization, community structure, habitat preferences and other issues in invertebrate ecology and population dynamics (see Sheldon 1984 and Mackay 1992 for reviews). Conclusions reached in the context of ecological research must be extrapolated with caution to environmental monitoring, where the objectives are quite different. Notwithstanding, because the utility of artificial substrates sampling depends on colonization of vacant samplers by benthic invertebrates, factors affecting invertebrate colonization of new habitats are relevant to the discussion. Therefore, the present state of knowledge concerning colonization by benthic invertebrates is briefly reviewed next, as a preamble to the analysis of artificial substrates sampling.

2.1 Colonization Dynamics

There are two questions with respect to colonization that are fundamental to the validity of the artificial substrate approach:

1. How long must the substrate sampler be left in place for complete colonization?
2. How closely will the benthic invertebrate community on the artificial substrate resemble that in the surrounding natural substratum?

An understanding of the dynamics of colonization by aquatic organisms is thus important to evaluation of sampling with artificial substrates.

Colonization of bare or denuded substrata by benthic invertebrates has been studied in two quite different contexts. The more common situation concerns artificial substrates placed in or on the bottom of an erosional stream reach which already supports a diverse population of benthic invertebrates. Rather less research has been done on colonization of samplers in new channels that do not yet support benthic fauna. Colonization of this kind occurs when stream channels are re-routed or temporarily dewatered, or when braided or unstable rivers change their course. From a practical perspective, the latter case is a better analogue of the placement of artificial substrates in deep or soft-bottomed watercourses, where colonizing organism would only arrive from upstream.

When a bare patch of substratum is placed on the bottom of a river, colonizing organisms can arrive by any of four routes: drifting in the water column from upstream; crawling or swimming from the substratum adjacent to the bare patch; flying in from any direction and resuming an aquatic existence; or hatching from eggs laid on the bare substratum (Mackay 1992). In flowing waters, downstream drift is generally regarded as the dominant mechanism of colonization, especially in the early stages (Waters 1964, Townsend and Hildrew 1976, Williams and Hynes 1976, Minshall and Petersen 1985, Benson and Pearson 1987). Williams and Hynes (1976) studied colonization in a southern Ontario stream (Nith River) using a quartet of cleverly designed artificial substrates that each permitted colonization from one direction only. Of the total number of organisms in the samplers after 28 days, the majority (41%) arrived in the drift. The aerial route, including oviposition by dispersing adults, accounted for 28% of the total number, while upstream movements and migration from the deep substrate (the hyporheos) accounted for the remainder (18% and 19%). This work is widely cited as illustrating the dominance of drift in colonization, but Williams and Hynes (1976) point out that different species arrived by different routes, and results would differ in another stream or time of the year. Similar work by Townsend and Hildrew (1976) found 82% of colonizing animals arrived in the drift.

In addition to passive drift, which carries organisms only in one direction, many organisms may disperse over short distances by actively swimming or crawling over the substratum. Mayflies of the families Baetidae and Leptophlebiidae, among others, are strong swimmers, as are leeches and amphipods such as *Gammarus* (Mackay 1992). Colonization by crawling along the bottom may also be important, especially where the artificial substrate is being colonized from the immediately surrounding substratum. This movement has been likened to molecular diffusion, in which benthic animals are continually redistributed about the substratum by random movements (Townsend and Hildrew 1976). Giller and Cambell (1989) found that six of eight mayfly species colonizing substrate trays planted in a stream bottom arrived by crawling. Organisms that feed on detritus or benthic algae (periphyton) tend to move actively as they search for patchily distributed food; on a small scale this activity leads to rapid movement onto newly bare patches (Mackay 1992). Crawling may be the only colonization mechanism available, aside from aerial dispersion by winged adults, for heavier species such as snails and cased caddisflies that cannot swim and do not ordinarily enter the drift.

Oviposition or aerial migration by winged adults is the last mechanism of colonization. Certain species of beetles and bugs can fly at some point in their life cycles, and will disperse that way to new areas of aquatic habitat (Williams 1981). Oviposition is highly seasonal, however, and for most Canadian watercourses it would be much more important in some seasons than in others. Aerial colonization differs from the other mechanisms in that it is both unrestricted in direction and much less limited in distance than drift, swimming or crawling. Hence, flying adults may be an important source of colonizers for artificial substrates placed in denuded reaches or otherwise inhospitable areas where colonization from the immediate surrounds is not possible Layton and Voshell 1991). This mode of colonization is not available, however, to non-insect species (leeches, molluscs, oligochaetes, crustaceans) whose life cycles are entirely aquatic.

Patterns of colonization on newly placed artificial substrates tend to be immensely variable, but a few common trends may be discerned. The development of an invertebrate community on an artificial substrate is linked to both the mobility of different species and the accumulation of food sources, i.e., periphyton and organic detritus, on the sampler. Generally, colonization by drifting organisms is fast; bare substrata usually house invertebrates within 24 h after placement (Waters 1964, Boulton et al. 1988, Mackay 1992). Rock-filled trays buried in the Pembina River, Alberta, contained more individuals and taxa than Hess samples taken nearby after only one day (Ciborowski and Clifford 1984).

The earliest colonizers are drift-borne organisms or strong swimmers. In particular, mayflies of the ubiquitous family Baetidae (especially the genus *Baetis*) are universally observed among the first colonists of new substrata (e.g., Waters 1964, Boulton et al. 1988, Robinson et al. 1990). Other primary colonists include blackflies (Simuliidae), midges (Chironomidae) and the amphipod *Gammarus* (Cover and Harrel 1978, Mackay 1992). In general the earliest colonizers represent the collector-gatherer and filterer functional groups. Some of these species may merely inspect the sampler as part of their normal foraging movements, and then move on (Mackay 1992). Filter-feeding caddisflies of the family Hydropsychidae, which do not depend on the substratum for food, can colonize bare substrates (Mackay 1992), but require a rough surface for attachment. They are repeatedly reported among the early colonizers. The preponderance of blackfly larvae among the early colonizers is attributable to a strong preference for bare substrata for attachment. As the artificial substrate begins to accumulate silt and algae, densities of blackflies frequently decline (Ciborowski and Clifford 1984).

With the passage of time, exposed surfaces on the artificial substrate will begin to develop periphyton, a mixture of dissolved organic matter, algal cells, bacteria and fine organic detritus, all embedded in a polysaccharide matrix excreted by the bacteria (Lock 1981). The periphyton is the principal food source for invertebrates in the "scrapers" functional group. The interstitial spaces in the sampler also tend to trap fallen leaves and other plant debris (referred to as coarse particulate organic matter, CPOM), as well as finer detritus particles (FPOM). As the periphyton and organic matter deposits develop, the artificial substrate becomes a more attractive habitat for scrapers and collectors. Shredders, which feed on CPOM, and large predatory species such as perlid and perlodid stoneflies, tend to be among the last arrivals (Gore 1982, Mackay 1992). Species that cannot disperse by drift or aerial flight, such as molluscs or sand-cased caddisflies, will also be slow to colonize.

The importance of food supply as a stimulus for colonization is debated. There is plentiful evidence that colonizing grazers can detect the density of periphyton on a rock and will migrate to areas of denser growth (see Sheldon 1984 and Mackay 1992). In field samples the density and diversity of invertebrates often varies according to the mass of organic matter trapped among stones (Boulton et al. 1988), or on samplers (Boothroyd and Dickie 1989) but Peckarsky (1980a) did not find any effect of CPOM concentration on density of detritivorous organisms in rock-filled cages. The density of shredders alone, however, was significantly greater when leaf litter was present. Similarly, the density of potential prey species did not affect colonization of rock-filled cages by any invertebrate predator, during any season, in either of two streams examined (Peckarsky and Dodson 1980a). Hence, while the accumulation of periphyton and detritus may stimulate colonization by some invertebrates, food availability may not be that important for many species compared with physical habitat, shelter from currents and refuge from predators (Boulton et al. 1988).

Total invertebrate densities on artificial substrates characteristically increase steeply in the first few days as rapidly dispersing organisms discover the new habitat. The initial colonization phase is sometimes followed by a brief decline in numbers, which has been variously ascribed to a lack of food resources on the clean substratum, accumulation of silt or detritus (in the case of sensitive species such as *Simulium*), or an adjustment of numbers to suit the capacity of the exposed substratum (Boulton et al. 1988). Thereafter, densities tend to increase gradually and steadily, following an approximately asymptotic curve, as periphyton and detritus accumulate and less rapidly dispersing species become established (Ciborowski and Clifford 1984). After reaching an initial peak, densities may again decline, before approaching a long-term equilibrium (Cover and Harrel 1978, Gore 1982, Sagar 1983, Sheldon 1984). This general pattern is illustrated in Figure 1; it must be stressed that the pattern in Figure 1 is a composite from many studies and any individual site may not show all the elements of the trend all the time.

The decline in population densities after the peak is reached corresponds with expectations based on the ecology of succession and island biogeography (Gore 1982). As the density of organisms increases, and a greater diversity of species and functional groups becomes established, interactions among species and conspecifics become more important than the arrival of new individuals. These interactions primarily concern competition for space, refugia, or food among or between species, and predation by large predators such as perlid stoneflies (Peckarsky 1980b, Peckarsky and Dodson 1980a, 1980b, Walton 1980). Also, a relatively greater number of organisms will emigrate from the sampler at high densities (Wiley 1980, Ciborowski and Clifford 1984). The decline in density corresponds with the "community re-organization" phase of succession, in which the unstructured collection of colonizing species is re-assembled into a stable benthic community (Gore 1982).

Mathematical models that include predation and competition as factors in the equation have successfully simulated the commonly observed pattern of community development (Sheldon 1984). These models predict that slow-colonizing species do not accurately track changes in the food supply, and hence overshoot the carrying capacity of the artificial substrate before declining abruptly. Finally, the population reaches a dynamic equilibrium maintained by high rates of both immigration and emigration (Sheldon 1984). These changes in community structure have important implications for the utility of artificial substrates for environmental monitoring because they determine the nature of the community developing on the sampler and the time needed to achieve equilibrium (see Section 2.2).

Colonization of any artificial substrate sampler at any given time and place may vary enormously from the broad patterns identified above. Among the variables influencing the rate and sequence of colonization are season, discharge, sedimentation, substratum particle size, history of disturbance, and distance to source areas of colonizers. Seasonal differences reflect differing mobility of organisms during different seasons and the annual cycles of growth, emergence and reproduction among the insects. Thus, the number of species and individuals colonizing an artificial substrate sample may vary widely among seasons, and individual taxa each have their own seasonal pattern (Williams 1980). Moreover, the rate of periphyton growth varies seasonally in response to temperature and illumination, and this in turn affects how soon the habitat will be suitable for grazers (Robinson et al. 1990).

Mackay (1992) concludes from a review of the literature that substratum particle size has conspicuous effects on the density and taxonomic composition of the colonizing fauna. Large pebbles and cobbles >40 mm in diameter tend to be more stable and therefore attract a greater variety of clinging organisms than smaller particles. Gravel-sized particles provide better shelter, however, and if siltation is low, gravel substrata tend to attract greater densities of organisms than surrounding areas. Fine particles tend to trap more FPOM than coarser substrata, and this contributes to their attractiveness to benthic organisms. Conversely, in turbid waters fine particles tend to trap more inorganic silt, which inhibits invertebrate colonization (Peckarsky 1985). Finer experimental substrata tend to collect a different fauna than cobbles, including more burrowers such as oligochaetes, clams, and certain Chironomidae (Mackay 1992).

Reice (1983) demonstrated that substratum particle size was a more important factor than fish predation in the microdistribution of invertebrates in a stream. *Simulium* was more abundant on cobbles, but several genera of mayflies preferred pebble-sized particles. There were also clear preferences for detritus (leaf litter) by some species and clean particles by others.

The physical and biological characteristics of the site where the artificial substrate is placed contributes to colonization dynamics in a number of ways. The natural population of benthic invertebrates in the water body determines the pool of organisms available for colonization. Where source areas are far away, as in a denuded river, or where pools or other barriers impair downstream drift, colonization may be prolonged considerably (Gore 1982). Periods of moderately elevated flow (spates) can accelerate colonization by increasing drift density (Sagar 1983), but floods often lead to scouring, catastrophic drift, and a retardation of colonization. The frequency with which the water body is subjected to floods or other disturbances strongly influences the nature of the benthic community and its capacity to colonize new habitats (Boulton et al. 1988).

A number of studies have examined colonization of multiplate samplers at different time intervals. Tsui and Breedlove (1978) found that 90% of the total number of taxa colonizing samplers were present after 30 days of exposure. In another study, the greatest number of taxa and individuals on the samplers occurred after 35 days of exposure, with a second peak in total individuals after 56 days (Boothroyd and Dickie 1989). Meier et al. (1979) reported maximum abundance on samplers after 39 days, but the mean number of taxa increased linearly throughout the 60-day study period, though community composition on samplers changed little during the second half of the study.

The time required for complete colonization of a newly placed artificial substrate depends on, among other things, the criteria used to define when colonization is finished. Very different estimates are obtained if total density, number of taxa, diversity, or similarity with surrounding benthic communities are used as criteria. Rosenberg and Resh (1982) summarize the older literature on colonization times and concluded that extant data were insufficient to allow a firm conclusion on when "equilibrium" was reached, the usual criterion for the appropriate sampling time. However, the studies they cite used a wide variety of criteria to define equilibrium. Similarly, recommended exposure times in the literature vary from about two weeks to several months, but often lack an experimental justification (Rosenberg and Resh 1982).

When equilibrium is equated with a plateau in the number of species, the apparent colonization period has been as short as 4-6 d in some experiments (Townsend and Hildrew 1976, Lake and Doeg 1985), but more usually is in the range of 10-25 d for substrates placed in ordinary river channels (Rosenberg and Resh 1982, Minshall and Petersen 1985, Peckarsky 1986, Mackay 1992). Total invertebrate densities have usually levelled off in 30 days or less (Gore 1982, Boothroyd and Dickie 1989, Mackay 1992), and the same figures appear to apply to biomass (Rosenberg and Resh 1982, Sagar 1983). Brief colonization periods (<2 weeks) cannot represent a true equilibrium because the habitat provided by the artificial substrate itself will still be changing relatively rapidly. On the other hand, in stressed or denuded channels, where the only source of colonizers is a considerable distance upstream, time to maximum density ranges from 70 to 150 d (Gore 1982).

Gore (1982) has reported one of the few tests of equilibrium defined as a similar community on the artificial substrate as in the surrounding substratum. In a new channel formed after strip-mining in Wyoming, the artificial substrate community was similar (coefficient of similarity >85%) to the natural upstream community after about 125 d, somewhat longer than the time for maximum density (75 d). Whether it is truly necessary or possible to achieve equilibrium in this sense for effective environmental monitoring is discussed in Section 2.2.4.

2.2 Advantages and Disadvantages of Artificial Substrates for Monitoring

Regardless of the type of sampler and the protocol employed, artificial substrates have a number of supposed advantages and disadvantages compared with conventional sampling of benthic invertebrate communities. Rosenberg and Resh (1982) provide a comprehensive evaluation of the strengths and weaknesses of artificial substrates for benthic invertebrate sampling, as presented in the published literature up to 1980 (Table 1). Their work provides a good starting point for the present evaluation of artificial substrates for environmental monitoring in the mining industry. Again, however, many of their conclusions are based on pure research needs, and may be incorrect or irrelevant in the context of environmental monitoring.

Further, many of the so-called advantages or disadvantages of artificial substrates are not absolute; a particular attribute of the approach may be a benefit from one perspective, a drawback from another. It all depends on the questions being asked and the kind of information needed to answer them. Thus, we have used Rosenberg and Resh (1982) only as a framework for the present evaluation, but have amended and expanded their conclusions to bring the focus squarely on environmental monitoring, and to incorporate new information published in the past 15 years. Because so many of the supposed advantages and disadvantages are interconnected, they have been grouped together for discussion under the general topics of Sampling Flexibility, Variability, Applicability and Logistics.

2.2.1 Sampling Flexibility

The attraction of artificial substrates most often cited, and indeed the only reason for using them in many instances, is that they allow benthic invertebrate sampling at locations that cannot be sampled effectively by other means (Weber 1973, Boothroyd and Dickie 1989, Voshell et al. 1989). Such places include (1) water bodies with very deep or turbid water, (2) water bodies with soft or unstable bottoms of sand, mud or organic ooze, (3) water bodies with unbroken bedrock bottoms (including cement-lined channels) or bottoms of large boulders and (4) rivers with torrential currents. Rivers such as the Fraser, North and South Saskatchewan, Peace-Athabasca, Qu'Appelle, Red, and St. Lawrence, as well as the Great Lakes and their connecting channels, are conspicuous examples of habitats amenable to sampling with artificial substrates. They may also be useful in northern bog streams and boulder-strewn streams draining the Canadian Shield or the Rocky Mountains, to name just a few possibilities.

The validity of this advantage is unquestionable. Artificial substrates are the only feasible sampler at many sites and are more efficient than conventional sampling at many others (Rosenberg and Resh 1982). Artificial substrates can be placed and retrieved under a range of weather and flow conditions, including some that would make conventional grab sampling inconvenient or dangerous.

Finally, artificial substrates can be used in habitats where the invertebrate population would be decimated by conventional sampling. This last would be a consideration if, for instance, a small area of riffle in an otherwise soft-bottomed stream were the only site available for benthic invertebrate sampling. Artificial substrates could be used instead of conventional sampling to avoid disturbing or exhausting the indigenous community (Layton and Voshell 1991). However, Rosenberg and Resh (1982) argue that the net effect is the same regardless of sampling technique because the organisms colonizing the artificial substrate are drawn from the present benthos, thus diluting the population. This argument is probably not valid, except possibly for rare species. The ubiquity of invertebrates in suitable habitats and the rapidity with which new areas are colonized strongly suggests that populations are habitat limited, that is, that immigrants are being supplied to the community at any given point through drift, migration or reproduction at a greater rate than the habitat can sustain. Thus, adding new habitat in the form of an artificial substrate increases the total population of the reach, and should not diminish populations in the native habitat.

There is nothing to restrict placing artificial substrates in streams or lakes with clean cobble bottoms that could as easily be sampled conventionally, of course. The applicability of artificial substrates to such a wide variety of situations has two important secondary benefits. First, it permits much greater flexibility in the monitoring program and second, it allows comparisons among otherwise noncomparable sites. For example, monitoring programs based on conventional sampling are frequently limited in the number and placement of sampling sites by the availability of suitable habitat. With artificial substrates, samples can be collected at the ideal distribution of sites relative to the effluent outfall, or nearly so, thereby optimizing the sensitivity of the monitoring program. While there still may be restrictions on where samples can be collected, the range of options is broader with artificial substrates.

Equally significant, artificial substrates potentially allow comparison of environmental effects of effluents along a watercourse where the macrohabitat is not constant, such as rocky bottoms upstream and silty bottoms downstream, without the confounding influence of habitat types overwhelming the effluent effect (Boothroyd and Dickie 1989). This is a key consideration because differences in habitat are among the largest sources or variance in benthic invertebrate monitoring, and therefore a major limitation on the sensitivity and utility of such monitoring.

Rosenberg and Resh (1982) argue that it is not valid to compare artificial substrate samples taken from different macrohabitats (e.g., riffles and pools) just as it is not valid for grab samples. The reasoning supporting this conclusion is not clear. With respect to substratum characteristics, benthic invertebrates evidently respond at the microscale, regardless of the larger surrounds. Thus, a rock-filled basket placed on a sand-bottomed river will attract typical invertebrates of a rocky bottomed reach, even if the nearest such area is far upstream (personal observation). Other habitat factors, particularly current, will still vary among sites, and will contribute to sample variability. But within broad limitations, it should still be possible to compare physically dissimilar habitats with artificial substrates. To put it another way, artificial substrates control one important source of variability, microhabitat, but do not eliminate another source, macrohabitat. For a mine effluent that discharges into a small stream above a large river or lake, artificial substrates may be the only feasible approach to benthic invertebrate monitoring, habitat variability notwithstanding. Naturally, any source of variability between sites should be avoided, if possible.

Artificial substrates allow sampling flexibility in another sense because the design of the samplers can be modified to suit local conditions. Heavier or larger samplers can be used where currents are strong or invertebrate densities are low. A design with a lower profile could be substituted where trapping of silt or detritus is a problem. A variety of methods for anchoring or flagging samplers in place is available. In the context of scientific research, flexibility of sampler design may be construed as unfortunate because it leads to data that cannot be compared among studies (Rosenberg and Resh 1982). This consideration does not apply to monitoring, however, where the objective is only to detect and assess differences among sites within the study. Quantitative comparisons among sites is not normally an objective of monitoring studies, so there is no reason not to modify sampler design if it improves performance. It is desirable, however, to maintain the same design for all monitoring at the same site, so that improvements in effluent quality over the years can be evaluated.

2.2.2 Sample Variability

The second most common advantage claimed for artificial substrates is that they reduce variance in organism densities among samples, and thereby improve the precision of density estimates (Weber 1973, Voshell et al. 1989). In a monitoring program any increase in precision also improves sensitivity because smaller differences between sites can be detected statistically. Several studies in the earlier literature, including several key works in the development of artificial substrates (e.g., Beak et al. 1973) claimed that the sampling variability, in terms of the coefficient of variation (CV, the standard deviation as a percentage of the mean) for densities of total invertebrates or numbers of taxa were substantially less for artificial substrates compared with conventional samplers such as the Surber sampler. However, other comparisons have either found less convincing differences or even the reverse, i.e., greater variability from artificial substrates. The controversy has been further confused by disagreements over the appropriate methods and statistics for comparing variability of sampling methods (Hellawell 1978), and by calculation errors in several published works that have been perpetuated in later citations (Rosenberg and Resh 1982).

Rosenberg and Resh (1982) re-analyzed data from 14 studies using Surber and Hess Samplers and 19 studies using various kinds of artificial substrates, which these authors classify as representative (RAS) for rock-filled baskets and the like, or standardized (SAS) for multiplate samplers and similar artificial materials. The data sources spanned the years 1959 to 1978. Their results, reproduced here as Figure 2, illustrate that coefficients of variation for all methods can range from <10% to >120%. CVs for conventional sampling methods are approximately normally distributed, with a median around 50%. The distributions of CVs for artificial substrates, on the other hand, are strongly skewed toward the lower end of the range, with median values around 20% to 30% (Figure 2). Thus, in spite of the greater range of sampling devices and protocols included in the artificial sampler data, coefficients of variation could be reduced by as much as 20% to 30% compared with the same number of replicate samples by conventional methods (Rosenberg and Resh 1982).

More recently, Morin (1985) compared the variance of artificial substrates and conventional sampling methods as part of a larger study of the effects of sample size. Data were drawn from 19 studies of benthic invertebrate densities in running waters of cold temperate regions. Morin (1985) calculated the variance of the total number of individuals and total numbers within functional groups for each sample and fit the variance to a regression on sample mean and sampler size. Residuals from this equation (Figure 3) indicate the relative precision of different sampling types; samplers with more precise data than average (lower CV) produce negative residuals, more variable methods produce positive residuals. Artificial substrates as a group were no more or less variable than other methods, but the variability for rock-filled baskets and trays was substantially less than that for any conventional sampling method (Figure 3), supporting Rosenberg and Resh's conclusion. The other kinds of samplers are not likely to be used for water quality monitoring in the mining industry.

The reduced variability afforded by artificial substrates can not only improve the sensitivity of biomonitoring, it can also dramatically reduce the effort needed to produce results of a given precision. Slack et al. (1986) compared four kinds of artificial substrate against Ponar samples in a river in California. They calculated the number of replicates needed to produce estimates of numbers of taxa or total organisms within a given percentage of the population mean at the 95% confidence level. To obtain estimates within 20% of the population mean, widely considered an acceptable uncertainty level in biomonitoring, from two to six samples with the artificial substrates would be sufficient, compared with 20 (number of taxa) or 34 (number of individuals) for the Ponar grabs. Thus, relatively precise estimates of general population parameters can be estimated using artificial substrates with a reasonable level of replication.

The conclusion from this review is that certain types of artificial substrate sampler can substantially reduce the variability of benthic invertebrate samples compared with conventional sampling methods, although a reduction may not be apparent in every study. This improved precision is generally ascribed to the uniformity of habitat provided by the artificial substrates. Even within a seemingly uniform riffle, microhabitat differences produce aggregated distributions of benthic organisms which increase the variability among samples. Properly designed and placed artificial substrates produce a uniform particle size (or particle size distribution) and surface area among samplers and therefore remove this source of variation

(Ciborowski and Clifford 1984, Boothroyd and Dickie 1989). This is an important consideration because high variability often limits the resolution of environmental monitoring with benthic invertebrates. It is worth noting, however, that even where particle size is uniform, strongly aggregated distributions of benthic invertebrates persist (Reice 1983).

Artificial substrates could also reduce sampling variability by removing differences between operators, a significant source of error in large-scale or long-term monitoring programs (Furse et al. 1981, Mackey et al. 1984, Clifford et al. 1992). It has even been claimed that artificial substrates allow a reduction in costs because they do not require a trained biologist to place or remove (Rosenberg and Resh 1982). The assumption here is that because artificial substrate are essentially passive samplers, the experience of the operator is not important to the results obtained.

No quantitative tests of this assumption have been undertaken, but it is probably only partly correct. While it is true that artificial substrates are sometimes easier to deploy than many conventional sampling methods, some experience with the technique is nonetheless necessary. This is especially true for retrieval, when there is a potential for loss of organism while the sampler is being lifted. If the samplers are disassembled in the field, variability can arise in the separation of invertebrates from the substratum particles. Placement of samplers in deep or turbid rivers requires close familiarity with the river, in particular the location of depositional zones, so that replicate samplers are placed at comparable sites (W. Dwernychuk, Hatfield Consultants, personal communication 1995). In conclusion, while sampling precision may be improved by artificial substrates because of the removal of operator differences as a factor, appropriate use of artificial substrates will still require trained and experienced personnel.

The capacity of artificial substrates to allow meaningful samples to be taken from widely different habitats, discussed in the previous section, can also be viewed as an issue in sample variability. Because artificial substrates reduce or remove variation in community composition and population densities caused by microhabitat, they improve the ability of the monitoring program to detect site differences caused by an effluent. This advantage can be taken as one extreme of the improvement in precision discussed above; where circumstances dictate that a depositional reach must be compared against a fast-water reach, the differences in the native benthic fauna would normally be so great (i.e., the variability between samples would be so high) that detecting an effluent effect would be all but impossible. Artificial substrates are not a complete solution to this intractable problem, but they do at least reduce one major source of variability sufficiently that site differences of the magnitude expected from industrial effluents can be detected (Boothroyd and Dickie 1989).

In the same way, the true area being sampled is more easily measured and standardized with artificial substrates than with conventional sampling techniques. Calculation of surface areas for multiplate samplers and Beak trays is straightforward (hence the designation *standardized* artificial substrates, Rosenberg and Resh 1982), and can be simplified in rock baskets by using substratum particles of uniform size. Results from artificial substrates can be expressed meaningfully as density per unit area or volume. This is done implicitly when results are expressed as numbers "per sampler". Conventional sampling techniques lack a true unit, even if they are said to sample a given area, because the surface area available within it may vary widely (Rosenberg and Resh 1982).

Colonization rates of artificial substrates are subject to strong seasonal variation (Williams 1980, Sagar 1983) which contributes to variability of data collected over time. Colonization tends to be faster in summer when animals are more active. Life-cycle changes of each species over the year also contribute to seasonal variation. These seasonal differences, however, affect conventional sampling to the same degree, and should not pose any additional difficulty for artificial substrate sampling as long as it is done in the same season each year.

2.2.3 Sample Applicability

A key issue in the assessment of artificial substrates is the validity of the benthic invertebrate samples collected with this method. If artificial substrates are selective for particular taxa or particular types of organisms, they community that develops on them might not be adequately representative of the indigenous fauna living on the native sediments. That, in turn, calls into question the validity of the environmental assessments based on species abundance data from artificial substrates. Some researchers maintain that the deviance of artificial substrate samples from conventional samples is a severe drawback that invalidates their use (Williams 1980, Ciborowski and Clifford 1984).

There is no question but that artificial substrates are selective with respect to the organisms that colonize them. Section 2.1 discusses the nature and causes of this selectivity in detail. In erosional zones, artificial substrates favour rapid dispersers, particularly organisms prominent in the drift, and select against burrowing organisms, unless the samplers collect sediment. In standing waters, artificial substrates collect mostly littoral zone organisms, while conventional samples collect mostly profundal organisms (Tsui and Breedlove 1978). The bias is greater the briefer the time allowed for colonization. Selectivity by artificial substrates is reported repeatedly; Rosenberg and Resh (1982) present a table of 26 studies that have reported selectivity by artificial substrates in the literature up to 1980.

When artificial substrates such as rock-filled baskets are placed in depositional zones or suspended in the water column, profound differences in community structure between the invertebrates on the sampler and those on the native sediments typically emerge. For example, multiplate samplers in a Texas canal collected 102 species of invertebrates, but 34 of these were not found in benthic samples. The soft-bottom benthos was dominated by tubificid worms, while chironomids and other insects dominated the samplers (Cover and Harrel 1978). Similarly, rock-filled baskets suspended in the Ohio River, Cincinnati, were colonized largely by chironomids and caddisflies with a few mayflies and dragonflies. Animals caught in Petersen grab samples of the bottom sediments contained mostly clams and oligochaete worms, which were not present in the artificial substrate samples (Anderson and Mason 1968). Slack et al. (1986) compared four kinds of artificial substrate samplers placed on the bottom of the sandy Sacramento River, California, against Ponar grabs. The grab samples contained a monotonous assemblage of predominantly a bivalve mollusc, an annelid worm, and a single genus of Chironomidae. The artificial substrate samples, in contrast, contained about 10 common species, including worms, crustaceans, mayflies and a diversity of chironomids.

The data of Tsui and Breedlove (1978) reproduced here as Table 2, are typical. They compared benthic invertebrate samples taken with a Ponar grab (0.05 m^2) at 8 m depth in a lake or 2 m depth in a slow-flowing river, against samples collected on multiplates suspended in the water column. Of the 32 species collected in the lake, only six were commonly collected on both samplers. In the river, the Ponar sample was dominated by oligochaete worms and snails, while the artificial substrates were dominated by amphipods, isopods and chironomids. Given these discordant observations, can artificial substrates be legitimately used to assess effects of effluents on the native fauna?

The key to resolving this dilemma lies in knowing exactly what question is being asked. Researchers who object to artificial substrates on the ground of selectivity are primarily interested in questions of aquatic ecology. For their purposes, "the objective of sampling is to obtain as true as possible a representation of the natural condition" (Rosenberg and Resh 1982: 201). However, the objectives of environmental monitoring are to assess the nature, severity and extent of environmental impairment arising from a human intervention such as mining. For this purpose the selectivity of artificial substrates is an important advantage (Boothroyd and Dickie 1989).

The fauna of depositional zones consists largely of robust species that are notably insensitive to many kinds of environmental degradation. Thus, a mild effect of toxicity or enrichment that would detectably alter the species composition of an erosional site may have no significant effect on numbers or proportions of depositional zone communities. This is especially true of toxicity, the principal effect anticipated from metal-bearing mine effluents. Moreover, the much larger number of taxa and the correspondingly wider range of sensitivities contained in the erosional zone community (and mimicked in the artificial substrate community) increases the range of severities that can be quantitatively estimated.

The difference is analogous to a continuous meter of environmental degradation compared with a simple yes/no indicator. Environmental degradation severe enough to cause an alteration in depositional zone communities would be necessarily severe. Diverse communities on artificial substrates allow detection of much smaller changes, as is necessary if the monitoring program is to act as an early warning system or to track changes through time. Such data are also more suitable for numerical analysis methods that were developed specifically for this kind of community. Multivariate methods (cluster analysis, ordination, correspondence analysis) function more effectively when the data set contains a wider number and range of species, and simpler methods such as evaluation of taxon sensitivities work better for erosional zone species which are both more sensitive and better understood.

The dramatically greater numbers of organisms commonly found in artificial substrate samplers compared with soft-bottom habitats may also be considered an advantage for detecting environmental effects. Benthic invertebrate densities in water bodies with bottoms of silt, sand, mud, or peat are often very low, and may be entirely dominated by one or a few adapted taxa (Slack et al. 1986). In contrast, artificial substrates of ordinary size typically attract hundreds, occasionally thousands, of organisms when placed in the same environment. The species distribution contains abundant and rare species, as well as those of intermediate abundance. For example, multiplate samplers in a New Zealand river collected 16 000 to 19 000 invertebrates, while a 0.05-m^2 box sampler yielded <2000 (Boothroyd and Dickie 1989). Three kinds of artificial substrates in the lower Sacramento River each collected about 60-70 individuals, on average, while a standard Ponar grab collected <10 (Slack et al. 1986). A side-by-side comparison in the lower Fraser River, yielded as few as a hundred organisms in six replicate Surber samples, while artificial substrates (Beak trays) collected many hundreds each, and presented a much greater diversity of taxa (W. Dwernychuk, Hatfield Consultants, personal communication). Again, higher numbers tend to increase the usefulness of benthic invertebrate data because sample variability tends to be relatively less and a greater number of species are present in densities sufficient for statistical analysis.

It follows from the above that monitoring based on artificial substrates may find a significant difference in benthic invertebrate communities between sites above and below an effluent outfall where no such difference would be detectable if conventional sampling were used. It could be argued that the artificial substrates demonstrate the effect that would be expected if the entire water body were comparable hard-bottomed habitat. It is for this reason that the objectives of the monitoring program must be specified exactly. Artificial substrates that collect a benthic invertebrate community substantially different from that on surrounding substrata demonstrate the potential effects of an effluent, not the real effect. Real effects can only be demonstrated by sampling the indigenous fauna.

Nevertheless, there remain strong reasons for using artificial substrates in these situations, in addition to the increase in sensitivity discussed earlier. In environmental toxicology, effects of toxicants are typically assessed using sensitive organisms, on the ground that those organisms reveal the lower threshold of effects in the wild. A toxicant concentration that is below the effect threshold for the test species, if the species is well chosen, should also be safe for most other organisms in natural ecosystems, including those that are rare or difficult to sample. Moreover, organisms resist toxicity and other stresses by diverting part of their energy intake to combating the stress. There is thus less energy available for a stressed organism to devote to growth, reproduction and other functions.

It follows that if a stress from a mine effluent is strong enough that it is altering the community composition of benthic invertebrates on artificial substrates, it may reasonably be expected to be stressing other components of the ecosystem, even if those stresses are too small or too diffuse to be detected in traditional benthic surveys. Artificial substrates used in this manner represent a kind of on-site, multi-species toxicity test, using native organisms that colonize the samplers. This reasoning has been used to justify using floating artificial substrates in large rivers, where the samplers are colonized only by drifting organisms (M. Payne, Payne Ledge Associates, personal communication 1995).

Two considerations temper the utility of artificial substrates to detect effluent toxicity. First, because artificial substrates collect colonizing organisms, the invertebrate samples taken from them represent present water quality conditions, perhaps modified by any sediments trapped in the sampler. The capacity of benthic invertebrates to integrate long-term water and sediment quality, often cited as a major benefit for environmental monitoring, is not realized in this application. Moreover, at most sites the invertebrates will be responding largely to water quality, not sediment quality, because samplers are generally designed to attract the silt-intolerant organisms of riffles and to avoid trapping sediments. This limitation has import for monitoring the mining industry, because heavy metals in mine wastewaters tend to partition rapidly into the solid phase; ecosystem effects of these effluents are thus likely to arise from sediment toxicity.

The second drawback is more subtle. Because artificial substrates tend to be colonized largely by drifting organisms, they are selective for organisms prone to drift. Behavioural drift functions as a means of avoiding inhospitable areas of the watercourse. Faced with a mildly toxic, silty, or saline effluent plume, many of these organisms would be apt to re-enter the drift, lowering the species richness of the sample, and exaggerating the true effect of the effluent. Conversely, the emigrating organisms may be replaced by new colonists, particularly vagile organisms like *Baetis*, leading to a rapid turnover of organisms, rather than the succession predicted by the colonization curve (Figure 1). Even though the sampler might be in place for a month or so, the majority of the organisms resident on it could be recent colonizers that have only been exposed to the effluent for a few days. We were unable to find any studies that have specifically examined this possibility. Nonetheless it remains an issue, especially at sites where upstream drift is the primary route of colonization.

These limitations suggest that artificial substrates would be best used as one component of a sampling program. Indigenous organisms should be sampled where possible, and sediment toxicity tests can be used to directly assess the effects of particle-bound metals. The selective populations on artificial substrates do not convey information about the actual population on the native sediments, nor about links to other ecosystem components such as abundance of fish food organisms. Where the natural substratum is suitable, indigenous organisms will always provide the best information for monitoring. With the exception of surveys encompassing several different habitats (where artificial substrates might be used in all, for consistency), there is no justification for using artificial substrates to sample erosional, rocky-bottomed watercourses or clean lake bottoms that are amenable to sampling by conventional methods (Voshell et al. 1989). Artificial substrates should be reserved for those situations where conventional sampling will not prevail.

A limitation of artificial substrates that is frequently mentioned is that colonization dynamics are incompletely known (Rosenberg and Resh 1982). This is still true, although much progress has been made in the past decade (Mackay 1992). Aside from the issue of selectivity, discussed above, colonization dynamics are important in monitoring applications because they determine the appropriate length of time to leave artificial substrates in place. This issue is discussed in more detail in Section 2.1. Recommended exposure times are given in Section 3.3.

2.2.4 Sampling Logistics

The last group of advantages and disadvantages of artificial substrates pertains to the mechanics of sampling, ease of use, cost and convenience. Opinions differ widely on many of these points, and there are frequently differences among sampling devices, making generalizations difficult. Consequently most of the issues here are also discussed in the following section (Section 3) where different artificial substrate samplers are compared.

On the one hand, artificial substrates have been promoted as being simple and convenient to use by some researchers, while others have claimed just the opposite (Rosenberg and Resh 1982). To the extent that artificial substrates are small, light, inexpensive and simple to build, and that they permit researchers to avoid conventional sampling in hostile locations, they are convenient. But most of those claims can readily be contested. Most kinds or artificial substrates are constructed of simple and easily available materials and can be built without special skills. They are of course less expensive than a conventional device like a Ponar grab, but this savings must be balanced against the need for numerous replicates and frequent replacements. The cost of samplers of any kind is usually a minor part of the field component of most water quality monitoring programs (Rosenberg and Resh 1982).

The claim that artificial substrates are small and light, and therefore easy to handle, is substantially true only for multiplate samplers. On the contrary, rock-filled baskets or trays and Beak trays, the kinds most likely to see use in a mine effluent monitoring program, are big and heavy, and rock-filled baskets are bulky as well. Placing and retrieving these samplers requires considerable exertion, which increases absolutely in proportion with the volume of the sampler, and perceptually with each replicate the worker has to hoist. Ease of handling diminishes further where site conditions such as fast current must be battled as well. While the effort required to manipulate artificial substrate samplers may not be much different than that required for conventional sampling, ease of handling cannot be claimed as an advantage of artificial substrates generally.

Artificial substrates may provide a convenience once the samples are collected because some models collect less debris that other sampling methods (Weber 1973, Klemm et al. 1990, Rosenberg and Resh 1982). The amount of detritus and inorganic material in a benthic sample is significant because it strongly influences the time, and hence the cost, required to sort the animals from the detritus, one of the most labour-intensive steps in any benthic survey. Again, the published literature provides conflicting evidence about the ease of sorting artificial substrate samples compared with conventional samples. A number of authors cited in Rosenberg and Resh (1982) found artificial substrate samples are easy to clean and can be sorted quickly, while others found debris accumulations increased sorting time. The propensity to trap debris also varies with the type and size of sampler. It should also be remembered that the amount of accumulated detritus may affect colonization, especially by shedders (Peckarsky 1980a, Boulton et al. 1988).

Among the kinds of artificial substrates considered here, only multiplate samplers are likely to collect significantly less detritus than conventional samples, because of the small size and structural simplicity of these devices. Many investigators have found that rock-filled baskets tend to trap detritus (Ciborowski and Clifford 1984) and this has also been our experience. Accumulations will be greater in samplers with a high profile. Larger samplers require longer sorting time simply because of the large number of animals they contain. This objection can be partly overcome by subsampling, but only after the animals and detritus have been separated from the rocks in the sampler.

Unlike conventional sampling, in which samples are collected during a single field trip, artificial substrates require two trips for each sample: one to place the sampler and one to retrieve it (Hellawell 1978). This requirement automatically doubles the field cost of the sampling program, unless benthic sampling can be combined with other field work. This is illustrated in Table 3, which contrasts the approximate field costs associated with a survey using artificial substrates with that of a survey employing conventional bottom sampling devices. Such a large difference in cost should be considered a major disincentive to using artificial substrates, although it is seldom mentioned in the literature.

Added to the effort of a second sampling trip is the additional complexity of installing, anchoring, flagging and relocating the samplers, all of which create difficulties of one sort or another. Artificial substrates in flowing water must be anchored to the substratum or connected to a solid object in or near the water. They may be difficult to find after exposure unless they are conspicuously marked with buoys in the water or flags or markers on the tielines. The former may be a hazard to navigation (Klemm et al. 1990), and any device that makes samplers conspicuous increases the probability of vandalism (see later). Rosenberg and Resh (1982) devote a five-page table to suggested ways to minimize handling problems of artificial substrates.

A related disadvantage to handling difficulties is the long exposure time needed to collect a sample. A month or more is usually required for colonization and succession to proceed to the stage where a stable and representative benthic invertebrate community develops on the sampler (see Section 2.2.3). Given this time requirement, utility of artificial substrates for short-term or event-based water quality evaluations is limited at best. They can only profitably be employed in a long-term program where average water quality over the exposure period can be considered a useful unit. The long exposure time is doubly disadvantageous because it increases the probability of samplers being disturbed or lost due to spates, droughts, accidents (collisions with logs, etc.), burial with sediments, and vandalism. Moreover, whereas a spilled conventional sample can be replaced immediately, loss of an artificial substrate sample is permanent.

Loss of artificial substrate samplers is not an occasional inconvenience but a persistent and intractable problem that frequently hampers the effectiveness of benthic surveys (e.g., Mason et al. 1973, Roby et al. 1978, Meier et al. 1979, Wise and Molles 1979, Peckarsky 1980a, Sagar 1983, Klemm et al. 1990). Effective water quality monitoring programs routinely incorporate extra samplers at each site to allow for losses (M. Payne, personal communication 1995). Vandalism is a particularly vexing problem because it is unpredictable yet backed by intelligence and curiosity, rather than a simple act of nature. The researcher may be assured of some lost samples when artificial substrates are placed in populated areas unless great care is taken to ensure they are inconspicuous or firmly secured.

Lost or disturbed artificial substrates are the bane of benthic surveys because they create irreparable data gaps and increase the cost of field work. Further, the long exposure times required by artificial substrate sampling and the presence of predictable disturbances like spring spates and summer droughts restricts the frequency and timing of sampling. Samplers can only be placed when the researcher is confident that no severe disturbance will occur over the next month. Conventional sampling is much less restricted, normally requiring only one or a few days of agreeable conditions.

A final sampling problem with artificial substrates is loss of organisms while the sampler is being retrieved. Some animals will be lost to passive drift or actively leave the sampler when it is disturbed during retrieval. The magnitude of the loss varies widely, but figures as high as 20% for some insect orders are not atypical (Rosenberg and Resh 1982). Naturally, losses would be greater in deeper water or faster current than in shallow or lentic water bodies, and would also vary according to the kind of sampler being used.

The loss of organisms during retrieval is of interest because it can be a source of variance between samples and it potentially increases the deviance of the sample from the indigenous benthos, because certain species on the artificial substrate will be more likely to be lost than others. In shallow waters of all kinds, loss of organisms can be neatly prevented by placing a fine-mesh net around the artificial substrate as it is retrieved (Weber 1973). This solution is not available, however for samplers placed in deep rivers or lakes. Some artificial substrates, such as the Beak tray, are designed to prevent organism loss during retrieval. These options are generally sufficient to minimize losses of organisms in the situations where they can be applied. The difficulty of controlling organism loss in some situations, however (such as rock-filled baskets placed at the bottom of a deep river) imposes a serious limitation on the utility of artificial substrates.

3.0 COMPARISON OF ARTIFICIAL SUBSTRATE SAMPLERS

3.1 Types of Artificial Substrates

Flannagan and Rosenberg (1982) identified eight basic types of artificial substrate samplers:

1. containers filled with various substrates
2. multiplate (or multiple-plate) samplers
3. boards, panels, tiles
4. bricks and blocks
5. plastic sheets, polyethylene and fabric strips, ropes
6. implanted substrates
7. natural organic substrates
8. miscellaneous substrates

A brief description of devices in each category is provided below.

Containers Filled with Various Substrates

This category includes the most frequently used artificial substrates. The sampler generally consists of a porous container such as a wire mesh cage, basket or tray, filled with particles of various size, shape and surface texture. The most common sampler of this type is the rock-filled, cylindrical barbecue basket or rectangular cage made from coarse wire mesh. They are placed on the bottom of the water body or suspended in the water column. Other variations on the basic theme include trays filled with rocks (Townsend and Hildrew 1976, Clements 1994) or containing a wire mesh screen (Beak et al. 1973) and collapsible baskets (Bull 1968), plastic baskets or cages (Bournaud et al. 1978), mesh bags (De Pauw et al. 1994) or open-ended boxes (Pearson and Jones 1975) filled with rocks, gravel or synthetic particles.

Multiplate Samplers

Samplers in this category are based on the design of Hester and Dendy (1962), and are frequently referred to as Hester-Dendy samplers. The device consists of alternating small and large, circular or square plates made of tempered hardboard (Masonite), mounted on a centrally positioned eye-bolt. The sampler is generally suspended in the water column. Modifications of this sampler include varying the texture, shape, size, spacing and number of plates, the material used and the anchoring or floatation device.

Boards, Panels, Tiles

These samplers may vary in size (microscope slides to large panels) and the in the nature of the material used (glass, ceramic, wood, concrete, plastic). The samplers are either placed on the bottom or are suspended in the water column at various depths. None of these samplers have been adopted as a standard design.

Bricks and Blocks

Samplers may be of varying size and made of different materials. They are placed on the bottom of the water body sampled.

Plastic Sheets, Polyethylene and Fabric Strips, Ropes, etc.

This group includes a large number of devices which vary greatly in terms of design and the material used, and are generally intended to mimic aquatic vegetation. Samplers may be anchored to the bottom or mounted along an anchored and buoyed string.

Implanted Substrates

This category includes a large number of devices of widely varying design. Samplers may consist of trays, boxes, perforated pipe, pots or baskets buried in the stream bed, filled with natural organic or inorganic materials, rocks or synthetic particles.

Natural Organic Substrates

These samplers generally consist of dried plant material (usually leaves) placed in a mesh bag or attached to an anchoring device.

Miscellaneous Substrates

This category includes samples of various design, made from various materials, which do not fit into any of the above categories.

3.2 Criteria for Evaluation of Samplers

A comprehensive evaluation of all these types of sampler would be impractical, since many of them are not useful for routine biomonitoring or are designed for experimental purposes. The range of samplers examined in detail was therefore reduced to those that (1) sample the entire benthic macroinvertebrate community (as opposed to those on hard surfaces or aquatic plants only) and (2) are considered standard devices. Samplers which satisfy these criteria fall into the first two sampler types described above. These samplers are: multiplate samplers, rock-filled baskets and trays and Beak trays. The use, advantages, disadvantages and the type of data generated by the selected samplers have been widely reported in the literature, and the performance of each device has been compared with those of other devices as well as with quantitative bottom sampling techniques. Most other samplers either (1) only have flat surfaces (boards, panels, tiles, bricks and blocks) which do not provide a variety of microhabitats for colonization and are thus selective for certain taxa, (2) simulate vegetation or organic deposits (plastic sheets, polyethylene and fabric strips, ropes, natural organic substrates), or (3) are devices which have not been standardized or generally accepted (implanted substrates, miscellaneous substrates).

The following criteria were used to evaluate the samplers:

advantages

disadvantages
sampler cost
reliability
sensitivity in detecting environmental effects
usefulness as an environmental effect monitoring tool for mining
applicability to different habitat types

Sampler characteristics outlined above are discussed specifically for each device and are summarized in Table 4; general characteristics, advantages and disadvantages of artificial substrates are discussed in Section 2.2. These apply to all of the samplers evaluated and thus will not be repeated below.

3.3 Multiplate Samplers

General Description

All multiplate samplers are based on the original design by Hester and Dendy (1962). The original multiplate sampler consists of alternating small and large, square plates made of tempered hardboard (Masonite), mounted on a centrally positioned eye-bolt. It is generally suspended in the water column, but may be installed on a cement block anchoring device placed on the bottom. Frequent modifications of this sampler include varying the texture, shape, size, spacing and number of plates, the material used and the method of positioning. A more refined version of this sampler consists of 14 square plates made of roughened non-wood material with spacers of varying width separating the plates (Slack et al. 1988, Boothroyd and Dickie 1989, Klemm et al. 1990). Additionally, the use of round plates may also improve the original design, since it would allow the entire sampler to fit in a jar after retrieval, as suggested by Tsui and Breedlove (1978).

Although one study reported that density of animals on multiplate samplers compared favourably with bottom density calculated from stovepipe samples (Robertson and Piwowar 1985), it is generally agreed that this sampler cannot be used to estimate bottom density. Nearly all studies comparing the invertebrate assemblage on multiplate samplers with quantitative bottom samples found major differences from the benthic community on native substrata (Cover and Harrel 1978, Tsui and Breedlove 1978, Slack et al. 1986, Boothroyd and Dickie 1989, Klemm et al. 1990, Modde and Drewes 1990). Multiplate samplers generally collect larger numbers of taxa and organisms than bottom samples, and are dominated by invertebrates typical of hard bottoms, with much lower numbers of burrowing taxa (especially oligochaetes, chironomids, clams and heavy-cased caddisfly larvae) than conventional samples (Cover and Harrel 1978, Tsui and Breedlove 1978, Robertson and Piwowar 1985, Slack et al. 1986, Boothroyd and Dickie 1989, Barton and Metcalfe-Smith 1992). The divergence in community composition between multiplate and benthic samples would be greater where the natural river bottom consists primarily of sand and silt, which lack large, flat surfaces for invertebrate colonization.

Advantages

Multiplate samplers can be used to sample all freshwater habitats with the exception of wetlands (Klemm et al. 1990). They provide a standard surface texture, area and variety of microhabitats for colonization, are relatively small, light-weight, and easy to manipulate. Samples collected by suspended samplers usually contain relatively low amounts of extraneous material (Klemm et al. 1990). Multiplate samplers tend to collect large numbers of invertebrates regardless of orientation relative to flow and light direction (Slack et al. 1988, Hill and Matter 1991) and generate data with low variation among replicate samples (Klemm et al. 1990).

Disadvantages

Samples collected by the frequently-used hardboard devices may be biased toward large numbers of wood-eating chironomid larvae which can feed on the plates, especially if the device is re-used or colonized by fungi (Voshell et al. 1989). Plates may become contaminated by oil and toxicants, which may also render them unsuitable for re-use (Klemm et al. 1990). Additionally, the hardboard may warp or expand with time in the water, thus reducing the space between the plates available for colonization (Voshell et al. 1989). These disadvantages are easily remedied by using a different type of material for the plates, as suggested above.

Slack et al. (1988) found that the hardware used to keep the samplers in position may also influence sample composition. Multiplate samplers are less stable than the heavier, substrate-filled basket type samplers and thus may be moved by fast current if not securely anchored (Hall 1982).

Multiplate samplers, like most artificial substrate samplers, are selective for certain taxa, and samples are generally not representative of the benthic community on natural substrata (Cover and Harrel 1978, Tsui and Breedlove 1978, Slack et al. 1986, Boothroyd and Dickie 1989, Klemm et al. 1990, Modde and Drewes 1990). However, this bias may be greater for multiplate samplers, which provide a completely artificial environment, than that for representative artificial substrate samplers which mimic the natural substratum in the area sampled. Multiplate samplers provide relatively little variation in the types of microhabitats to be occupied by colonizing animals, and tend to collect lower numbers of animals than representative samplers such as the rock-filled basket (Hall 1982).

Sampler Cost

Multiplate samplers are inexpensive to assemble, but the actual cost will depend on the material used for the plates. Ideally, samplers should be made of inert, synthetic material which allows their re-use. Hardboard samplers have a finite life-span, sometimes limited to a single use, which may increase the cost of repeated use of this sampler.

Reliability

Samplers may fail if snagged by floating debris, but by far the most significant cause of failure is vandalism, which affects all artificial substrate samplers (see Section 2.2.4). Sampler losses of 24% (Meier et al. 1979) and 35% (Hall 1982) have been reported, indicating that the potential for disturbance or loss is considerable unless efforts are made to conceal the samplers.

Sensitivity

Reports of sensitivity in detecting environmental effects, relative to conventional benthic sampling, are mixed. Using a variety of diversity and biotic indices to analyze invertebrate data collected from sites with varying degrees of pollution, Barton and Metcalfe-Smith (1992) concluded that although both techniques provided similar results concerning water quality at the control sites and the most degraded municipal and industrial sites, results from multiplate samples were not necessarily consistent with those from bottom samples at sites affected by sewage and agricultural runoff. In contrast, Modde and Drewes (1990) and Slack et al. (1986) concluded that biotic index values derived from multiplate samples were more consistent and accurate than those from natural substrata.

Usefulness as a Monitoring Tool for Mining

An examination of 23 papers published from 1979 to 1994 on the effects of mining and metals on resident benthic macroinvertebrates in freshwater rivers and lakes (Appendix I) revealed that only one used this sampling device. The multiplate sampler can be useful for monitoring the effects of mining because of its low cost, small size and ease of manipulation. These samplers are very fast to retrieve and clean because the smooth surfaces and low detritus retention makes removal of organisms easy. And because of their small size, multiplate samplers can be individually placed in preservative-filled bottles when collected, for later sorting and cleaning in the laboratory. They therefore are attractive for studies in which site access, time or budget are limited.

Applicability to Different Habitat Types

Most studies reviewed used this sampler in small, wadeable, rocky streams, where it was generally found to be effective for collecting macroinvertebrates, though samples were biased as described above. In such streams, the advantages of using artificial substrates are not obvious, since natural substrata can be sampled with less effort, and yield more relevant data regarding the benthic community, and variability among replicates is similar in both sample types (Voshell et al. 1989). As a result, the disadvantages of using multiplate samplers in this situation outweigh the advantages. Multiplate samplers are generally recommended for use in large rivers, where bottom sampling is difficult or impossible, or would not yield useful data regarding environmental effects because the bottom fauna consists predominantly of animals adapted to live in shifting sand or mud.

Tsui and Breedlove (1978) used multiplate samplers in a lake and compared the composition of the invertebrate samples collected with that of bottom samples taken with a Ponar grab. They concluded that the efficiency of the multiplate sampler compared favourably with the petite Ponar grab, but the composition of the samples collected by the two devices was significantly different, as was the case in lotic systems. Multiplate samplers collected mostly littoral zone invertebrates, whereas the grab samples consisted mostly of substratum-associated organisms. In the absence of more reports of the use of this device in lentic habitats, the multiplate sampler is not recommended for routine use in lakes or reservoirs.

3.4 Substrate-filled Bags, Baskets and Trays

General Description

The most commonly used device in this group is the rock-filled basket, a representative artificial substrate sampler which has been widely tested and used to assess the effects of pollution in rivers (21 references cited by Flannagan and Rosenberg 1982; Slack et al. 1986, Kirk and Perry 1992, Mathooko and Mavuti 1992, De Pauw et al. 1994). Other variations of this sampler type include rock-filled plastic mesh bags (De Pauw et al. 1986, 1994, Slack et al. 1982) and trays (six references cited by Flannagan and Rosenberg 1982, Slack et al. 1986, Clements et al. 1989, Clements 1991). Standardized artificial substrates in this category include all of the above containers filled with wire mesh (Beak tray; Beak et al. 1973) Styrofoam balls (Jacobi 1971, Crowe 1972), glass marbles (De Pauw et al. 1994), cement spheres or cones (Jacobi 1971, Benfield et al. 1974, Hall 1982), plastic rings and brushes (De Pauw et al. 1986), conservation webbing (Prins and Black 1971, Hocutt et al. 1976, Voshell and Simmons 1977), porcelain balls (Roby et al. 1978), combinations of these and various other materials. Samplers are either deployed on the bottom or are suspended in the water column.

Because rock-filled baskets (or bags) and trays have been generally accepted as standard representative artificial samplers, they were evaluated in detail below. The Beak tray is the only standardized artificial substrate sampling device in this category which has been widely used for water quality monitoring and was thus also evaluated.

3.4.1 Rock-filled Basket (or bag)

Advantages

Rock-filled baskets are representative artificial substrate samplers which can be used to ample all freshwater habitats with the exception of wetlands (Klemm et al. 1990). With careful screening of the fill material, this device provides a uniform area for colonization. The fill material can be specifically chosen to resemble natural substratum particles in the area to be sampled (e.g. Mathooko and Mavuti 1992), allowing the investigator some flexibility to enhance the relevance of the samples collected. Irregularly-shaped fill material, such as gravel or crushed brick, provides many different microhabitats for colonization. Samples collected by suspended samplers usually contain relatively low amounts of extraneous material (Klemm et al. 1990), but tend to retain detritus to a greater extent than multiplate samplers (Slack et al. 1982). Rock filled basket samplers tend to collect large numbers of invertebrates with low variation among replicate samples (see Section 2.2.3). These devices are heavier and thus, when placed on the bottom, are more stable in currents than multiplate samplers.

Disadvantages

Because of their greater weight, suspended rock-filled baskets may require sturdy suspension and anchoring devices in deep, fast-flowing water (Klemm et al. 1990), and are bulky and difficult to work with. Bottom-placed baskets may collect excessively large amounts of detritus and sediment in large, organically enriched rivers (personal observation), which prolongs sorting time in the laboratory and may increase variability among sites. Other disadvantages of this sampler are common to all artificial substrate samplers.

Sampler Cost

The cost of assembling rock-filled baskets is relatively low. If the fill material consists of gravel or rocks, it is very inexpensive, and widely available. The basket can be purchased at reasonable cost (barbecue basket), or made of metal screening which can be purchased in bulk quantities at even lower cost. Inexpensive plastic mesh bags (e.g. potato bags used by De Pauw et al. 1986) or perforated plastic bags (Slack et al. 1982) may be substituted for the basket. The floatation or anchoring device (an example is described by Klemm et al. 1990), may be the most expensive part of the sampler. However, this part is not needed if the baskets are placed on the bottom or are suspended from fixed structures such as bridges.

Reliability

Failure of basket-type samplers is generally associated with inadequate anchoring, which can result in the movement or loss of samplers, and with conspicuous placement which frequently leads to loss by vandalism (Rosenberg and Resh 1982). Bottom-placed baskets may be turned over, moved, or be deformed by floating logs and debris which becomes entangled in the anchoring rope under conditions of high flow. Water level fluctuation may expose-bottom-placed samplers and may also make them prone to vandalism (personal observation, Rosenberg and Resh 1982).

Sensitivity

Because of the large number and variety of invertebrates this sampler tends to collect, it is a potentially sensitive technique to monitor effluent effects or other human disturbances. A number of studies using this sampler reported that biotic indices based on artificial substrate data sufficiently described the environmental quality of the rivers sampled (e.g. Crossman and Cairns 1974, De Pauw et al. 1994).

Usefulness as a Monitoring Tool for Mining

Of the 23 papers reviewed which investigated the effect of mining and metals on benthic macroinvertebrates (Appendix I), only one had used this sampling device. However, this sampler would be useful to monitor the effects of mining, especially in deep or fast-flowing rivers, where sampling of natural substrata is difficult or impossible.

Applicability to Different Habitat Types

Although rock-filled baskets have been used in all types of lotic habitats and in lakes or reservoirs, the use of this device has been extensively evaluated only in rivers. The basket sampler is suitable for sampling rivers and lakes of all sizes, but is particularly well-suited for large rivers, which are difficult to sample using conventional bottom sampling techniques.

3.4.2 Beak Trays

This sampler consists of a round metal tray with two round, expanded aluminum mesh inserts, which provide the colonization surface (Beak et al. 1973). To retrieve the tray, a lid of slightly larger diameter is lowered to cover the tray by means of a rope attached to the centre of the tray, and the entire apparatus is lifted from the water. The sampler is relatively heavy compared with other artificial substrates and provides a standardized, but not representative surface area for colonization.

Advantages

Beak trays are flat and relatively heavy, which makes them stable in fast rivers. This device provides a standard colonization area and, because water does not flow through the sampler, collects relatively low amounts of detritus and sediments. Variability among replicate samples tends to be low compared with benthic samples (Slack et al. 1986). Beak trays collect large numbers and variety of organisms from sandy, shifting river bottoms that cannot be sampled effectively using conventional means.

Disadvantages

Beak trays are heavy, which may complicate their use to some extent. The colonization substrate is not representative of bottom material, nor can it be adjusted to mimic the locally occurring substratum. The range of microhabitats provided to colonizing animals is relatively low compared with rock-filled containers, which may magnify the bias associated with the use of standardized artificial substrates.

Sampler Cost

The cost of manufacturing this device is greater than that of rock-filled baskets, because it is made of non-pliable materials. However, unless lost, Beak trays are re-usable indefinitely.

Reliability

Although reports of the loss of this sampler are not available, it is a common occurrence (W. Dwernychuk, Hatfield Consultants, personal communication 1995). Sample loss may occur if floating vegetation or debris becomes entangled in the rope used for retrieval, but the sampler may still be recovered. The flat profile of the trays ensures that failure due to turning over or lateral movement is limited.

Sensitivity

Beak trays collect fewer taxa and individuals than multiplates or rock-filled baskets (Slack et al. 1986), which suggests that this device may be less effective for evaluating water quality. Nevertheless, use of this sampler may provide data from rivers which cannot be sampled otherwise.

Usefulness as a Monitoring Tool for Mining

None of the studies reviewed had used this sampler to assess the effect of mining on benthic macroinvertebrates. However, because of its rugged design and ability to sample very large rivers, this sampler is potentially useful to monitor mining effects, but only in large rivers.

Applicability to Different Habitat Types

This sampler is primarily applicable in large, deep rivers, where other sampling techniques tend to fail. It is especially useful in areas with strong currents and an unstable substratum. Use of this sampler has not been extensively demonstrated in small streams or lakes.

3.4.3 Rock-filled Trays

Rock-filled trays of various sizes have been used primarily in small, rocky-bottomed streams to measure colonization rates and to evaluate the usefulness of this device in biomonitoring (Townsend and Hildrew 1976, Shaw and Minshall 1980, Clements et al. 1989, Clements 1991). Trays may be made of metal or plastic with porous or solid walls, and may be placed on the bottom or on a platform above the bottom. Platforms are usually constructed of wood, and allow a row of samplers to be placed across the stream (e.g. Clements et al. 1989).

Advantages

Rock-filled trays are representative artificial substrate samplers. Using standard-sized rocks, this device provides a nearly standard area for colonization. As with rock-filled baskets, the fill material can be specifically chosen to resemble the natural substratum in the area to be sampled and irregularly-shaped fill material provides a large variety of microhabitats for colonization. Rock-filled trays tend to collect large numbers of invertebrates with low variation among replicate samples (Shaw and Minshall 1980, Clements et al. 1989, Clements 1991). This sampler can also be used to collect invertebrate assemblages for laboratory microcosm studies to test the effects of specific toxicants at the community level (Clements et al. 1988, Kiffney and Clements 1994a, 1994b).

Disadvantages

Rock-filled trays cannot be used to sample large, deep rivers, because of complications with removal following colonization, and problems with stability in fast currents. In particular, small trays are not stable in fast currents and may be lost during spates (Clements et al. 1989). Trays may also require a platform for placement in areas with uneven substratum or to reduce the variation in physical variables among replicates, which increases costs, and because of greater visibility, the chance of vandalism.

Sampler Cost

Trays and fill material can be obtained at relatively low cost. The platform required to position trays above the bottom may be the most significant cost associated with this sampler. Bottom-placed trays are thus less expensive.

Reliability

Rock-filled trays have only been used in small, rocky-bottom streams where they have performed well (Clements et al. 1988, 1989). Sampler failure was associated with losses during floods, and vandalism. As noted above, trays placed on platforms above the bottom may be vandalized at higher rates than bottom-placed devices because of greater visibility.

Sensitivity

This sampling device has been demonstrated to be effective for biomonitoring of effluents containing heavy metals by Clements et al. (1988, 1989), who claim that this technique is particularly sensitive in detecting such effects. Because it collects a diverse assemblage with a range of sensitivities to pollutants, the rock-filled tray is a potentially sensitive biomonitoring tool in small streams.

Usefulness as a Monitoring Tool for Mining

The review of 23 papers describing field studies of the effects of mining and metal contamination (Appendix I) uncovered 2 studies using rock-filled trays *in situ*. Clements et al. (1988, 1989) used rock-filled trays successfully to monitor the effluent of a power generating station containing high levels of heavy metals, which resembles the effluents discharged by mines. Based on this information, this technique appears useful to monitor mine discharges in small rivers. Use of this sampler to collect test communities for microcosm toxicity studies (Clements et al. 1988, Kiffney and Clements 1994a, 1994b) is an interesting and potentially valuable application, but is at the experimental stage at this time.

Applicability to Different Habitat Types

The rock-filled tray is primarily suitable for sampling shallow, wadeable streams and potentially, shallow lakes, where conventional bottom sampling is also feasible. The applicability of this sampler in toxicity testing presents a worthwhile topic for further research.

3.5 Sampling Protocol

All artificial substrates are used to collect benthic macroinvertebrates according to the same basic sampling protocol. Replicate samplers are installed at the desired locations and are marked in some manner to facilitate recovery. After a pre-determined length of time, the samplers are removed and cleaned to remove all colonizing animals, which are then preserved for enumeration and identification. Artificial substrate samples are processed according to protocols used for benthic samples collected using conventional means.

Aspects of the sampling protocol which have received considerable attention by investigators or are controversial are discussed below for the samplers discussed in this section. A number of these may be adjusted to fit the objectives of specific studies.

Sampling Season

Most investigators agree that sampling using artificial substrates should be conducted during the warmer seasons, when colonization is more rapid than in winter (e.g. Shaw and Minshall 1980, Klemm et al. 1990, Mathooko and Mavuti 1992). Additional considerations regarding when to sample include annual patterns in river discharge, water level fluctuation and public use of the water body sampled. It is especially important to avoid spates and floods which may cause considerable sampler loss. In temperate areas of Canada, the late summer-early fall low flow period is generally suitable for invertebrate sampling using any sampling technique.

Sampler Size and Number of Replicates

Artificial substrate samplers of varying sizes have been used by different investigators, but few assessed the effect of varying sampler size on data variability and sample processing time. The number of plates in multiplate samplers may vary from four (Meier et al. 1979) to fourteen (Fullner 1971). Similarly, the fill material used in rock-filled baskets may vary from 1400 to 9000 cm^3 (Khalaf and Tachet 1980, De Pauw et al. 1986) and the bottom area of rock-filled trays can vary from 10 x 10 cm to 30 x 30 cm (Crossman and Cairns 1974, Clements et al. 1989, Clements 1991). Only the standard (40 cm diameter) Beak tray was used in the literature reviewed (Beak 1973, Slack et al. 1986).

It is frequently stated that the use of a larger number of smaller sampling units can improve the quality of data collected because a larger number of replicate samples can be collected and processed with a given amount of effort than when using larger sample units (Downing 1979, Morin 1985, Voshell et al. 1989). Therefore, it seems reasonable that the artificial substrate samplers used to assess water quality should be as small as possible. De Pauw et al. (1986) evaluated the effect of varying the amount of fill material in rock-filled plastic mesh bags (2250-10250 cm^3) and concluded that the medium-sized (4500 cm^3) samplers were ideal, though even the sampler containing the smallest amount of material (2250 cm^3) provided results comparable with standard hand-net collections in terms of the number taxa per sampler. Clements et al. (1988, 1989) and Clements (1991) have routinely used the smallest-sized rock-filled trays described in the literature (10x10 cm) and did not report any shortcomings regarding the variation among replicate samples, though sampler stability in strong currents is probably compromised as its size is reduced. Khalaf and Tachet (1980) evaluated three different-sized (1400, 2500, 3900 cm^3) rock-filled baskets to arrive at the optimum volume for this sampler, and concluded that the 2500 cm^3 baskets provided the best balance between the number of individuals and taxa collected and processing time required. Overall, these studies indicate that up to a certain limit, smaller sampling units generally provide similar data to those generated by the frequently larger, "standard" samplers.

The most frequently used number of replicate samplers is three to five. Several studies calculated the number of replicates required to achieve a pre-determined degree of precision. The most frequently calculated number of replicates is the number necessary to achieve a standard error equal to 20% of the mean, which is considered reasonable for benthic invertebrates (Elliott 1977). The required number of replicates to achieve this precision in different studies varies from two to three (Hall et al. 1982, Slack et al. 1986) for total taxa and from six to eleven (Hall et al. 1982, Slack et al. 1986) for total individuals on multiplate samplers. The number of replicates required to achieve the same precision on rock-filled trays and baskets and on Beak trays are similar (Slack et al. 1986, Shaw and Minshall 1980) or slightly higher (Hall et al. 1982, Clements et al. 1988).

The most frequently recommended number of replicates for artificial substrate samplers is three (Mason et al. 1973, Voshell and Simmons 1977, De Pauw et al. 1986). Based on a review of the literature, Klemm et al. (1990) also recommended the use of three replicate samplers of multiplates and rock-filled baskets to achieve acceptable precision. However, the majority of studies reviewed only estimated the number of replicates required to obtain precise estimates of total individuals and total taxa, and occasionally, total biomass and the value diversity indices. In the majority of benthic invertebrate studies evaluating environmental quality, estimates of the abundances of dominant taxa or groups of taxa are also of interest, which will invariably require a larger number of replicates. Five or six replicates appears more suitable for the majority of studies, with allowances for factors described below.

Three additional issues regarding the number of replicates involve the size and environmental quality of the river sampled and the potential for sampler loss. In small, unproductive streams, benthic invertebrate communities are characterized by greater variability, lower density and fewer available colonists than in large rivers (Clements 1991). As a result, larger number of replicates may be needed to collect samples with sufficient numbers of invertebrates and acceptable variability among replicates. It is also generally agreed that the less polluted a river is, the more replicates will be needed to achieve the same level of precision (De Pauw et al. 1986, Dickson et al. 1971). Extra replicates are necessary in rivers of any size to compensate for sampler loss, which is inevitable when using artificial substrates.

In light of the information summarized above, the number of replicate samples should usually be greater than the widely recommended three. Ideally, a pilot study should be conducted before a larger-scale investigation using the sampler of choice in the study system to obtain information regarding the ideal sampler size and the required number of replicates. However, this is frequently not feasible due to budget and time constraints. Therefore, at the very least, the investigator should review the available literature on the fauna and physical characteristics of the water body studied to uncover potentially useful information which may be used in lieu of the pilot study. In the absence of such information, the number of replicate samplers required should be five or six. Additionally, use of a sequential sampling scheme, consisting of evaluating precision during the sample processing phase and adjusting the number of replicates processed, allows the use of only the required number of replicates.

Sampler Placement

Artificial substrate samplers (except Beak Trays) may be suspended in the water column (Mason et al. 1967) or placed on the bottom (Slack et al. 1986) depending on the objectives of the study and the characteristics of the water body monitored. Bottom placement is attractive because it allows colonization from all natural sources and is thus more likely to result in an invertebrate assemblage on the sampler which resembles the bottom fauna. Despite this feature, a number of arguments can be made against bottom placement. Depending on the natural substratum and the amount of suspended sediments in the water column,-bottom-placed samplers may accumulate large amounts of fine sediments to the extent that they become fouled. The accumulation of sediments can result in the loss of control over substratum composition, the most important variable standardized by the use of artificial substrates (Mason et al. 1973). In addition, it has been shown that the composition of the invertebrate fauna on bottom-placed samplers still tends to be different from the indigenous benthic fauna (Voshell and Simmons 1977, Khalaf and Tachet 1980, Slack et al. 1986). As well, Townsend and Hildrew (1976) have found only slight differences between invertebrate communities on bottom-placed trays and trays placed on platforms. It has also been shown that the largest proportion of colonizing animals in streams are derived from the drift (Townsend and Hildrew 1976, Williams and Hynes 1976).

The above information suggests that the advantages of bottom placement may not be meaningful, especially when considering the disadvantages associated with this mode of deployment. Although the fauna developing on suspended samplers are not representative of the bottom, this disadvantage evidently affects all artificial substrates regardless of placement in the water column. It is generally recommended that suspended samplers be positioned within the euphotic zone, generally within one metre of the surface (Klemm et al. 1990). Boothroyd and Dickie (1989) compared invertebrate fauna on samplers suspended just below the surface and near the bottom in a shallow river and found only minor differences, in spite of consistent differences in current velocity at the two depths sampled.

Suspended samplers are not without their disadvantages. In the absence of a structure from which to suspend the samplers, they require elaborate floats and anchoring devices which can fail under high flows or if snagged by floating debris. Another disadvantage of suspended samplers is related to the type of colonizing organisms. Because suspended rock-filled baskets are colonized by frequently-drifting invertebrates, those animals may evacuate faster than others in response to a disturbance, and the investigator may conclude that the effect is more severe than is the real effect (see Section 2.3.3).

Duration of Exposure

Most research on exposure time has debated the time necessary to achieve equilibrium, defined operantly as the point where community composition on the sampler is not significantly different (as defined by a similarity index) from that on surrounding substratum of similar material (Gore 1982). Community equilibrium in this sense is probably not necessary for effective monitoring, and considering the selectivity of artificial substrates, it may not even be possible. Equilibrium defined more narrowly as a lack of change in species composition on the sampler still may not be reached at many sites without a prohibitively long exposure time. In some situations it may not be reached at all, for example where a sampler is continuously collecting silt.

For effective monitoring, the appropriate exposure time is that which permits a reasonably stable community to develop which reflects the ambient water quality conditions at the site. The ideal exposure time is therefore near the peak of the colonization curve in Figure 1, where numbers and diversity are maximal, and rapid changes in habitat suitability (periphyton, detritus) and species composition are finished. This community may still undergo re-structuring during the final stages of succession as density-dependent forces such as predation and competition become important, but these changes should not materially affect the sensitivity of the method.

In river channels where artificial substrates are surrounded by suitable habitat for invertebrates, species richness, total numbers and biomass usually plateau in under 30 days (Section 2.1). In practice, artificial substrates used for water quality monitoring are routinely left in place for four to six weeks (Klemm et al. 1990). The optimal duration is a trade-off between the benefit of more complete colonization and the risks of losing samplers, trapping too much silt, or missing a sampling window. Based on the literature, four weeks would be sufficient in rock-bottomed streams, but direct benthic sampling should be used in such sites. For depositional zones where drift from upstream is the principal route of colonization, it would be best to leave artificial substrates in place for six weeks, to allow for delayed colonization. That time may have to be adjusted for pragmatic reasons, depending on the particular site in question. A pilot study is recommended to confirm that the selected exposure time is sufficient. It is self-evident that exposure times should be the same for all sites in any monitoring program.

Loss of Animals During Sampler Retrieval

Loss of invertebrates from samplers during retrieval has been noted as a disadvantage of using artificial substrates (Section 2.3.4). Rosenberg and Resh (1982) provided a summary of the percentages of individuals lost during retrieval of samplers if measures are not taken to prevent it. Typical losses from rock-filled baskets during retrieval were in the 10 to 20% range, though losses of 30-60% have also been reported. Zillich (1967) tested a number of artificial substrate samplers and concluded that most insects quickly leave the sampler when it is initially disturbed during retrieval. In light of this information, it is advisable to devise some method of retaining animals which drift from the sampler during retrieval. The most common technique is the placement of a fine-mesh net below the sampler or around it during retrieval, and adding the collected material to the sample (Weber 1973, Rosenberg and Resh 1982, Klemm et al. 1990). This may not be feasible in deep or turbid rivers where fast currents prevents the use of a downstream net or the samplers may not be visible. In those situations, the use of the Beak Tray is recommended, since its design incorporates a lid which is lowered during retrieval to prevent sampler loss.

Another point of debate in the literature concerns whether or not to discard the animals which have colonized the sample container. One study which used standardized artificial substrates retained animals from the containers and included them in the sample (De Pauw et al. 1994), whereas another did not (Hall 1982). Studies using representative artificial substrates tended to include those animals. For the purposes of biomonitoring, it is advisable to include animals from the container because the container may provide additional microhabitats for colonists that are not provided by the filling material. Occasionally, mats of vegetation or filamentous algae may be snagged by the sampler (personal observation). In those cases, it is advisable to discard the affected sampler, since sample composition may be considerably different relative to other samplers.

Field Measurements

A number of variables should be measured at the time or deployment and removal of artificial substrate samplers. These measurements facilitate data interpretation and the identification of factors, other than the disturbance monitored, which may affect the benthic community at the sampling sites. Variables which should be recorded at the time of deployment and retrieval include (1) current velocity and depth at the sampler locations, (2) pH, dissolved oxygen, conductivity and temperature if these variables may be affected by the disturbance studied, (3) qualitative habitat-related information such as bottom type and the amount and type of aquatic vegetation. Quantifying the surface area of the artificial substrate is usually not necessary, because this measure is not a good indicator of the space available for colonization and will vary little, if any, among samplers. However, measurements of the amount of detritus collected by the sampler (as dry weight or ash-free dry weight) and the amount periphyton growth on the artificial substrate (as chlorophyll *a*, if the sampler was placed in the euphotic zone) may be valuable during data interpretation.

Prevention of Sampler Loss

Several techniques are available to ensure minimal sampler loss, though none will eliminate it altogether. The major causes of losses are vandalism, exposure during low water level, movement or damaging of samplers by fast currents during spates or by floating objects and burial by sedimentation (Rosenberg and Resh 1982). Based on information summarized by Rosenberg and Resh (1982) and subsequent papers, techniques to minimize sampler loss include:

> inconspicuous marking of sites, careful sampler design and placement, avoidance of areas frequented by the public, or conversely, the use of warning or explanatory signs;
>
> increasing the number of replicates, and using inexpensive materials to compensate for losses;
>
> sampling during periods of stable, low flow and adjusting the depth of sampler placement based on information on the amplitude of water level fluctuation during the sampling period;
>
> altering sampler design by making samplers sturdy, heavy and well-anchored; and
>
> guards to protect samplers from fouling.

4.0 USEFULNESS OF ARTIFICIAL SUBSTRATES TO MONITOR THE EFFECTS OF MINING

4.1 Potential of the Method

Relatively few recent studies have used artificial substrates to monitor the effects of mining or metal pollution on benthic macroinvertebrate communities. During the course of this review we examined 23 papers describing field studies investigating the effects of mining and metals in freshwater systems, spanning the period from 1979 to 1994 (Appendix I). Twenty studies were done in small, rocky streams or in shallow riffles of larger rivers, or obtained invertebrates from small streams for use in mesocosm studies; two were in lakes or pits; and only one was in a large river. Thirteen studies used kicknets, driftnets, Surber samplers, Hess samplers or box samplers; the two lentic studies used the Ekman dredge and the single large-river study used an airlift sampler and driftnets. Eight studies used artificial substrates: bricks (1), rock-filled trays (5), multiplates (1), polyurethane foam (1), and rock-filled basket (1). Four of those studies used artificial substrates to collect invertebrates for mesocosm studies. This survey of the recent literature indicates that artificial substrates are occasionally being used to assess the effects of mining and metal pollution, but only in small streams where traditional bottom sampling techniques are already adequate to obtain quantitative samples.

Nonetheless we conclude that artificial substrates do have a place in an efficient and cost-effective biomonitoring program for the Canadian mining industry. We do not recommend that artificial substrates be used as the standard method for sampling benthic invertebrate communities at all sites. There is no advantage to be gained from using artificial substrates in shallow streams and rivers with cobble or gravel substrata. In these kinds of systems conventional sampling techniques provide at least as reliable data as artificial substrates without many of their drawbacks and difficulties. Moreover, because all artificial substrates are selective for certain kinds of organisms, they can never be depended upon to produce reliable samples of the indigenous invertebrate community. This sampling bias will be greatest in many of the habitats were artificial substrates are most likely to be used. Wherever conditions are amenable to conventional sampling methods, these should be preferred over artificial substrates; the indigenous community will always be the best indicator of environmental quality.

Rather, artificial substrates should be reserved for those locations where conventional sampling is inefficient or unfeasible, especially lentic habitats or those with soft or unstable substrata. In these kinds of habitats, artificial substrates are a potentially useful means of assessing water quality and effluent effects. While the approach is not without its shortcomings even here, in many instances artificial substrates allow samples to be collected from environments that simply cannot be sampled effectively by any other means.

The effects of mining on receiving water bodies are generally exhibited as increases in the concentrations of metals or suspended sediments. Both of these disturbances cause declines in invertebrate abundance and potentially in taxonomic richness, as sensitive animals leave the affected area or are killed by toxic components of the effluent. It follows that, to effectively monitor such effects, a sampling technique that collects large numbers of invertebrates is desirable to obtain an adequate representation of the fauna in the affected reach and to minimize the variation among replicates. In depositional zones, artificial substrate samplers may be better suited to monitor mining effects than traditional bottom sampling, because they collect very large numbers of invertebrates compared with natural substrata and collect diverse assemblages which include organisms with a wide range in pollution tolerance.

The key to successful application of artificial substrates is to have a clear and precise objective beforehand, and to understand exactly what the artificial substrates are capable of measuring. The invertebrate community on an artificial substrate is an indicator of water quality (or effluent quality if it is in the effluent plume) during the period of exposure. These samplers do not (1) measure the composition of the native bottom fauna, (2) indicate habitat conditions other than water quality, (3) estimate availability of food organisms, or (4) integrate long-term effects of pollution. The samplers function essentially as an on-site, multi-species toxicity test that uses the colonization success of drifting and migrating organisms as the endpoint. Careful comparison of community composition of artificial substrate samples from above and below a point source such as mine effluent can provide information on the nature, degree and extent of potential environmental effects from the effluent, one of the objectives of a biomonitoring program. Direct sampling of the indigenous fauna must be used to assess the real condition of the ecosystem. Therefore, artificial substrates are best used as one component of a multi-part program, in which measurements of indigenous fauna, water or sediment quality, and possibly laboratory toxicity tests, are combined to provide a clear picture of the state of the system and the effects of mine effluents.

4.2 Conclusions and Recommendations

1. Artificial substrate samplers may be a useful component of a biomonitoring program for the Canadian mining industry if the strengths and limitations of these devices are understood. Because artificial substrates have a number of disadvantages relative to sampling the natural substratum, they should only be used for environmental monitoring on rivers or lakes that cannot be sampled using traditional means. Situations where artificial substrates could be used include (1) water bodies with very deep or turbid water, (2) water bodies with soft or unstable bottoms of sand, mud or organic ooze, (3) water bodies with unbroken bedrock bottoms or bottoms of large boulders and (4) rivers with torrential currents. As also noted by Voshell et al. (1989), use of artificial substrates is not justified in shallow, rocky-bottomed streams or rivers where the variation in habitat type within the study reach is relatively minor and an abundant and diverse indigenous fauna may be expected. An exception could be made to this rule if the study area included both hard-bottomed and soft-bottomed habitats and consistency in the sampling method were desired.

2. The principal advantages of artificial substrates for environmental monitoring are:

    They permit sampling from habitats that would be otherwise difficult to sample effectively;

    They allow greater flexibility in selection of sampling sites than conventional sampling, and allow comparison of environmental effects of effluents along a watercourse where the macrohabitat is not constant (such as erosional zones upstream and depositional zones downstream);

    They reduce variance in organism densities among samples, and thereby increase the sensitivity of the monitoring program by allowing detection of smaller site differences than conventional sampling methods;

They collect greater numbers, and a much greater diversity, of invertebrates in lentic or depositional habitats, and thereby improve the sensitivity of the monitoring program compared with conventional methods;

They allow quantification and standardization of the area being colonized by benthic invertebrates in each sample;

They can be modified in design or deployment to suit local conditions; and

They are relatively inexpensive and simple to construct.

3. The principal disadvantages of artificial substrates for environmental monitoring are:

They do not collect a representative sample of the indigenous benthos at the site where they are placed, but rather select for mobile, drift-prone species of hard substrata. Therefore they indicate the potential effect of an effluent or disturbance, not the real effect;

They indicate only the water quality during the colonization period, and do not integrate long-term effects over several months as do conventional benthic invertebrate samples; conversely they cannot be used for event monitoring because of the long exposure time required;

They do not effectively monitor the effects of sediments or sediment-bound toxicants on aquatic biota because sediment-dwelling taxa tend to be under-represented in artificial substrate samples. This is a potentially significant difficulty in using artificial substrates to monitor mining effects because metals tend to partition onto fine sediments, which are not effectively sampled by artificial substrates;

They may overestimate the real severity of an effluent or disturbance because vagile organisms colonizing the samplers are apt to re-enter the drift, lowering the species diversity and possibly interrupting the expected successional sequence;

They require a long period for colonization, and colonization dynamics, and hence optimum exposure times, are incompletely known;

They require two trips for each sample, effectively doubling the cost of field sampling compared with conventional sampling;

They are prone to loss from accidents, high flows and vandalism, which creates irreparable gaps in the data and adds to the cost of field work;

They may be bulky, heavy and difficult to handle and transport, and field deployment is often logistically complicated; and

They may lose organisms while the sampler is being retrieved, especially in deep waters were it is not feasible to use a collecting net.

4. Four kinds of artificial substrate sampler are potentially useful for environmental monitoring in the Canadian mining industry: multiplate samplers, Beak trays, rock-filled baskets and rock-filled trays. Rock-filled baskets are recommended as the sampler of choice for most applications in mine effluent monitoring because (1) they closely mimic natural substrata yet (2) permit standardization of sampler area, (3) provide abundant microhabitat for colonization, (4) produce low replicate variability, (5) are reasonably stable in currents and (6) are easy and cheap to build. Beak trays are recommended for the particular application of sampling large, fast-flowing rivers with unstable substrata, where other sampling techniques would be ineffective, dangerous, or prone to failure. Though they collect less representative samples than rock-filled baskets, multiplate samplers have the advantages of small size and ease of use, and may be useful for sampling large, soft-bottomed rivers, where bottom sampling is difficult or impossible. Rock-filled trays hold considerable promise but should be considered experimental for now.

5. An exposure period of six weeks is recommended as optimal for artificial substrates used for biomonitoring. The period may sometimes be shortened somewhat, to a minimum of four weeks, if circumstances require it. Pilot studies to determine the optimum exposure time are recommended in unusual environments or those that have not previously been sampled.

6. The low flow period from late summer to early fall is usually the best time for benthic invertebrate sampling with any artificial substrate. Where site conditions permit, the sampler should be placed on the bottom of the water body to take advantage of all possible sources of colonization. Samplers suspended in the water column can still be effective, but are more difficult to deploy. Fine-mesh nets or other means should be

used to minimize losses of invertebrates while the sampler is being removed. A number of environmental variables (pH, dissolved oxygen, conductivity, temperature, current velocity, depth) should be measured when the samplers are placed and again when they are retrieved. Measuring the amount of periphyton growth or detritus accumulation in the samplers can aid data interpretation and is strongly recommended.

7. Sampling efficiency would be greatly improved by using smaller samplers and increasing the number of replicates. We recommend using the smallest feasible sampler, which for rock-filled baskets is 2500 cm^3, and increasing the number of replicates to at least six, with an additional allowance for lost samplers. Time and effort can be saved in this plan by using a sequential sampling plan, in which samples are only sorted and identified until the variance of mean numbers (or other sample variables) falls within a pre-determined range.

8. There are too few published data on which to base an assessment of the utility of artificial substrates in lakes, or to properly compare the efficacy of the various designs. Limited data suggest artificial substrates are promising tools for assessment of environmental impacts of mining on lakes. This information deficiency should be remedied by undertaking a simple study comparing benthic invertebrate populations with populations colonizing artificial substrates in a lake or lakes with different substratum characteristics. The study should include a comparison of invertebrate populations in a lake or part of a lake receiving mine effluent.

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APPENDIX I

SELECTED REFERENCES ON THE EFFECTS OF MINING AND METALS ON BENTHIC MACROINVERTEBRATES IN FRESHWATER SYSTEMS

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Faith, D.P., C.L. Humphrey and P.L. Dostine. 1991. Statistical power and BACI designs in biological monitoring: comparative evaluation of measures of community dissimilarity based on benthic macroinvertebrate communities in Rockhole Mine Creek, Nothern Territory, Australia. Aust. J. Mar. Freshwater Res. 42:589-602.

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APPENDIX II

ANNOTATED BIBLIOGRAPHY ON THE USE OF ARTIFICIAL SUBSTRATES TO MONITOR BENTHIC INVERTEBRATES

American Public Health Association, American Water Works Association and Water Pollution Control Federation. 1985. 1005 A. Benthic macroinvertebrates. In Standard methods for the examination of water and wastewater. 16th Ed. Washington, D.C., pp. 1113-1130.

Description of benthic invertebrate sampling devices and detailed sampling methods, including conventional bottom samplers and artificial substrates.

Anderson, J.B. and T. Mason, Jr. 1968. A comparison of benthic macroinvertebrates collected by dredge and basket sampler. J. Water Poll. Con. Fed. 40:252-259.

Performance of the basket sampler was compared with that of the Petersen dredge. Basket samplers were found to collect a greater variety and density of invertebrates than the dredge sampler, but collected fewer representatives of the sediment infauna. The capability of the basket sampler to collect a more complete representation of benthic macroinvertebrates is of great value in water pollution investigations.

Beckett, D.C. and M.C. Miller. 1982. Macroinvertebrate colonization of multiplate samplers in the Ohio River: the effect of dams. Can. J. Fish. Aquat. Sci. 39:1622-1627.

The importance of contrasting current velocities was investigated in a large river. Multiplate samplers were colonized in fast and slow-flowing water and some samplers were switched between the two treatments before the end of the study. Widely different communities became established on the samplers in the two contrasting flow conditions. The transfer portion of the experiment demonstrated that a sudden reduction in current velocity will cause large increases in invertebrate drift.

Barton, D.R. and J.L. Metcalfe-Smith. 1992. A comparison of sampling techniques and summary indices for assessment of water quality in the Yamaska River, Quebec, based on benthic macroinvertebrates. Environ. Monitor. Assessment. 21:225-244.

The responses of the resident and colonizing components of the benthic macroinvertebrate community to municipal/industrial versus agricultural pollution were investigated in the Yamaska River drainage basin, and the performances of seven diversity and biotic indices for assessing water quality were evaluated. Samples of riffle-dwelling, infaunal and colonizing invertebrates were collected from 13 stations representing a wide variety of types and degrees of pollution using Surber, scoop and artificial substrate samplers. With most of the samples, all of the summary indices suggested that the impact of agricultural practices on stream ecosystems may be as severe as the impacts of municipal and industrial wastes.

Beak, T.W., T.C. Griffing and A.G. Appleby. 1973. Use of artificial substrate samplers to assess water pollution, In Biological methods for the assessment of water quality. ASTM Spec. Tech. Publ. 528, J. Cairns Jr. and K.L. Dickson, Eds. (Philadelphia: American Society for Testing and Materials, 1973), pp. 227-241.

Description of the Beak tray and its use in the Mackenzie River.

Boothroyd, I.K.G. and B.N. Dickie. 1989. Macroinvertebrate colonization of Perspex artificial substrates for use in biomonitoring studies. N. Zeal. J. Mar. Freshwater Res. 23:467-478.

Perspex multiplate artificial substrates were deployed in the Ohinemuri River on two occasions from May to November 1987. A pilot study was conducted to compare the fauna on substrates with that occurring naturally in the benthos, and a second study to investigate the colonization dynamics. The artificial substrates were slightly more variable in their density estimates than was the natural benthic sampler, but were considered suitable for collecting macroinvertebrates for biomonitoring studies where conventional techniques are impractical or inappropriate, and the stated aims of the use of artificial substrates are clearly defined.

Bull, C.J. 1968. A bottom fauna sampler for use in stony streams. Prog. Fish Cult. 30:119-

120.

Description of the Bull basket and its use.

Clements, W.H. 1991. Characterization of stream benthic communities using substrate-filled trays: Colonization, variability, and sampling selectivity. J. Freshwater Ecol. 6:209-221.

This research examined colonization rate, variability and sampling selectivity of substrate-filled trays collected from six streams (second-sixth order) in Virginia and West Virginia. The length of time required to obtain equilibrium communities in trays varied among streams. The results suggest that longer colonization periods may be necessary to characterize the benthic communities of small streams. Trays were selective for collector-filterers; however, most dominant taxa present in the natural substrate were also present in trays. Sampling variability of trays was generally less than or similar to variability of Hess samplers and decreased in larger streams. Because of lower variability and ease of collection, the trays described in this study are a practical alternative to conventional sampling devices and will be useful for assessing the impacts of contaminants on benthic communities.

Clements, W.H., D.S. Cherry and J. Cairns, Jr. 1988. Impact of heavy metals on insect communities in streams: A comparison of observational and experimental results. Can. J. Fish. Aquat. Sci. 45:2017-2025.

This research compared effects of heavy metals on macroinvertebrate communities in outdoor experimental streams with those observed at impacted field sites. The similarity of experimental results to those obtained form field sites suggests that outdoor stream mesocosms may be employed to predict macroinvertebrate community responses to heavy metals.

Clements, W.H., J.H. Van Hassel, D.S. Cherry and J. Cairns, Jr. 1989. Colonization, variability, and the use of substratum-filled trays for biomonitoring benthic communities. Hydrobiologia 173:45-53.

Sampling variability and colonization rate of introduced substrates (plastic trays filled with pebble and cobble) in two southwestern Virginia streams are described. Substrates were rapidly colonized by aquatic macroinvertebrates, but colonization rates differed between years, possibly due to annual variability in macroinvertebrate abundance. To examine the applicability of using these substrates for biomonitoring benthic communities, trays were placed at several locations in a river receiving power plant discharges. Only six samples were necessary to detect a 15% reduction in macroinvertebrate density and a 12% reduction in number of taxa at effluent sites. Benthic communities established on rock-filled trays and multiplate samplers collected from the same stations during the same period were compared. Although multiplate samplers were more variable than rock trays and were selective for different taxa, both substrate types showed significant differences in community parameters among locations.

Clifford, H.F., R.J. Casey and K.A. Saffran. 1992. Short-term colonization of rough and smooth tiles by benthic macroinvertebrates and algae (chlorophyll *a*) in two streams. J. N. Am. Benthol. Soc. 11:304-315.

The importance of substratum texture and the colonization dynamics of stream macroinvertebrates and algae (measured artificial substrata and two sampling designs in two ecologically different streams. Rough and smooth clay tiles were used in two short-term colonization studies, which were conducted in a 2nd-order Rocky Mountain foothill stream and a 2nd-order stream in a boreal mixed woodland. Similar results provide strong evidence for the importance of substratum texture in streams. Several taxa showed similar trends in colonization to the quantity of chlorophyll a on the tiles. But after 1-4 d, when there was little chlorophyll a on the tiles, density of total number of organisms and most taxa was greater on rough tiles than on smooth tiles.

Cover, E.C. and R.C. Harrel. 1978. Sequences of colonization, diversity, biomass, and productivity of macroinvertebrates on artificial substrates in a freshwater canal. Hydrobiologia, 59: 81-95.

The sequence of colonization, species diversity, biomass and productivity of macroinvertebrates on artificial substrates were determined in a freshwater canal. Benthic community structure was also compared with artificial substrate community structure. Neither collection diversity or cumulative diversity reached an asymptote during the 16 week study period. Biomass increased linearly to seven weeks, fluctuated widely until 14 weeks and then increased sharply to the end of the study period. Community composition in benthic samples was different from that on artificial substrates.

Crossman, J.S. and J. Cairns, Jr. 1974. A comparative study between two different artificial substrate samplers and regular sampling techniques. Hydrobiologia 44:517-522.

A commercially available floating sampler consisting of styrofoam and conservation webbing was compared with a bottom basket sampler and the Surber sampler. The bottom basket sampler was more reliable than the floating sampler as indicated by comparison of diversity indices between the artificial substrate samplers and the Surber sampler. Artificial substrate samplers have limitations but may be very useful tools in pollution assessment.

De Pauw, N., D. Roels and A.P. Fontoura. 1986. Use of artificial substrates for standardized sampling of macroinvertebrates in the assessment of water quality by the Belgian Biotic Index. Hydrobiologia 133:237-258.

The paper reviews 3 years of experience in Belgium and Portugal with artificial substrates for collecting macroinvertebrates used in water quality assessment by means of the Belgian Biotic Index (B.B.I.). Artificial substrates provide a valid alternative method for sampling the macroinvertebrate fauna and the possibility of standardizing the sampling effort, whereas sampling with a handnet may be more subjective. Research has been focused on the effect of sampler design and composition as well as conditions of exposure on the number of systematic units and the biotic index obtained. With artificial substrates correct assessments could be performed in different types of watercourses, including lowland brooks and canals as well as fast running upland rivers located in different climates. Guidelines for the development of a simple standard procedure with artificial substrates are proposed.

De Pauw, N., V. Lambert, A. Van Kenhove and A. Bij De Vaate. 1994. Performance of two artificial substrate samplers for macroinvertebrates in biological monitoring of large and deep rivers and canals in Belgium and the Netherlands. Env. Monitoring and Assessment 30:25-47.

An extensive monitoring campaign was organized in Belgium and The Netherlands to test the efficiency of artificial substrates colonized by macroinvertebrates as an alternative for natural communities sampled with a handnet. The results show that both the Belgian and the Dutch artificial substrate sampler can replace the usual samples obtained by means of a handnet, and provide a correct assessment. A major drawback of the use of artificial substrates in uncontrolled monitoring sites remains the unforeseen losses. For that reason the cost price of the substrates may have to be considered when making a selection.

Dickson, K.L., J. Cairns, Jr. and C.J. Arnold. 1971. The evaluation of the use of a basket-type artificial substrate for sampling macroinvertebrate organisms. Trans. Am. Fish, Soc. 100: 553-559.

The results obtained from the use of bottom, basket type, artificial samplers were analyzed statistically to determine the sampler s efficiency in collecting aquatic macroinvertebrates at two ecologically similar riffle stations. When using this type of sampler for biomonitoring, the number of taxa and the community structure are less variable than the number of specimens obtained. The types of analyses described in this publication are useful for establishing the appropriate number of samples for a routine survey.

Elliott, J.M., C.M. Drake and P.A. Tullett. 1980. The choice of a suitable sampler for benthic macroinvertebrates in deep rivers. Pollut. Rep. Dep. Environ. No. 8, pp. 36-44.

Although macroinvertebrates are relatively easy to sample in shallow water (depth < 1m), quantitative sampling poses more problems than qualitative sampling because a large number of replicate sampling units are usually required for accurate estimates of numbers or biomass per unit area. Both qualitative and quantitative sampling are difficult in deep water (depth > 1m). The present paper first considers different types of samplers with emphasis on immediate samplers, and then discusses some problems in choosing a suitable sampler for benthic macroinvertebrates in deep rivers.

Faith, D.P., C.L. Humphrey and P.L. Dostine. 1991. Statistical power and BACI designs in biological monitoring: comparative evaluation of measures of community dissimilarity based on benthic macroinvertebrate communities in Rockhole Mine Creek, Northern Territory, Australia. Aust. J. Mar. Freshwater Res., 42:589-602.

As part of investigations into strategies for biological monitoring of mining impacts in the vicinity of the Kakadu Conservation Zone, statistical procedures were evaluated in nearby Rockhole Mine Creek, a site of past mining activities. The BACI design and associated statistical test is based on temporal replication of some measure of difference between paired control and impact areas, and it requires that the difference values meet certain statistical requirements while providing adequate statistical power.

Flannagan, J.F. and D.M. Rosenberg. 1982. Types of artificial substrates used for sampling freshwater benthic invertebrates. Chapter 7, In Cairns, J. Jr. (editor) Artificial substrates. Ann Arbor Science, Ann Arbor, 279 p.

A comprehensive listing of artificial substrate samplers with descriptions of major features, based on an extensive review of the literature.

Gibbons, W.N., M.D. Munn and M.D. Paine. 1993. Guidelines for monitoring benthos in freshwater environments. Report prepared for Environment Canada, North Vancouver, B.C. by EVS Consultants, North Vancouver, B.C. 81 pp.

Environment Canada s guidance manual on benthic invertebrate monitoring in freshwater systems. Topics covered include quality assurance and quality control, study design, sampling equipment, field sampling, sample processing, data analysis and reporting.

Hall, T.J. 1982. Colonizing macroinvertebrates in the Upper Mississippi River with a comparison of basket and multiplate samplers. Freshwater Biology 12:211-215.

Colonizing aquatic macroinvertebrates were collected from two kinds of artificial substrate placed on wing dams in Pool 13 of the Upper Mississippi River in September 1978. Basket samplers had a significantly greater macroinvertebrate density, biomass and number of taxa compared with multiplate samplers. Basket samplers with 7.5-cm cement spheres are recommended for use instead of multiplate samplers.

Hellawell, J.M. 1978. Macroinvertebrate methods. In Biological surveillance of rivers. A biological monitoring handbook. Dorset Press, Dorchester, England. pp. 35-90.

Chapter 4, Macroinvertebrate Methods describes a number of types of artificial substrate samplers, with notes on their use and sampling efficiency.

Hester, F.E. and J.S. Dendy 1962. A multiple-plate sampler for aquatic macro-invertebrates. Trans. Am. Fish. Soc. 91: 420-421.

Description of the first version of the multiple plate sampler and its use.

Hill, J.P. and W.J. Matter. 1991. Macroinvertebrate colonization of Hester-Dendy samplers in different orientations to water flow. Calif. Fish and Game 77:94-97.

Hester-Dendy (multiple-plate) invertebrate samplers have been widely used in ecological monitoring studies. For some insect families the orientation of Hester-Dendy samplers to the direction of water flow can have a significant effect on the abundance of macroinvertebrates that colonize them. Uniform orientations of samplers may reduce variability in invertebrate colonization, but alternating orientations may offer a broader range of microhabitats for colonization.

Hilsenhoff, W.L. 1969. An artificial substrate device for sampling benthic stream invertebrates. Limnol. Oceanogr. 14: 465-471.

The role of aquatic insects and other macroinvertebrates as indicators of water quality is well recognized. In this role comparisons of populations are desirable, but quantitative samples are frequently difficult to obtain in streams with hard substrates or deep water. Artificial substrates provide a method for sampling hard bottom areas, and quantitatively comparable samples can be obtained from any type of stream. A new artificial substrate sampler described in this paper proved to be rugged enough for use in any type of stream, and the data show its ability to sample macroinvertebrates. Additional studies are needed to determine conditions under which these samplers can most effectively be used.

Jacobi, G.Z. 1971. A quantitative artificial substrate sampler for benthic-macro-invertebrates. Trans. Am. Fish. Soc. 100:136-138.

Description of the design and used of a basket type artificial substrates sampler which is filled with spheres made from styrofoam, concrete and wood.

Khalaf, G. and H. Tachet. 1980. Colonization of artificial substrata by macro-invertebrates in a stream and variations according to stone size. Freshwater Biol. 10:475-482.

Plastic cages containing artificial substrata were placed on the stony bottom of a stream where the environmental conditions were homogeneous. Analysis of the catches (density and number of taxa in each cage) revealed no significant differences in connection with the position of the cages in the section of stream. Cages with 48-mm stones contained the least abundant fauna. The taxa which colonized cages with 14- or 24-mm stones were more numerous than those collected from cages with 48- or 96-mm stones. Catches in the cages were not the same as those taken with a Surber sampler because the two samplers did not take samples from the same habitats and also because the baskets offered a more specialized habitat than the surrounding bottom.

Kiffney, P.M. and W.H. Clements. 1994. Effects of heavy metals on a macroinvertebrate assemblage from a Rocky Mountain stream in experimental microcosms. J. N. Am. Benthol. Soc. 13: 511-523.

Rock-filled trays were used to collect natural benthic invertebrate assemblages from a Rocky Mountain stream. The invertebrates were exposed for 10 days to a mixture of heavy metals in stream microcosms. Most ephemeropterans an plecopterans were sensitive to metals. Chironomids were generally tolerant of metals. Overall, the mixture was extremely toxic to the invertebrates, and effects were similar to those in streams. Combining multispecies experiments with field biomonitoring is recommended to rigorously define the biological effects of heavy metals in lotic systems.

Kiffney, P.M. and W.H. Clements. 1994. Structural responses of benthic macroinvertebrate communities from different stream orders to zinc. Environ. Toxicol. Chem. 13:389-395.

Rock-filled trays were used to collect natural benthic invertebrate assemblages from a third and a fourth order stream. The invertebrates were exposed for 7 days to a different concentrations of zinc in indoor artificial streams. Significant effects were observed at the community and population levels as a result of zinc, stream order and the interaction between these two factors. Mayflies were sensitive to zinc from both streams but the magnitude of the response varied between sites.

Kirk, E.J. and A.P. Perry. 1993. Differences in macroinvertebrate taxa richness and density between samplers located along the shoreline and inside the navigation channel of the Kanawha River, West Virginia. J. Freshwater Ecol. 8:77-79.

Two types of basket samplers (gravel and large-cobble) were deployed near the shoreline and inside the navigation channel in the Kanawha River, West Virginia. In general, gravel basket samplers suspended in the water column collected more macroinvertebrates and more taxa than large-cobble basket samplers deployed on the river bottom. Gravel basket samplers collected significantly more individuals inside the navigation channel than near the shoreline, whereas large-cobble basket samplers collected significantly more individuals along the shoreline than inside the navigation channel. Taxa richness was not significantly different between the shoreline and the navigation channel. The observed differences were attributed to the relative amounts of fine sediments in the two areas of the river.

Klemm, D.J., P.A. Lewis, F. Fulk and J.M. Lazorchak. 1990. Macroinvertebrate field and laboratory methods for evaluating the biological integrity of surface waters. Environmental Monitoring Systems Laboratory, Cincinnati, U.S. Environmental Protection Agency, EPA/600/4-90/030, 256 p.

Manual describing guidelines and standard procedures for using benthic macroinvertebrates in evaluating the biological integrity of surface waters. Included are sections on quality assurance and quality control procedures, safety and health recommendations, selection of sampling stations, sampling methods, data evaluation and an extensive taxonomic bibliography of the benthic macroinvertebrate groups. Supplementary information on the pollution tolerance of selected species, examples of macroinvertebrate bench sheets, and a list of equipment and supplies for conducting biomonitoring studies are provided in the appendices.

Kreis, R.D., R.L. Smith and J.E. Moyer. 1971. The use of limestone-filled basket samplers for collecting reservoir macroinvertebrates. Water Res. 5: 1099-1106.

Limestone-filled basket samplers were suspended in a southern Oklahoma reservoir to determine macroinvertebrate colonization potentials and optimum sampling depth for the collection of the greatest diversity of organisms. The optimum sampling depth was found to be near the surface at all stations.

Mason, W.T., J.B. Anderson and G.E. Morrison. 1967. A limestone-filled, artificial substrate sampler-float unit for collecting macroinvertebrates in large streams. Progressive Fish Culturist 29:74.

A cylindrical, welded-wire chromium-plated "Bar-B-Q" basket filled with limestone and suspended from a float is described. Experience indicates that exposure for about 6 weeks at a 5-foot depth is adequate to collect macroinvertebrates that cling or adhere to the rocks. Placing the basket within the euphotic zone creates a shallow stream environment that attracts a larger number and variety of organisms than will appear when the basket is hung lower.

Meier, P.G., D.L. Penrose and L. Polak. 1979. The rate of colonization by macroinvertebrates on artificial substrate samplers. Freshwater Biol. 9:381-392.

The influence of exposure time upon macroinvertebrate colonization on modified Hester-Dendy substrate samplers was investigated over a 60-day period. The duration of exposure affected the number of individuals, taxa and community diversity. Investigation of the relationship between 'equitability' and length of exposure revealed that equitability did not vary like diversity with increased time of exposure.

Modde, T. and H.G. Drewes. 1990. Comparison of biotic index values for invertebrate collections from natural and artificial substrates. Freshwater Biol. 23:171-180.

The use of a biotic index was evaluated in a small mountain stream on the basis of collections of benthic macroinvertebrates from both artificial and natural substrates in years of above and below normal discharge. Invertebrate composition sampled from artificial and natural substrates exhibited inverse trends in density associated with discharge patterns. Biotic index values derived from artificial substrates provided a more consistent and accurate description of the water quality of a small stream between years of high and low discharge than did those determined from natural substrates.

Pearson, R.G. and N.V. Jones 1975. The colonization of artificial substrata by stream macro-invertebrates. Prog. Water Technol. 7:497-504.

Description of the design and use of an artificial substrate sampler consisting of an open-ended aluminum box with Perspex roof, partly filled with substrate.

Prins, R. and W. Black 1971. Synthetic webbing as an effective macrobenthos sampling substrate in reservoirs. In Reservoir Fisheries and Limnology. G.E. Hall, editor. Am. Fish. Soc. Spec. Publ. 8: 203-208.

Comparison of limestone-filled basket samplers with samplers composed of a non-woven synthetic web material in a reservoir. The web samplers collected greater numbers of organisms than the baskets particularly later in the summer. Web samplers consistently collected greater numbers of lake-dwelling invertebrates than did the baskets, whereas the baskets collected greater numbers of typical rock-dwelling invertebrates, even under low oxygen levels and in areas with mud bottom.

Robertson, D.J. and K. Piwowar. 1985. Comparison of four samplers for evaluating macroinvertebrates of a sandy Gulf Coast Plain stream. J. Freshwater Ecol. 3:223-231.

Aquatic macroinvertebrates were collected from two sections of a stream disturbed by surface mining, channelization, and grazing. Benthic organisms were sampled over a twelve month period with "stovepipe" substrate cores, drift nets, dip nets and multiple plate artificial samplers. Species richness, organism density and Shannon-Weiner species diversity values were calculated for each sample. The results of the study suggest that artificial substrate samplers may not reduce sampling variability in sandy Coastal Plain streams. In addition, the decision to use any of a variety of sampling techniques should be based on the nature of the assessment since sampling devices differ in the types of data they produce.

Roby, K.B., J.D. Newbold and J.D. Erman 1978. Effectiveness of an artificial substrate for sampling macroinvertebrates in small streams. Freshwater Biol. 8:1-9.

Comparison of the performance of porcelain ball-filled baskets containing layers of screening with that of the Surber sampler. The authors suggest that carefully taken Surber samples are as good as those taken using the artificial substrate samplers, and present fewer problems during sampling.

Rosenberg, D.M. 1978. Practical sampling of freshwater macrozoobenthos: a bibliography of useful texts, reviews, and recent papers. Fisheries and Marine Service. Technical Report No. 790. Department of Fisheries and the Environment, Winnipeg, Manitoba.

Bibliography of benthic macroinvertebrate sampling techniques, with topic areas including equipment and techniques, comparisons of equipment and techniques, requisite numbers and size of samplers, sample sorting/identification and useful reviews on sampling marine benthos.

Rosenberg, D.M. and V.H. Resh. 1982. The use of artificial substrates in the study of freshwater benthic macroinvertebrates. Chapter 6, In Cairns, J. Jr. (editor) Artificial substrates. Ann Arbor Science, Ann Arbor, 279 p.

Comprehensive review of the advantages and disadvantages of the use of artificial substrates to sampler benthic macroinvertebrates. Each advantage and disadvantage is discussed and illustrated with examples from the literature.

Shaw, D.W. and G.W. Minshall. 1980. Colonization of an introduced substrate by stream macroinvertebrates. Oikos 34:259-271.

Trays filled with uniform-sized pebbles were allowed to become colonized to determine the time required to establish a stable macroinvertebrates community. Trays colonized for 64 d collected similar numbers of taxa compared to a Hess sampler and dip net in two separate tests. They also contained greater total numbers and biomass of invertebrates than did Hess samples from a riffle. Compared to samples taken on the stream bed, trays were effective in reducing sample variance but did little to reduce the clumping of organisms. In general, use of trays reduced the number of samples needed to obtain a standard error of the mean. Since the trays did not collect a fauna representative of the riffle community in terms of relative or absolute abundance, they cannot be recommended for studies requiring quantitative data directly relatable to the natural environment. However, because of their ability to control or eliminate extraneous variables and thus reduce sample variance, their use is appropriate for experimental or monitoring studies.

Slack, K.V., L.J. Tilley and S.S. Hahn. 1982. Detritus abundance and benthic invertebrate catch in artificial substrate samples from mountain streams. Water Res. Bull. 18:687-698.

Artificial substrates were designed using rock filled polyethylene bags which were perforated with holes. Colonization was compared in side-by-side tests with multiple plate samplers in mountain streams ranging from second to seventh order. Functionally the plastic bags act as detritus retention devices, offering a diverse, highly dynamic microhabitat for colonization. Results are interpretable in terms of research on microdistribution of stream benthos and the river continuum model. This study supports the conclusion that stream benthos abundance and diversity are related to the amount of detritus. Maximum diversity and numbers of individuals occurred in samples from third and fourth order streams. Although bag samples required more sorting time, the samplers are catch effective, inexpensive, and adaptable.

Slack, K.V., R.F. Ferreira and R.C. Averett. 1986. Comparison of four artificial substrates and the Ponar grab for benthic invertebrate collection. Water Res. Bull. 22:237-248.

Four different bottom-placed artificial substrates were compared with the Ponar grab for collecting benthic invertebrates. Artificial substrate samples of organisms were larger and more diverse than those of the grab. Differences between grab and artificial substrate samples are explainable in terms of major riverine habitats and characteristics of the collection methods. Results of sampler comparisons were summarized in terms of the types of invertebrate assemblages collected, required number of samples to achieve a certain precision, ease and reliability of use, cost and the amount of laboratory time required to process a sample.

Slack, K.V., R.F. Ferreira, R.C. Averett and S.S. Kennelly. 1988. Effects of spatial orientation of multiple plate artificial substrates on invertebrate colonization. Water Res. Bull. 24:781-789.

Jumbo multiple plate samplers were suspended in a river in one of three orientations: interplate spaces closed to downwelling light and open to flow, open to light and flow, or open to light and closed to flow. The results indicate lack of orientation effects on colonization or high variability that obscured such effects. The sampler suspension equipment possibly increased among-sampler variability by forming artificial snag habitats, and interplate light and flow conditions at different orientations may not have been sufficiently distinct to elicit different biological responses. Individual samplers provided diverse microhabitats regardless of orientation, but it would be prudent to include orientation among the variables considered in use of multiple plate samplers.

Townsend, C.R. and A.G. Hildrew. 1976. Field experiments on the drifting, colonization and continuous redistribution of stream benthos. J. Animal Ecol. 45:459-772.

This study evaluated the role that invertebrate drift plays in the colonization of new areas of the stream bed, using artificial substrates (rock-filled trays) and drift nets. Eighty-two per cent of the colonizing organisms on the introduced substrates arrived by drift. Colonization was rapid, but the patterns of colonization of the major taxa showed discontinuities.

Tsui, P.T.P. and B.W. Breedlove. 1978. Use of the multiple-plate sampler in biological monitoring of the aquatic environment. Florida Scientist 41:110-116.

Field studies indicate that the diversity of macroinvertebrates collected by the multiple-plate sampler is time-dependent. Pilot studies to determine optimum exposure period are recommended. Comparisons of samples of macroinvertebrates collected by the multiple-plate sampler and the petite Ponar grab from both lentic and lotic environments indicate significant differences between the types of organisms collected by grab and artificial substrate samplers.

Voshell, J.R., Jr and Simmons. 1977. An evaluation of artificial substrates for sampling macrobenthos in reservoirs. Hydrobiologia 53:257-269.

Artificial substrates were compared with a Ponar grab for sampling benthic macroinvertebrates in Lake Anna, Loisa Co., Virginia. The objective was to find which technique was best for assessment of thermal effluent effects using the following criteria: 1) provide reliable data on density and composition of the macrobenthos with a reasonable number of replicates; 2) collect the most taxa; 3) require the least amount of time. Leaves, conservation webbing, and limestone rocks placed in chicken wire baskets and small plastic containers at several depths were compared with grab samples. Samlpers were installed and retrieved using a SCUBA system. All basket type artificial substrate samplers collected significantly more individuals (P=0.05) and taxa than the Ponar grab. Small web and leaf samplers met all three of the established criteria.